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# Unlocking Energy Efficiency in the U.S. Economy

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# Preface

In 2007, during research on ways to abate greenhouse gas emissions in the United States,[1] we encountered the puzzle of energy efficiency: How is it that so many energy-saving opportunities worth more than $130 billion annually to the U.S. economy can go unrealized, despite decades of public awareness campaigns, federal and state programs, and targeted action by individual companies, non-governmental organizations, and private individuals?

Greater energy efficiency will almost certainly be an important component in comprehensive national – and global – strategies for managing energy resources and climate change in the future. For this reason, we launched an effort in 2008 to investigate opportunities for greater efficiency in the stationary (non-transportation) uses of energy in the U.S. economy. This research confirms what many others have found – that the opportunity is significant. The focus of our effort, however, has been to identify what has prevented attractive efficiency opportunities from being captured in the past and evaluate potential measures to overcome these barriers. Our goal is to identify ways to unlock the efficiency potential for more productive uses in the future. This report is the product of that work.

We hope this report will provide business leaders, policymakers, and other interested individuals a comprehensive fact base for the discussion to come on how to best pursue additional gains in energy efficiency within the U.S. economy.

Our research has been encouraged and challenged by contributions from many participants with many points of view and sometimes differing opinions. They have generously helped our team access data, test emerging findings and potential solutions, and prepare for the release of this report. We especially acknowledge our governmental, non-governmental, and corporate sponsors for sharing their expertise and co-sponsoring this report:

- Austin Energy
- Department of Energy
    - Office of Electricity Delivery and Energy Reliability
    - Office of Energy Efficiency and Renewable Energy
- DTE Energy
- Energy Foundation
- Environmental Protection Agency
- Exelon Corporation
- Natural Resources Defense Council
- PG&E Corporation
- Sempra Energy

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[1] *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?,* McKinsey & Company, 2007.

- Sea Change Foundation
- Southern Company
- U.S. Green Building Council

As part of this work, the team conducted several hundred interviews with representatives of government agencies, public and private companies, academic institutions and research foundations, and a number of independent experts. Though too many to mention by name, these individuals deserve our sincerest thanks for having shared their time and expertise so willingly.

While the work presented in "Unlocking Energy Efficiency in the U.S. Economy" has benefited greatly from these diverse contributions, the views this report expresses are solely the responsibility of McKinsey & Company and do not necessarily reflect the views of our sponsors or any other contributors.

# Executive summary

The efficient use of energy has been the goal of many initiatives within the United States over the past several decades. While the success of specific efforts has varied, the trend is clear: the U.S. economy has steadily improved its ability to produce more with less energy. Yet these improvements have emerged unevenly and incompletely within the economy. As a result, net efficiency gains fall short of their full NPV-positive potential. Concerns about energy affordability, energy security, and greenhouse gas (GHG) emissions have heightened interest in the potential for energy efficiency to help address these important issues.

Despite numerous studies on energy efficiency two issues remain unclear: the magnitude of the NPV-positive opportunity, and the practical steps necessary to unlock its full potential. What appears needed is an integrated analysis of energy efficiency opportunities that simultaneously identifies the barriers and reviews possible solution strategies. Such an analysis would ideally link efficiency opportunities and their barriers with practical and comprehensive approaches for capturing the billions of dollars of savings potential that exist across the economy.

Starting in 2008, a research team from McKinsey & Company has worked with leading companies, industry experts, government agencies, and environmental NGOs to address this gap. It reexamined in detail the potential for greater efficiency in non-transportation uses of energy,[2] assessing the barriers to achievement of that potential, and surveying possible solutions. This report is the product of that effort.

**The central conclusion of our work:** *Energy efficiency offers a vast, low-cost energy resource for the U.S. economy – but only if the nation can craft a comprehensive and innovative approach to unlock it. Significant and persistent barriers will need to be addressed at multiple levels to stimulate demand for energy efficiency and manage its delivery across more than 100 million buildings and literally billions of devices. If executed at scale, a holistic approach would yield gross energy savings worth more than $1.2 trillion, well above the $520 billion needed through 2020 for upfront investment in efficiency measures (not including program costs). Such a program is estimated to reduce end-use energy consumption in 2020 by 9.1 quadrillion BTUs, roughly 23 percent of projected demand, potentially abating up to 1.1 gigatons of greenhouse gases annually.*

Five observations are relevant to a national debate about how best to pursue energy efficiency opportunities of the magnitude identified and within the timeframe considered in this report. Specifically, an overarching strategy would need to:

1. Recognize energy efficiency as an important energy resource that can help meet future energy needs while the nation concurrently develops new no- and low-carbon energy sources
2. Formulate and launch at both national and regional levels an integrated portfolio of proven, piloted, and emerging approaches to unlock the full potential of energy efficiency
3. Identify methods to provide the significant upfront funding required by any plan to capture energy efficiency

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[2] Non-transportation uses of energy exclude fuel used by passenger vehicles, trucks, trains, airplanes, and ships, as well as transport energy used in agriculture, mining, and construction operations. For simplicity of expression, we sometimes refer to the energy covered by our analyses as “stationary energy.”

4. Forge greater alignment between utilities, regulators, government agencies, manufacturers, and energy consumers
5. Foster innovation in the development and deployment of next-generation energy efficiency technologies to ensure ongoing productivity gains.

In the body of the report, we discuss the compelling benefits of energy efficiency and why this energy resource warrants being a national priority. We then identify and "map" in detail the complex and persistent set of barriers that have impeded capture of energy efficiency at the level of individual opportunities. We also identify solution strategies, including those proven, piloted, or recently emerged, that could play a role in overcoming these barriers. Finally, we elaborate on the five observations noted above to outline important considerations for the development of a holistic implementation strategy to capture energy efficiency at scale.

We hope that our research and this report will help in the understanding and pursuit of approaches to unlock the benefits of energy efficiency, as the United States seeks to improve energy affordability, energy security, and greenhouse gas reduction.

## COMPELLING NATIONWIDE OPPORTUNITY

Our research indicates that by 2020, the United States could reduce annual energy consumption by 23 percent from a business-as-usual (BAU)[3] projection by deploying an array of NPV-positive efficiency measures, saving 9.1 quadrillion BTUs of end-use[4] energy (18.4 quadrillion BTUs in primary energy). This potential exists because significant barriers impede the deployment of energy efficient practices and technologies. It will be helpful to begin by clarifying the size and nature of this opportunity; then we will describe the case for taking action to address the barriers and unlock the energy efficiency potential.

The residential sector accounts for 35 percent of the end-use efficiency potential (33 percent of primary energy potential), the industrial sector 40 percent (32 percent in primary energy), and the commercial sector 25 percent (35 percent in primary energy). The differences between primary and end-use potentials are attributable to conversion, transmission, distribution, and transport losses. We present both numbers throughout as each is relevant to specific issues considered. Capturing the full potential over the next decade would decrease the end-use energy consumption analyzed from 36.9 quadrillion end-use BTUs in 2008 to 30.8 quadrillion end-use BTUs in 2020 (Exhibit A), with potentially profound implications for existing energy provider business models.[5]

This change represents an absolute decline of 6.1 quadrillion end-use BTUs from 2008 levels and an even greater reduction of 9.1 quadrillion end-use BTUs from the projected level of what consumption otherwise would have reached in 2020. Construction of new power plants, gas pipelines, and other energy infrastructure will still be required to address regions of growth, retirement of economically or environmentally obsolete

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[3] The Energy Information Administration's *Annual Energy Outlook, 2008* represents our business-as-usual projection; our analysis focused on the 81 percent of non-transportation energy with end-uses that we were able to attribute.

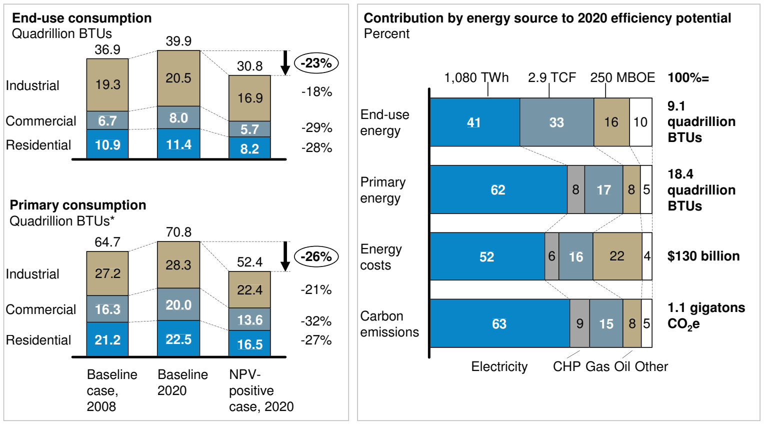
[4] End-use, or "site," energy refers to energy consumed in industrial, business, and residential settings, e.g., providing light, heating and cooling spaces, running motors and electronic devices, and powering industrial processes. By contrast, primary, or "source," energy represents energy in the form it is first accounted (e.g., BTUs of coal, oil, natural gas) before transformation to secondary or tertiary forms (e.g., electricity). From the end-use viewpoint primary energy is lost during transformation to other forms and in transmission, distribution, and transport to end-users; these losses are an important energy-saving opportunity but one that is outside the scope of this report. Unless explicitly defined as primary energy, energy usage and savings values in this report refer to end-use energy.

[5] We examine implications for energy provider business models in Chapter 5 of the full report.

energy infrastructure, and introduction of unaccounted-for consumption, such as electric vehicles. However, energy efficiency could measurably reduce the total new infrastructure investment required during this timeframe.

Beyond the economics, efficiency represents an emissions-free energy resource. If captured at full potential, energy efficiency would abate approximately 1.1 gigatons $CO_2e$ of greenhouse gas emissions per year in 2020 relative to BAU projections, and could serve as an important bridge to a future era of advanced low-carbon supply-side energy options.

Exhibit A: Energy efficiency potential in the U.S. economy



* Includes primary savings from CHP of 490 trillion BTUs in commercial and 910 trillion BTUs in industrial.
Source: EIA AEO 2008, McKinsey analysis

The left side of the exhibit shows total energy consumption, measured in quadrillion BTUs, for the portions of each sector addressed in the report, plus the corresponding consumption if the identified energy efficiency potential were realized. The right side provides different views of the energy efficiency potential in 2020 broken out by fuel type.

In modeling the national potential for greater energy efficiency, we focused our analysis on identifying what we call the "NPV-positive" potential for energy efficiency. We defined "NPV-positive"[6] to include direct energy, operating, and maintenance cost savings over the equipment's useful life, net of equipment and installation costs, regardless of who invests in the efficiency measure or receives the benefits. We used industrial retail rates as a proxy for the value of energy savings in our calculations,[7] applied a 7-percent discount factor as the cost of capital, and assumed no price on carbon. This methodology provides a representation of the potential for net-present-value-positive (NPV-positive) energy efficiency from the perspective of policymakers and business leaders who must make decisions in the broad interests of society. This is in contrast to some studies that report on "technical" potential, which applies the most efficient technology regardless of cost, and differs from reports that project "achievable" potential given historical performance and an implied set of constraints.

We acknowledge, however, that there are different views of future scenarios, societal discount rates, and what constitutes "NPV-positive" from the perspective of individual

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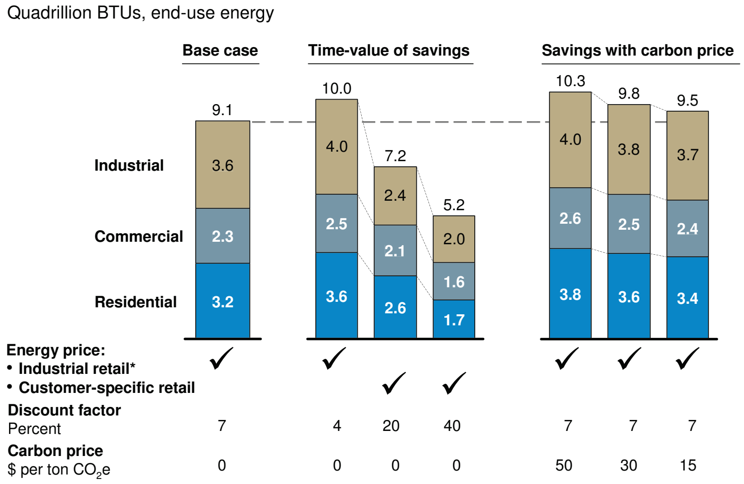
[6] See Appendix B of the full report for more details on this calculation methodology.

[7] Industrial retail rates represent an approximate value of the energy saved as they include generation, transmission, capacity, and distribution costs in regulated and restructured markets. The bulk of the rate is composed of generation cost, with minor contribution from transmission and capacity, and negligible contribution from distribution costs. Though load factor in these rates underestimates the national average, and thus this rate represents a slightly conservative estimate of the value of the energy savings, the other components are closer to the likely savings if significant energy efficiency were to be realized. We computed the avoided cost of gas also using an industrial retail rate, which likewise is close to the wholesale cost of gas plus a small amount of transport cost. A more detailed discussion of the avoided cost of energy is available in Appendix B of the full report.

actors. Thus we tested the resiliency of the NPV-positive opportunities by adjusting the discount rate (expected payback period), the value of energy savings (customer-specific retail prices), and possible carbon price ($0, $15, $30, and $50 per ton $CO_2$e). We found the potential remains quite significant across all of these sensitivity tests (Exhibit B). Introducing a carbon price as high as $50 per ton $CO_2$e from the national perspective increases the potential by 13 percent. A more moderate price of $30 per ton $CO_2$e increases the potential by 8 percent. Applying a discount rate of 40 percent, using customer-class-specific retail rates, and assuming no future cost of carbon, reduces the NPV-positive potential from 9.1 quadrillion to 5.2 quadrillion BTUs – a reduced but still significant potential that would more than offset projected increases in BAU energy consumption through 2020.

Exhibit B: Sensitivity of NPV-positive energy efficiency potential - 2020

The height of each column represents the energy efficiency potential in 2020 associated with non-transportation uses of energy under the conditions defined at the bottom of the exhibit -- energy price, discount factor, and carbon price. The height of each section corresponds to the efficiency potential in that sector, as labeled at the left, under those conditions.



* AEO 2008 industrial energy prices by Census division (national average weighted across all fuels: $13.80/MMBTU) are used as a proxy

Source: EIA AEO 2008, McKinsey analysis

Our methodology is based on detailed examination of the economics of efficiency potential and the barriers to capture of it. Using the Energy Information Administration's National Energy Modeling System (NEMS) and *Annual Energy Outlook 2008* (AEO 2008) as a foundation, for each Census division and building type, we developed a set of "business-as-usual" choices for end-use technology through 2020. Then, to identify meaningful opportunities at this level of detail, we modeled deployment of 675 energy-saving measures to select those with the lowest total cost of ownership, replacing existing equipment and building stock over time whenever doing so was "NPV-positive."[8] We disaggregated national data on energy consumption using some 60 demographic and usage attributes, creating roughly 20,000 consumption micro-segments across which we could analyze potential.

By linking our models with usage surveys and research on user-related barriers, we were able to re-aggregate the micro-segments as clusters of efficiency potential according to sets of shared barriers and usage characteristics. The resulting clusters as shown in Exhibit C are sufficiently homogeneous to suggest a set of targeted solutions.

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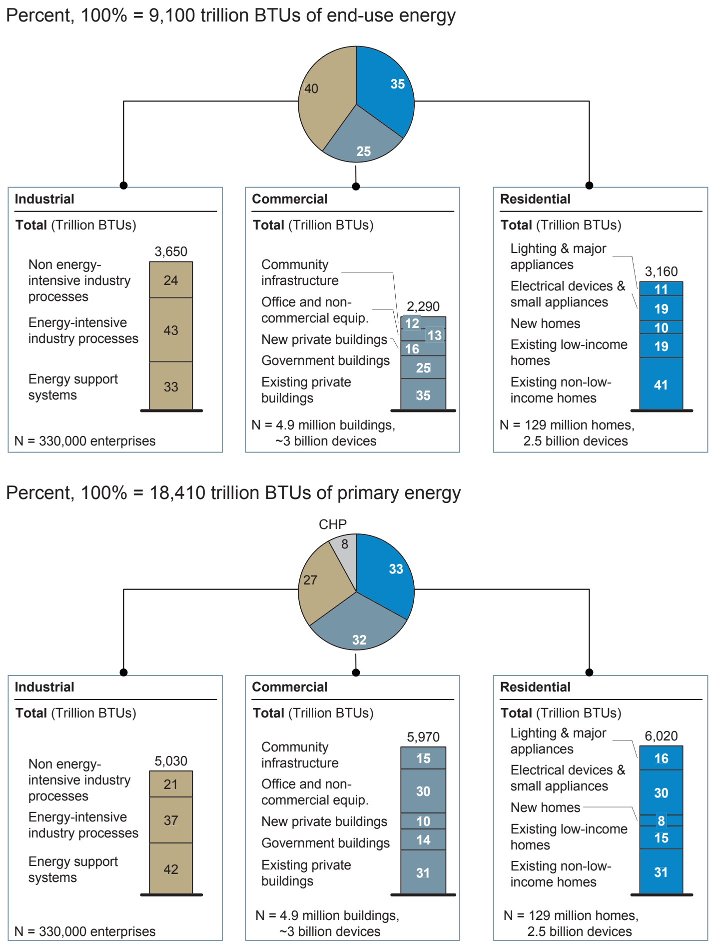
[8] We modeled the energy-savings potential of combined heat and power installations in the commercial and industrial sectors separately from these replacement measures.

Exhibit C: Clusters of efficiency potential in stationary uses of energy – 2020



Source: EIA AEO 2008, McKinsey analysis

The pie charts show the share (in percent) of energy efficiency potential in 2020 in each economic sector, with end-use energy in the upper chart and primary energy in the lower one. Each column chart shows the clusters of potential that make up each sector, with the total potential in the sector (in trillion BTUs) displayed at the top of the column and the share (in percent) in the corresponding segment. Below each column are numbers for relevant end-use settings.

While not all actions that decrease the consumption of energy represent NPV-positive investments relative to alternatives, by definition in our methodology, all the energy efficiency actions included in this report represent attractive investments. The required investment of these NPV-positive efficiency measures ranges upward from $0.40 per MMBTU saved, averaging $4.40 per MMBTU of end-use energy saved (not including program costs). This average is 68 percent below the AEO 2008 business-as-usual forecast price of saved energy in 2020, $13.80 per MMBTU weighted average across all fuel types (Exhibit D), and 24 percent below the projected lowest delivered natural gas price in the United States in 2020, $5.76 per MMBTU. Furthermore, the energy and operational savings from greater efficiency total some $1.2 trillion in present value to the U.S. economy: unlocking this value would require an initial upfront investment of approximately $520 billion (not including program costs).[9] Even the most expensive opportunities selected in this study are NPV-positive over the lifetime of the measure and represent the least expensive way to provide for future energy requirements.

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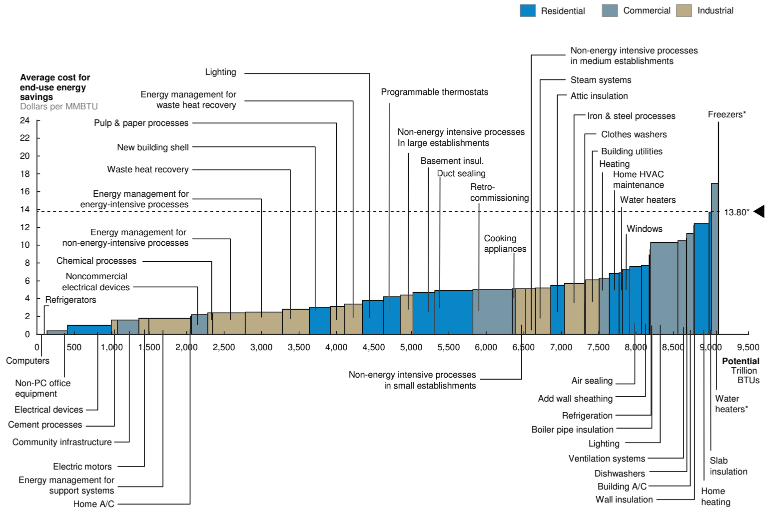
[9] The net present value of this investment therefore would be $1.2 trillion minus $520 billion, or $680 billion.

Exhibit D: U.S. energy efficiency supply curve – 2020

The width of each column on the chart represents the amount of efficiency potential (in trillion BTUs) found in the named group of measures, as modeled in the report. The height of each column corresponds to the average annualized cost (in dollars per million BTUs of potential) of that group of measures.



* Average price of avoided energy consumption at the industrial price; $35.60/MMBTU represents the highest regional electricity price used; new build cost based on AEO 2008 future construction costs

Source: EIA AEO 2008, McKinsey analysis

## SIGNIFICANT BARRIERS TO OVERCOME

The highly compelling nature of energy efficiency raises the question of why the economy has not already captured this potential, since it is so large and attractive. In fact, much progress has been made over the past few decades throughout the U.S., with even greater results in select regions and applications. Since 1980, energy consumption per unit of floor space has decreased 11 percent in residential and 21 percent in commercial sectors, while industrial energy consumption per real dollar of GDP output has decreased 41 percent. Though these numbers do not adjust for structural changes, many studies indicate efficiency plays a role in these reductions. As an indicator of this success, recent BAU forecasts have incorporated expectations of greater energy efficiency. For example, the EIA's 20-year consumption forecast shows a 5-percent improvement in commercial energy intensity and 10-percent improvement in residential energy intensity compared to their projections of 4 years ago.[10]

As impressive as the gains have been, however, an even greater potential remains due to multiple and persistent barriers present at both the individual opportunity level and overall system level. By their nature, energy efficiency measures typically require a substantial upfront investment in exchange for savings that accrue over the lifetime of the deployed measures. Additionally, efficiency potential is highly fragmented, spread across more than 100 million locations and billions of devices used in residential, commercial, and industrial settings. This dispersion ensures that efficiency is the highest priority for virtually no one. Finally, measuring and verifying energy not consumed is by its nature difficult. Fundamentally, these attributes of energy efficiency give rise to opportunity-specific barriers that require opportunity-specific solution strategies and suggest components of an overarching strategy (Exhibit E).

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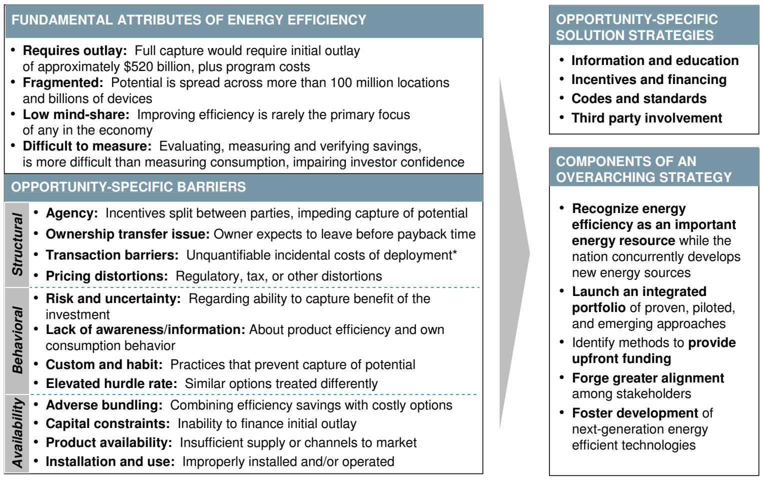
[10] AEO 2004 and 2008.

Exhibit E: Multiple challenges associated with pursuing energy efficiency



**FUNDAMENTAL ATTRIBUTES OF ENERGY EFFICIENCY**

- **Requires outlay:** Full capture would require initial outlay of approximately $520 billion, plus program costs
- **Fragmented:** Potential is spread across more than 100 million locations and billions of devices
- **Low mind-share:** Improving efficiency is rarely the primary focus of any in the economy
- **Difficult to measure:** Evaluating, measuring and verifying savings, is more difficult than measuring consumption, impairing investor confidence

**OPPORTUNITY-SPECIFIC BARRIERS**

*Structural*

- **Agency:** Incentives split between parties, impeding capture of potential
- **Ownership transfer issue:** Owner expects to leave before payback time
- **Transaction barriers:** Unquantifiable incidental costs of deployment*
- **Pricing distortions:** Regulatory, tax, or other distortions

*Behavioral*

- **Risk and uncertainty:** Regarding ability to capture benefit of the investment
- **Lack of awareness/information:** About product efficiency and own consumption behavior
- **Custom and habit:** Practices that prevent capture of potential
- **Elevated hurdle rate:** Similar options treated differently

*Availability*

- **Adverse bundling:** Combining efficiency savings with costly options
- **Capital constraints:** Inability to finance initial outlay
- **Product availability:** Insufficient supply or channels to market
- **Installation and use:** Improperly installed and/or operated

**OPPORTUNITY-SPECIFIC SOLUTION STRATEGIES**

- **Information and education**
- **Incentives and financing**
- **Codes and standards**
- **Third party involvement**

**COMPONENTS OF AN OVERARCHING STRATEGY**

- **Recognize energy efficiency as an important energy resource** while the nation concurrently develops new energy sources
- **Launch an integrated portfolio** of proven, piloted, and emerging approaches
- Identify methods to **provide upfront funding**
- **Forge greater alignment** among stakeholders
- **Foster development** of next-generation energy efficient technologies

* Financial transaction barriers and actual quality trade-offs are factored into the initial NPV-positive potential calculation as real costs.

Source: McKinsey analysis

On the left, this exhibit summarizes the fundamental difficulties of pursuing greater energy efficiency and the opportunity-specific barriers that affect and help define clusters of efficiency potential. On the right, it shows opportunity-level solution strategies to overcome barriers and suggests the essential elements of an overarching strategy for capturing energy efficiency potential.

Our research suggests that unlocking the full potential of any given opportunity requires addressing all barriers in a holistic rather than piecemeal fashion. To simplify the discussion, we have grouped individual opportunity barriers into three broad categories: structural, behavioral, and availability. Structural barriers prevent an end-user from having the choice to capture what would otherwise be an attractive efficiency option; for example, a tenant in an apartment customarily has little choice about the efficiency of the HVAC system, even though the tenant pays the utility bills.[11] This type of agency barrier affects some 9 percent of the end-use energy efficiency potential. Behavioral barriers include situations where lack of awareness or end-user inertia block pursuit of an opportunity; for example, a facility manager might replace a broken pump with a model having the lowest upfront cost rather than a more energy efficient model with lower total ownership cost, given a lack of awareness of the consumption differences. Availability barriers include situations when an end-user interested in and willing to pursue a measure cannot access it in an acceptable form; for example, a lack of access to capital might prevent the upgrade to a new heating system, or the bundling of premium features with energy efficiency measures in a dishwasher might dissuade an end-user from purchasing a more efficient model.

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[11] We refer to space conditioning systems generically as HVAC systems (heating, ventilation, and air conditioning), whether a building has a heating system, a cooling system, an air exchanger or all three systems.

## SOLUTIONS AVAILABLE TO ADDRESS THE BARRIERS

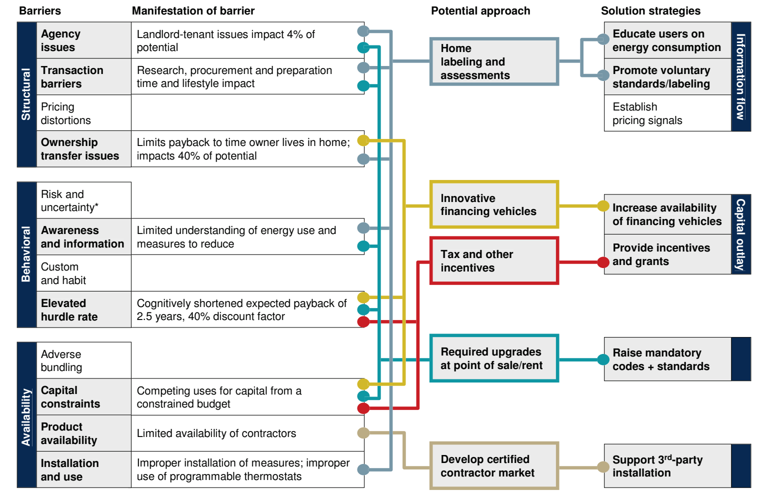
Experience over the past several decades has generated a large array of tools for addressing the barriers that impede capture of attractive efficiency potential, some of which have been proven at a national scale, some have been "piloted" in select geographies or at certain times at a city-scale, and others are emerging and merit trial but are not yet thoroughly tested. The array of proven, piloted, and emerging solutions falls into four broad categories:

- **Information and education.** Increasing awareness of energy use and knowledge about specific energy-saving opportunities would enable end-users to act more swiftly in their own financial interest. Options include providing more information on utility bills or use of in-building displays, voluntary standards, additional device- and building-labeling schemes, audits and assessments, and awareness campaigns.
- **Incentives and financing.** Given the large upfront investment needed to capture efficiency potential, various approaches could reduce financial hurdles that end-users face. Options include traditional and creative financing vehicles (such as on-bill financing), monetary incentives and/or grants, including tax and cash incentives, and price signals, including tiered pricing and externality pricing (e.g., carbon price).
- **Codes and standards.** In some clusters of efficiency potential, some form of mandate may be warranted to expedite the process of capturing the potential, particularly where end-user or manufacturer awareness and attention are low. Options include mandatory audits and/or assessments, equipment standards, and building codes, including improving code enforcement.
- **Third-party involvement.** A private company, utility, government agency, or non-governmental organization could support a "do-it-for-me" approach by purchasing and installing energy efficiency improvements directly for the end-user, thereby essentially addressing most non-capital barriers. When coupled with monetary incentives, this solution strategy could address the majority of barriers, though some number of end-users might decline the opportunity to receive the efficiency upgrade, preventing capture of the full potential.

For most opportunities, a comprehensive approach will require multiple solutions to address the entire set of barriers facing a cluster of efficiency potential. Through an extensive review of the literature on energy efficiency and interviews with experts in this and related fields, we have attempted to define solutions that can address the various barriers under a variety of conditions. Exhibit F illustrates how we mapped alternative solutions against the barriers for a cluster.

We do not believe it is possible to empirically prove that a particular combination of measures will unlock the full potential in any cluster, because the level of impact being considered has never previously been attained. However, we do believe that a holistic combination of solutions that address the full-range of barriers and system-level issues is a prerequisite for attaining energy-productivity gains anywhere near those identified in our analysis.

Exhibit F: Addressing barriers in existing non-low-income homes



* Represents a minor barrier
Source: McKinsey analysis

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

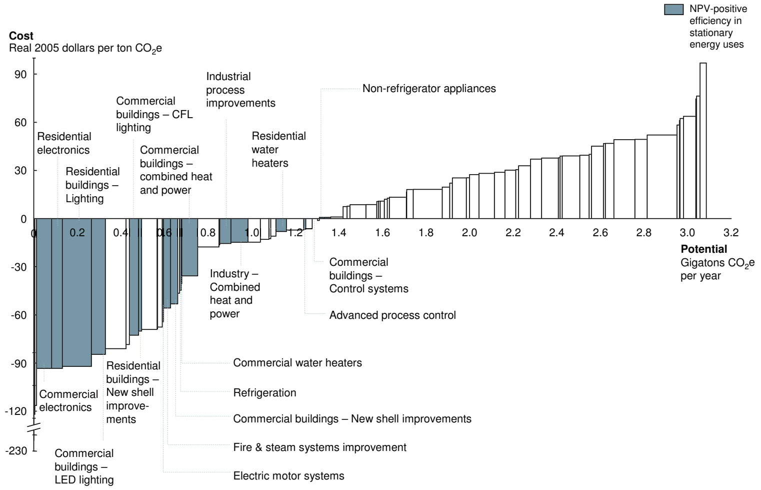
## ELEMENTS OF A HOLISTIC IMPLEMENTATION STRATEGY

Capturing the full efficiency potential identified in this report would require an additional investment of $50 billion per year (in present value terms), four- to five-times 2008 levels of investment, sustained over a decade. Even the fastest-moving technologies of the past century that achieved widespread adoption, such as cellular telephones, microwaves, or radio, took 10 to 15 years to achieve similar rates of scale-up. Without an increase in national commitment, it will remain challenging to unlock the full potential of energy efficiency. As noted previously, there are five important aspects to incorporate into the nation's approach to scale-up and capture the full potential of energy efficiency. An overarching strategy would need to:

1. **Recognize energy efficiency as an important energy resource that can help meet future energy needs, while the nation concurrently develops new no- and low-carbon energy sources.** Energy efficiency is an important resource that is critical in the overall portfolio of energy solutions. Likewise, as indicated in our prior greenhouse gas abatement work, new sources of no- and low-carbon generation are also important components of the portfolio. While it may seem counterintuitive initially given the magnitude of the energy efficiency potential available over the next decade, there are important reasons for continuing to develop new no- and low-carbon options for energy supply. First, as described in our original report on U.S. greenhouse gas abatement (Exhibit G), energy efficiency in stationary uses of energy represents less than half of the potential abatement available to meet any future reduction targets. In addition, some areas of the country will continue to experience growth, and some may need to retire and replace aging existing assets. The uncertain growth of electric vehicles could further complicate these requirements. Finally, pursuing energy efficiency at this scale will present a set of risks related to the timing and magnitude of potential capture. Consequently, there remains a strong rationale to diversify risk across supply and demand resources.

Exhibit G: U.S. mid-range greenhouse gas abatement curve – 2030

This exhibit shows greenhouse gas abatement potential as depicted in the mid-range case in McKinsey's greenhouse gas report (2007), with energy efficiency opportunities associated with stationary uses of energy highlighted. The height of each bar represents the incremental cost in dollars to abate one ton of carbon dioxide (or its equivalent); the width shows the gigatons of such emissions that could be abated per year.



Source: McKinsey analysis

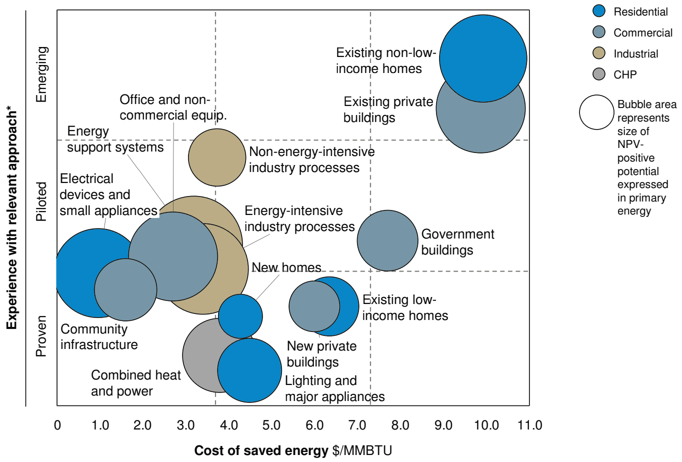
2. **Formulate and launch at both national and regional levels an integrated portfolio of proven, piloted, and emerging approaches to unlock the full potential of energy efficiency.** There are multiple combinations of approaches the nation could take to support the scaled-up capture of energy efficiency. In addition to seeking the impact of national efforts, this portfolio should effectively and fairly reflect regional differences in energy efficiency potential. Any approach would need to make the following three determinations:

   - The extent to which government should mandate energy efficiency through the expansion and enforcement of codes and standards
   - Beyond codes and standards, the extent to which government (or other publicly funded third parties) should directly deploy energy efficiency measures
   - The best methods by which to further stimulate demand and enable capture of the remaining energy efficiency potential.

   Exhibit H illustrates one example of a portfolio of solution strategies focusing on the most proven solution strategies deployed to date. Such a tool facilitates evaluation of a portfolio against the relevant parameters of cost, risk (i.e., experience), and return (i.e., size of potential).

3. **Identify methods to provide the significant upfront funding required by any plan to capture energy efficiency.** End-user funding for energy efficiency by consumers has proved difficult. Partial monetary incentives and supportive codes and standards increase direct funding by end-users: the former by reducing initial outlays and raising awareness, the latter by essentially requiring participation. Enhanced performance contracting or loan guarantees are relatively untested but could facilitate end-user funding. Alternatively, the entire national upfront investment of $520 billion (not including program costs) could be recovered through a system-benefit charge on energy on the order of $0.0059 cents per kWh of electricity and $1.12 per MMBTU of other fuels over 10 years. This would represent an increase in average customer energy costs of 8 percent, which would be more than offset by the eventual average bill savings of 24 percent. Different solution strategies and policies would result in different administrative cost structures. For example, codes and standards have been shown to typically incur program costs below 10 percent, whereas low-income weatherization

Exhibit H: Portfolio representing cost, experience, and potential of clusters possible with specified solution strategies



* Drawing an analogy to our work with business transformation; piloted solutions represent those tried on the scale of a state or major city (i.e., over 1 million points of consumption), emerging are untested at that level, and proven have broad success at a national scale

Source: EIA AEO 2008, McKinsey analysis

The bubbles depict the NPV-positive efficiency potential in each cluster, measured in primary energy, with the area of the circle proportional to the potential. The position of the bubble's center on the horizontal axis indicates the cost of capturing this potential with the measures modeled in this report (excluding program costs) in dollars per million BTUs per year. The center's position on the vertical axis represents the weighted average of the national experience with the approaches outlined for the cluster.

programs have averaged between 20 and 30 percent.[12] Federal energy legislation under discussion at the time of this report will likely offer flexibility as to the level of energy efficiency each state and energy provider chooses to pursue. It will therefore be incumbent on states and local energy providers to undertake a rigorous analysis to assess the role of efficiency in the context of their overall regional energy strategy.

4. **Forge greater alignment across utilities, regulators, government agencies, manufacturers, and energy consumers.** Designing and executing a scaled-up national energy efficiency program will require collaboration among many stakeholders. Three tasks in particular will need to be addressed to achieve the necessary level of collaboration. First, aligning utility regulation with the goal of greater energy efficiency is a prerequisite for utilities to fully support the pursuit of efficiency opportunities while continuing to meet the demands of their public or private owners. Second, setting customer expectations that energy efficiency will reduce energy bills, but not necessarily rates, will be important to securing their support. Finally, measuring energy efficiency requires effective evaluation, measurement, and verification to provide assurance to stakeholders that programs and projects are achieving the savings claimed for them. Rather than attempting to provide "perfect" information, such programs can provide "sufficient" assurance by focusing on consistency, simplicity of design, and addressing both inputs and impact.

5. **Foster innovation in the development and deployment of next-generation energy efficiency technologies to ensure ongoing productivity gains.** Finally, having launched a significant national campaign to pursue energy efficiency, part of the national strategy must address sustaining the innovation required to ensure future productivity gains can be realized. By design, given the near-term focus of this report, technology development plays a minor role in the potential identified in this report. However, we expect that innovative and cost-effective energy-saving technology will continue to emerge. Ongoing funding and support of energy efficiency research and development can help keep the U.S. on a trajectory toward even greater productivity gains than those presented in this report.

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[12] Further discussion of program costs is included in Chapter 5 of the full report.

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In the nation's pursuit of energy affordability, climate change mitigation, and energy security, energy efficiency stands out as perhaps the single most promising resource. In the course of this work, we have highlighted the significant barriers that exist and must be overcome, and we have provided evidence that none are insurmountable. We hope the information in this report further enriches the national debate and gives policymakers and business executives the added confidence and courage needed to take bold steps to formulate constructive ways to unlock the full potential of energy efficiency.

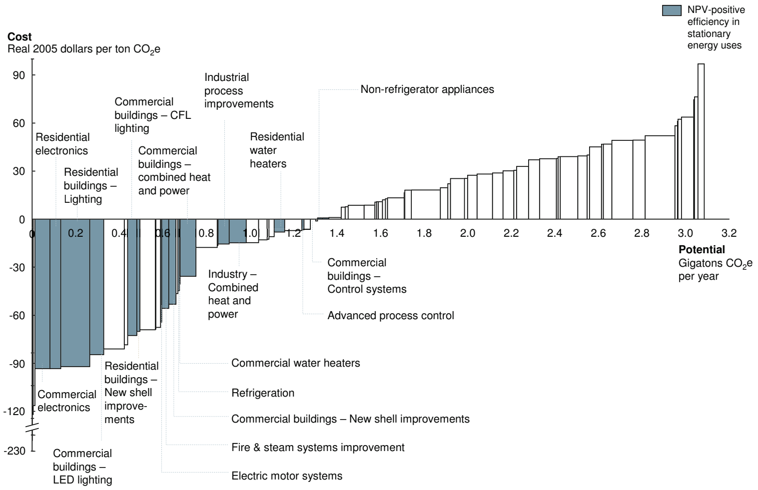
# Contents

## Sidebars

# Introduction

Energy has reemerged as an issue of national concern as the United States confronts the challenges of economic recovery, energy affordability, climate change, and energy security. In November 2007, McKinsey & Company published a report entitled "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?" and produced what has become a well-recognized abatement curve illustrating the sources, potential magnitudes, and incremental costs of options to abate greenhouse gases (Exhibit 1).

Exhibit 1: U.S. mid-range greenhouse gas abatement curve – 2030



Source: McKinsey analysis

This exhibit shows greenhouse gas abatement potential as depicted in the mid-range case in McKinsey's greenhouse gas report (2007), with energy efficiency opportunities associated with stationary uses of energy highlighted. The height of each bar represents the incremental cost in dollars to abate one ton of carbon dioxide (or its equivalent); the width shows the gigatons of such emissions that could be abated per year.

The colored bars in this exhibit identify the potential impact of greater efficiency in stationary uses (i.e., non-transportation-related) of energy, the focus of this report. It is important to note that to achieve the aggressive goals being discussed nationally for greenhouse gas reduction (i.e., on the order of 3.5 to 5.2 gigatons $CO_2e$ by 2030), the nation will need a portfolio of options that includes and goes well beyond energy efficiency. While this report focuses on what has been referred to as the "left-side" of the abatement curve, no one should view energy efficiency as a complete substitute for the "right-side":

sources of renewable energy, such as wind, solar, biomass, geothermal and hydroelectric energy, or low-carbon options like nuclear power and commercialization of carbon capture and storage. It would also be important to consider the transportation sector in detail, including the potential value of electric vehicles and alternatives for conventional motor fuels (gasoline, diesel) such as cellulosic biofuels, as a substitute for less carbon-efficient options. To achieve the nation's goals of energy affordability, climate change mitigation, and energy security, we will need a combination of these energy initiatives.

The reasons to focus on energy efficiency are as simple as the questions are puzzling: If the economics of energy efficiency are so compelling and the technology is available and proven, why has the U.S. economy not captured more of the energy efficiency available to it, particularly given the progression of efforts at federal and state levels, by government and non-government entities alike, over the past three decades? In other words, by what means could the United States realize a much greater portion of the energy efficiency available to it? A number of organizations asked us to examine this issue and consider what actions would enable greater success.

Working with a range of major U.S. based companies and government organizations, industry experts, foundations, and environmental NGOs we designed our analytical approach with this problem in mind. Our methodology identifies important clusters of energy efficiency potential in non-transportation settings, drawing on knowledge of barriers that have impeded capture of this potential in the past. To make our assumptions and modeling more transparent, we relied heavily on publicly available sources of data. Using the Energy Information Administration's National Energy Modeling System and *Annual Energy Outlook 2008* (AEO) as a foundation, we developed a set of "business-as-usual" (BAU) choices for end-use technology through 2020 in line with the AEO for each Census division and building type. Then, to identify meaningful efficiency opportunities at this level of detail, we modeled deployment of more than 675 energy-saving measures to select those with the lowest total cost of ownership, replacing existing stock over time whenever doing so was "NPV-positive."[1] We then disaggregated national data on energy consumption using some 60 demographic and usage attributes, creating more than 20,000 micro-segments of consumption to further granulate our findings. By linking our models with usage surveys and research on user-related barriers, we were able to re-aggregate the micro-segments as clusters of efficiency potential according to sets of shared barriers and usage characteristics. The resulting clusters (14 in all, five each in the residential and commercial sectors, three in the industrial sector, and combined heat and power (CHP) systems in both commercial and industrial settings) are sufficiently homogeneous to suggest a set of targeted solutions.

We focused our exploration of barriers and solutions on 2020 in order to identify near-term opportunities relatively unaffected by technological uncertainty. Our modeling is based on a 2008 baseline, but we recognize that mobilizing to pursue energy efficiency on a national scale will likely take time. Therefore, references throughout this report to 2020 represent the possible outcome of a decade of effort focused on energy efficiency, which would in reality depend on when significant initiatives are launched.

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[1] By "NPV-positive" we mean the present value of energy, operation, and maintenance cost savings that accrue over the life time of the measure are equal to or greater than the upfront investment to deploy that measure when discounted at an appropriate discount rate. We varied assumptions about the value of energy saved and discount rate to reflect different perspectives on the potential.

In defining opportunities within this near-term horizon, we use a stock-and-flow approach and allow accelerated deployment of energy efficiency measures, represented for example by substitution of building shell improvements or lighting prior to end-of-life for the existing stock, whenever the measure minimizes total lifetime cost. By "minimizes total lifetime cost," we mean the full cost of adopting a measure, be it improving a building or replacing an energy-consuming device before the normal end of its useful life, is more than offset by the associated savings over the measure's lifetime.[2] By contrast, the portfolio of opportunities mostly contains measures that generate only enough savings to offset their incremental cost relative to a business-as-usual alternative. These "end-of-life" NPV-positive opportunities represent the majority of the efficiency potential identified in the residential (50 percent) and commercial (70 percent) sectors. In this way, our modeling uses both "accelerated" replacement and standard stock-and-flow "end-of-life" replacement to maximize the net present value of the total cost of energy consumption. This concept is not as applicable in the industrial sector, where we have assumed upgrades coincide with other needed maintenance schedules or deployment of new equipment or processes.

Our central result for energy efficiency potential used a 7 percent real discount rate and regional industrial energy prices to value the energy savings of reduced consumption. In this regard, the efficiency potential identified in this report is a variant of the "economic" potential described in the preexisting literature on energy efficiency and uses a cost test similar to but not the same as the Total Resource Cost test.[3] We have not evaluated a "technical" potential, which would derive from existing technology regardless of incremental technology cost and yield a higher potential. Nor have we identified an "achievable" potential, which would discount the amount of economic potential captured based on demographic, market, and regulatory factors used to approximate the behavior of various economic agents and estimate what could be realistically expected using current approaches.

Using existing literature, primary interviews, our modeling, the underlying data, and judgment, we synthesized and structured the barriers that impede deployment of energy efficiency measures, attributing to each cluster the most significant barriers. We then gathered available information on existing and past programs targeting energy efficiency in these clusters and evaluated their ability to overcome the associated barriers. Finally, we explored the system-level actions the nation would need to take to drive broad demand for and adoption of energy efficiency, analyzing the proposed trade-offs in various policies and market mechanisms.

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2 Our analysis assigns no residual value to an existing energy-consuming device that is replaced prior to the end of its life. A less conservative calculation might subtract the residual (i.e., undepreciated) value of the existing device from the total cost of the accelerated device. As this requires resale of a piece of equipment that is not cost effective to use, we have taken the more conservative approach of assuming such equipment cannot be resold and assigned it zero residual value.

3 Our analysis does not include program administration costs, incentives paid to program administrators, costs or benefits of other resources (e.g., water), or non-resource costs or benefits (e.g., productivity) as are sometimes included in the Total Resource Cost test.

Importantly, there are aspects that differentiate this research from other reports on energy efficiency. We have focused on understanding how to pursue energy efficiency on a national scale by connecting the related activities of estimating potential, identifying barriers, reviewing solutions, and discussing policy implications in a single report. Specifically, we:

- Focused on end-use[4] energy to facilitate the conversation among business leaders and policymakers, while noting the importance of primary energy, its technical match to efficiency topics, and making such numbers available where appropriate
- Included only those energy efficiency initiatives that could be "hard-wired," as opposed to relying on sustained behavioral change among end-users (e.g., conservation efforts, such as turning off unnecessary lights)
- Assumed no material change in consumer utility[5] or lifestyle preferences
- Leveraged existing technologies and did not attempt to forecast future technology innovations or incorporate the most "extreme" forms of whole-building redesign, which can further reduce consumption. Accordingly, we have not presented a "technical" potential
- Attempted to identify the most significant barriers and solutions, but not necessarily be exhaustive of all possibilities
- Applied data wherever possible, but recognized that we could not quantitatively map solutions to every barrier in every cluster
- Avoided the temptation to predict how much of the available "economic" potential could or would be realized by adopting new, scaled-up approaches. Nowhere in this report do we calculate an "achievable" potential as is typically done using top-down estimates from an "economic" potential.

Our research suggests the net cost of achieving these levels of energy efficiency would produce energy savings that approximately double the upfront investment on an economy-wide basis. Although these savings are even more attractive for most participating consumers, issues of timing and allocation would likely lead various stakeholders to perceive the costs differently. It is likely that not all energy consumers would benefit equally from pursuit and capture of greater energy efficiency on a national scale. One outcome we discuss in this report is the inverse relationship between energy bills and electric rates: bills and total energy costs would decline, but the per-unit price (i.e., rate) would likely rise from current levels. The impact relative to business-as-usual is less certain, since in absence of energy efficiency investment, rates may rise due to other factors. Details of this effect on rates will vary throughout the country.

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[4] End-use, or "site," energy refers to energy consumed in industrial, business, and residential settings, e.g., providing light, heating and cooling spaces, running motors and electronic devices, and powering industrial processes. By contrast, primary, or "source," energy represents energy in the form it is first accounted (e.g., BTUs of coal, oil, natural gas) before transformation to secondary or tertiary forms (e.g., electricity). From the end-use viewpoint primary energy is lost during transformation to other forms and in transmission, distribution, and transport to end-users; these losses are an important energy-saving opportunity but one that is outside the scope of this report. In addition, we focus on non-transportation uses of energy, excluding fuel used by passenger vehicles, trucks, trains, airplanes, and ships; in line with this focus, we have also excluded transport energy used in agriculture, mining, and construction operations. For simplicity of expression, we sometimes refer to the energy covered by our analyses as "stationary energy."

[5] By "consumer utility" we mean functionality or usefulness for end-users, including level of comfort; in this context, holding consumer utility constant would imply, for example no change in thermostat settings or appliance use; no downsizing of homes or commercial floor space. In a strict economic sense, maintaining constant consumer utility assumes a constant economic surplus for the consumer while delivering against a common benefit. We have not attempted to calculate potential changes in consumer utility that might result from energy price changes associated with pursuing the options outlined in our report.

The intention of this report is not to recommend particular policy solutions; rather, our hope is that this research will aid in the understanding and further pursuit of economically sensible and effective approaches to unlocking the potential of energy efficiency. This report presents the findings of our work in five chapters:

1. A compelling nationwide opportunity
2. Approaches to greater efficiency in the residential sector
3. Approaches to greater efficiency in the commercial sector
4. Approaches to greater efficiency in the industrial sector
5. Developing a holistic implementation strategy.

The report also contains boxed areas with brief treatments of a number of topics related to energy efficiency but not included directly in our analyses. Additional supporting material, covering technical terms and methodology, as well as works cited and consulted, are located in the appendices.

# 1. A compelling nationwide opportunity

The United States faces an important opportunity to transform how it uses energy in its residential, commercial, and industrial sectors. Capturing energy savings across the U.S. economy, however, will be a daunting challenge for two reasons: first, each opportunity has meaningful and persistent barriers that have prevented it from being captured in the past, and second, a number of complex issues will have to be addressed at the level of local and regional energy markets – as well as at the national level – if the United States is to realize the full potential of its energy efficiency opportunity.

This chapter describes the NPV-positive efficiency potential the nation can pursue in an accelerated manner in the relative near term (through 2020) and explores the multi-level challenge presented by this attractive opportunity.

## SIGNIFICANT POTENTIAL AVAILABLE IN THE NEAR TERM

The opportunity for greater efficiency in stationary energy use is substantial. It is less sensitive to discount factors, participant costs of capital, and carbon prices – and could be pursued more quickly – than is typically acknowledged, but only if the United States can find ways to address the associated barriers and unlock the potential.

Business-as-usual (BAU) projections for 2020 suggest U.S. end-use energy consumption addressed in this report[6] will grow by 0.7 percent per year from 2008, reaching 39.9 quadrillion BTUs in 2020. If the nation can overcome the barriers and capture the full NPV-positive efficiency potential in 2020, the U.S. could consume some 23 percent less energy per year, saving more than 9.1 quadrillion BTUs of end-use energy (including 1,080 billion kWh of electricity) relative to the BAU forecast (Exhibit 2). This reduction would require an upfront investment of approximately $520 billion[7] and would yield present-value savings of roughly $1,200 billion. If deployed over 10 years, this annual spend of roughly

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[6] Appendix B discusses the methodology of this report including the scope of energy uses addressed.

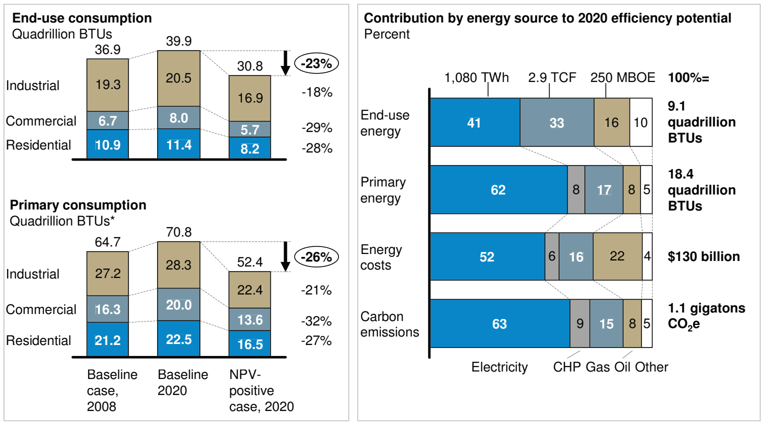
[7] This amount includes $56 billion of upfront investment associated with deploying 50 GW of combined heat and power generation.

$50 billion would represent a four- to five fold increase over current levels of spending on energy efficiency[8] with corresponding annual energy savings valued at $130 billion.[9]

Measured in primary energy,[10] savings would total 18.4 quadrillion BTUs, or 26 percent relative to a BAU baseline. If attained in its entirety, this efficiency potential would reduce annual U.S. GHG emissions in 2020 by 1.1 gigatons $CO_2e$, some 15 percent of 2005 greenhouse gas emissions and equivalent to 26 percent of non-transportation GHG emissions in the sectors that we modeled.

Exhibit 2: Significant energy efficiency potential in the U.S. economy

The left side of the exhibit shows total energy consumption, measured in quadrillion BTUs, for the portions of each sector addressed in the report, plus the corresponding consumption if the identified energy efficiency potential were realized. The right side provides different views of the energy efficiency potential in 2020 broken out by fuel type.



* Includes primary savings from CHP of 490 trillion BTUs in commercial and 910 trillion BTUs in industrial.

Source: EIA AEO 2008, McKinsey analysis

If the U.S. economy could realize the NPV-positive efficiency potential identified in this report, it would more than fully offset expected consumption growth, leading to an absolute decline in energy use over this period. The nation would see stationary energy use decline equivalent to a rate of 1.5 percent per year, decreasing from 36.9 quadrillion BTUs in 2008 to 30.8 quadrillion BTUs in 2020. This change represents an absolute decline of 6.1 quadrillion end-use BTUs from 2008 levels and an even greater reduction of 9.1 quadrillion end-use BTUs over the projected level of what consumption otherwise would have reached in 2020. This magnitude of change could have profound implications on existing energy provider business models.[11] Construction of new power plants, gas pipelines, and other energy infrastructure will still be required to address selected pockets

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[8] Annual efficiency spend of $10 billion to $12 billion includes spending on utility programs ($2.5 billion), ESCO efficiency ($3.5 billion), and incremental investment in insulation and devices ($4–6 billion), but excludes business-as-usual insulation spend ($8–$10 billion) to satisfy building codes and standard practices.

[9] Annual energy savings in 2020 would consist of 3.7 quadrillion end-use BTUs of electricity at $18.72 per MMBTU, 3.0 quadrillion end-use BTUs of gas at $6.88 per MMBTU, 1.5 quadrillion end-use BTUs of oil savings at $20.00 per MMBTU, and 0.9 end-use quads of other energy at $6.35 per MMBTU. The resulting total, 9.1 quadrillion end-use BTUs, has an average savings of $13.80 per MMBTU. CHP offers an additional $7.9 billion per year of energy savings. The total annual energy savings in 2020 of $133 billion has been rounded to $130 billion throughout this report.

[10] Primary energy consumption savings for electricity have been calculated by converting end-use BTUs to primary BTUs at a multiple of 3.1, which includes conversion, transmission, and distribution loss. We convert end use gas consumption to primary use gas consumption by multiplying by 1.039 to include pump energy to move gas through pipelines, and storage and transportation leaks. Data for transport energy of other fuels is not readily available; therefore we use the same as end-use and primary use consumption though some small adjustment would likely be required.

[11] We examine implications for energy provider business models in Chapter 5 of the full report.

of growth, retirement of economically or environmentally obsolete energy infrastructure, and introduction of unaccounted-for consumption such as electric vehicles. However, energy efficiency could measurably reduce the total required investment for additional assets during this timeframe.

### The efficiency potential remains significant across scenarios

In modeling the national potential for greater energy efficiency, we calculated net lifecycle benefits less costs, regardless of who invests in measures or receives benefits. For our central result, we used industrial retail rates to value the energy savings and applied a 7 percent discount factor as the cost of capital; we assumed there was no price on carbon. We tested the sensitivity of the NPV-positive opportunities by adjusting the discount rate (expected payback period), value of energy saved (sector-specific retail rates versus industrial retail rates)[12], and possible carbon price ($0, $15, $30, and $50 per ton $CO_2$e). Exhibit 3 shows the resulting NPV-positive potential beyond business-as-usual levels exploring sensitivity to these three factors:

- **The perspective used to view costs and benefits.** The total potential from a "participant" perspective (i.e., taking the perspective of an end-user with retail energy prices and a 20 percent discount rate)[13] is 7.2 quadrillion BTUs, 21 percent less than potential from the national perspective (using industrial energy prices and a 7 percent discount rate to value the energy savings), indicating significant potential from either perspective.
- **Time-value of savings.** Residential customers' expectation of a 2 to 3 year payback period for household investments is an often-cited barrier to energy efficiency. This expectation of rapid payback limits potential, but still provides considerable opportunities across all sectors. A 40 percent discount rate across sectors with retail power prices reduces potential by 43 percent, but an economy-wide potential of 5.2 quadrillion BTUs remains. By contrast, decreasing the real discount rate from a national perspective from 7 percent to 4 percent increases the potential 10 percent to 10.0 quadrillion BTUs.
- **Value of energy savings through a carbon price.** Introducing a carbon price as high as $50 per ton $CO_2$e from the national perspective increases the potential by 13 percent. A price of $30 per ton $CO_2$e would increase the potential by 8 percent. The direct impact of carbon pricing, namely the microeconomic expectation that increasing energy price should reduce energy consumption, is outside the scope of this report.

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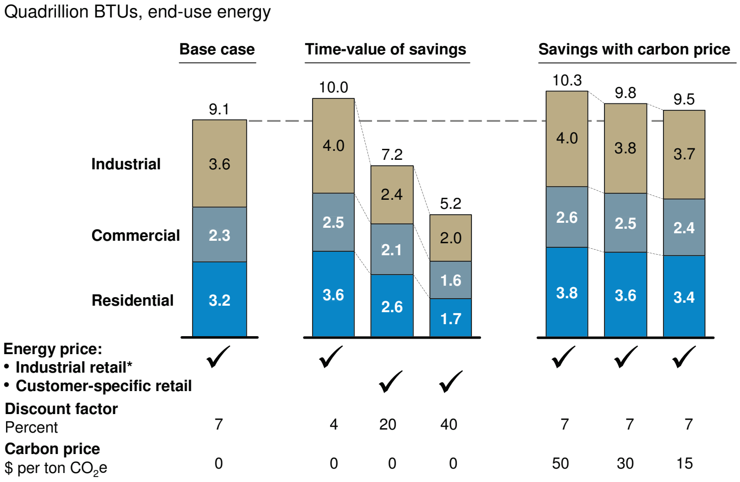
[12] Industrial retail rates represent an approximate value of the energy saved as they include generation, transmission, capacity, and distribution costs in regulated and restructured markets. The bulk of the rate is composed of generation cost, with minor contribution from transmission, capacity, and negligible contribution from distribution costs. Though load factor in these rates underestimates the national average, and thus this rate represents a slightly conservative estimate of the value of the energy savings, the other components are closer to the likely savings if significant energy efficiency were to be realized. We computed the avoided cost of gas also using an industrial retail rate, which likewise is close to the wholesale cost of gas plus a small amount of transport. A more detailed discussion of the avoided cost of energy is available in Appendix B of the full report.

[13] Twenty percent approximates the marginal cost of capital for many unsecured financing sources; though home equity lines or revolving credit lines are available at lower rates, they may be more difficult to obtain.

Exhibit 3: Sensitivity of NPV-positive energy efficiency potential

The height of each column represents the energy efficiency potential in 2020 associated with non-transportation uses of energy under the conditions defined at the bottom of the exhibit -- energy price, discount factor, and carbon price. The height of each section corresponds to the efficiency potential in that sector, as labeled at the left, under those conditions.



| | Base case | Time-value of savings | | | Savings with carbon price | | |
|---|---|---|---|---|---|---|---|
| Energy price: Industrial retail* | ✓ | ✓ | | | ✓ | ✓ | ✓ |
| Energy price: Customer-specific retail | | | ✓ | ✓ | | | |
| Discount factor, Percent | 7 | 4 | 20 | 40 | 7 | 7 | 7 |
| Carbon price, $ per ton $CO_2e$ | 0 | 0 | 0 | 0 | 50 | 30 | 15 |

* AEO 2008 industrial retail prices by Census division (national average weighted across all fuels: $13.80/MMBTU) are used to value the energy saved

Source: EIA AEO 2008, McKinsey analysis

## Opportunities distributed throughout the economy

Because efficiency potential is present in nearly all energy-consuming devices and processes, it is highly fragmented with substantial opportunities in the residential, commercial, and industrial sectors.

- **Residential sector.** The residential sector accounts for 29 percent of 2020 BAU end-use consumption and offers a slightly disproportionate 35 percent of the end-use efficiency potential. The residential opportunity is extremely fragmented, as it is spread across conditioning the space of 129 million households and energizing the dozens of appliances and devices in each household.[14]
- **Industrial sector.** The industrial sector offers the reverse proportion: the sector accounts for 51 percent of 2020 BAU end-use consumption but only 40 percent of end-use efficiency potential. The opportunity is, however, more concentrated: half of the potential is concentrated in 10,000 facilities, with the remainder distributed among 320,000 small and medium-sized enterprises. The relatively smaller proportion of savings potential is likely driven by the sector's historically greater focus (than the residential sector) on capturing energy efficiency opportunities.
- **Commercial sector.** The commercial sector consumes 20 percent of the 2020 BAU end-use energy and offers 25 percent of the efficiency potential across 87 billion square feet of floor space, supporting functions as diverse as retail, education, and warehousing. Electricity represents a larger share of consumption in this sector; as such it offers the largest primary energy opportunity at 35 percent of the total when including commercial CHP opportunities.

Opportunities are indeed scattered across a range of climates, users, end-uses, and fuels. Appliances, building shells, industrial processes, and a wide range of other end-uses offer substantial potential.

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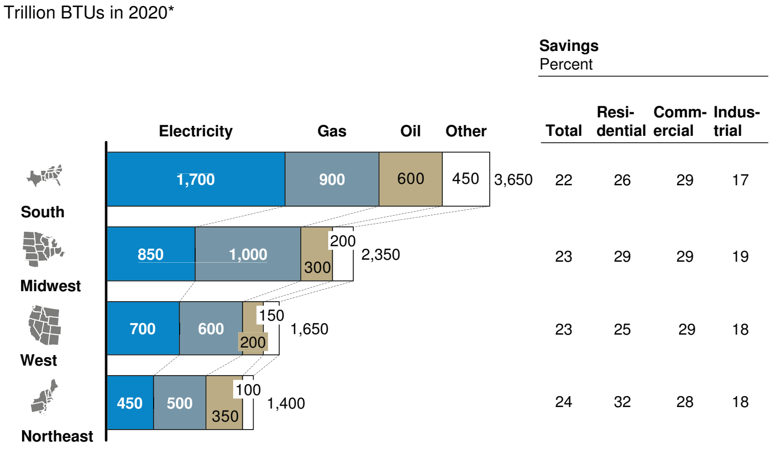
[14] The number of homes, 129 million, is based on EIA's number of occupied homes. In 2020, there will be an additional 10 million to 15 million unoccupied homes counted by the Census. Our analysis, and most products of the EIA, use only the 129 million occupied homes, because unoccupied homes consume little energy and present little, if any, NPV-positive efficiency potential.

Finally, while the nature of efficiency opportunities changes across geographies; substantial potential is present in all areas. Each Census region has efficiency potential equivalent to at least 20 percent of its total energy consumption (Exhibit 4). The South Census region offers the largest absolute potential, more than twice the Northeast Census region, though relative to total consumption its proportion of potential is below the national average. The greatest efficiency potential relative to total consumption is in the Northeast, due to high potential especially in the residential sector.

Exhibit 4: Energy efficiency end-use potential across Census regions



* Numbers rounded to 50 trillion BTUs
Source: EIA AEO 2008, McKinsey analysis

The bars at the left depict the end-use energy efficiency potential in the four Census regions in 2020, by fuel type, and measured in trillion BTUs, with the total for the region at the right end of the bar. The table on the right displays the potential energy savings in the Census region as a percent of BAU consumption in 2020; the total savings in percent is a weighted average of the savings in the three sectors -- residential, commercial, and industrial.

## Clusters of opportunity present themselves

In order to accurately represent the potential in these fragments of consumption our modeling uses these characteristics to analyze potential in "micro-segments" of consumption. Aggregating these micro-segments based on common characteristics reveals 14 addressable clusters: five each in residential and commercial sectors, three in the industrial sector, and combined heat and power (CHP) systems across both commercial and industrial settings.

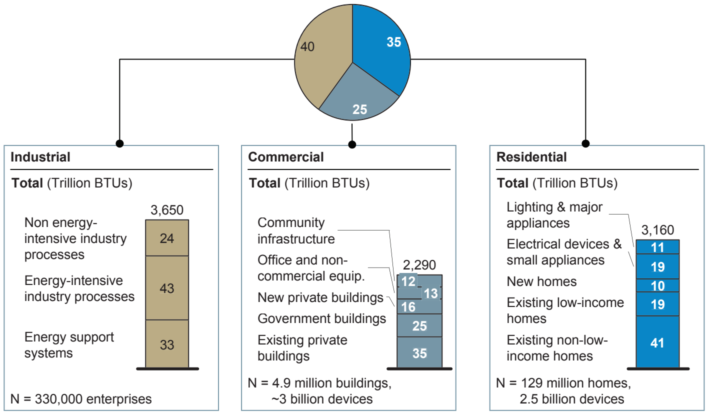
Each cluster represents a sizable and actionable opportunity and is sufficiently homogenous with similar barriers and potential responsiveness to solution strategies. The most relevant characteristics that define these clusters include home owner income, building age (i.e., new versus retrofit buildings), specific end-uses or opportunities (e.g., electrical devices, community infrastructure, waste heat recovery), private versus government ownership structure, and energy intensity. Exhibit 5 shows these clusters and their end-use and primary energy efficiency potential.

New homes, in residential, and new private buildings, in commercial, share similarities both in the barriers that impede the opportunity and the types of solution strategies that address the barriers. Electrical devices and small appliances, in residential, and office and non-commercial devices, in commercial, also exhibit similarities. The combined heat and power cluster, discussed in Chapter 4, differs from other clusters as it offers savings in primary energy but not necessarily in end-use energy, though it is a site-based energy source.

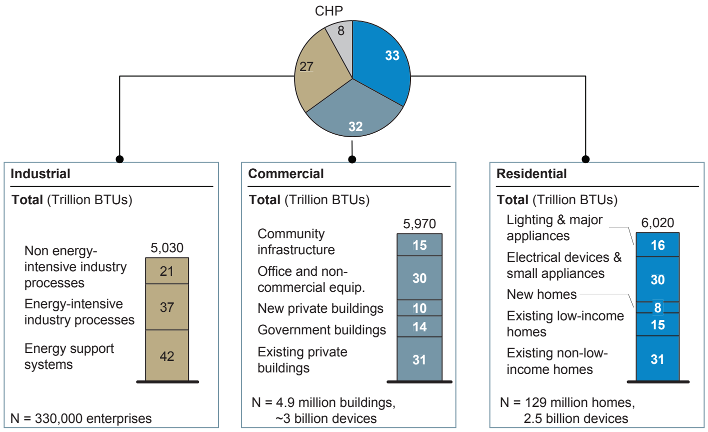
## Exhibit 5: Clusters of efficiency potential in stationary uses of energy – 2020

The pie charts show the share (in percent) of energy efficiency potential in 2020 in each economic sector, with end-use energy in the upper chart and primary energy in the lower one. Each column chart shows the clusters of potential that make up each sector, with the total potential in the sector (in trillion BTUs) displayed at the top of the column and the share (in percent) in the corresponding segment. Below each column are numbers for relevant end-use settings.

Percent, 100% = 9,100 trillion BTUs of end-use energy



Percent, 100% = 18,410 trillion BTUs of primary energy

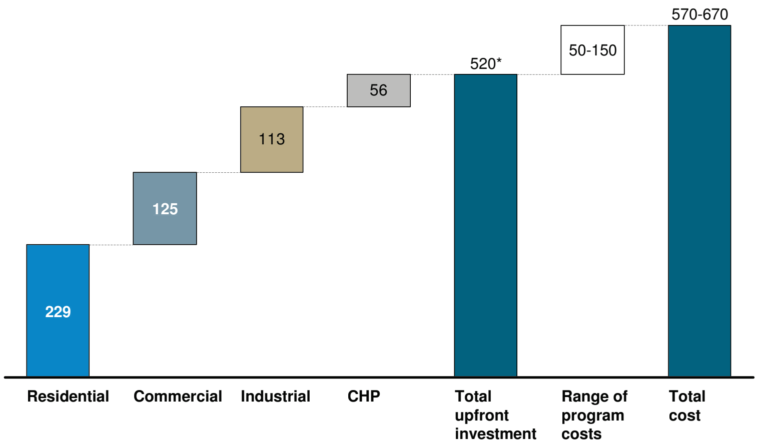


Source: EIA AEO 2008; McKinsey analysis

## Exhibit 6: Upfront cost of energy efficiency corresponding to $1.2 trillion savings

The height of each column represents the present value of the cost of NPV-positive energy efficiency measures: the four columns on the left (the sectors, plus CHP) total to the amount shown in the fifth column. The total upfront investment plus the range of program costs totals to the column on the far right, which provides a range for the total cost.

U.S. dollars, billions



* Rounded to the nearest ten billion

Source: EIA AEO 2008, McKinsey analysis

## INDIRECT BENEFITS OF ENERGY EFFICIENCY

Improving energy efficiency in residential and commercial space offers a host of non-financial benefits. For example, in the residential sector, energy efficiency upgrades can help reduce exposure to volatility in energy prices, reduce basement water damage (estimated at $1.4 billion annually), decrease food spoilage, and extend clothing life.[1] According to many home performance contractors, the non-financial benefits of efficiency-related upgrades may have greater value to many homeowners than the purely financial ones. Although increased energy efficiency may contribute to such auxiliary benefits as greater reliability and resilience in the electricity grid, this section describes three sets of indirect benefits associated with energy efficiency upgrades: enhanced health and comfort, improved productivity, and increased standard of living, particularly for low-income households.

**Impact on comfort and health.** Energy efficiency upgrades, including proper insulation and sealing against air infiltration, can address a number of common residential problems, such as drafty rooms, cold floors in the winter, damp basements, dry air, musty odors, and mold. Because people spend up to 90 percent of their time indoors,[2] many of these issues can lead to health risks, contributing to chronic allergies and asthma, as well as periodic illness. Sick building syndrome (SBS), which is associated with poor indoor air quality, can manifest itself in building occupants as irritation of the eyes, nose, throat, or skin, as well as other ailments. Flaws in HVAC systems, emissions from some types of building materials, volatile organic compounds used indoors, and inadequate exhaust systems may be contributing factors. Severe problems with heating or cooling systems, for example, can result in dangerous concentrations of carbon monoxide or radon gas. Air and duct sealing and periodic maintenance of HVAC equipment can mitigate a number of these risks. While quantifying the impact of higher air quality on health is difficult, research suggests that the benefits are significant. Improved indoor air quality can reduce symptoms of SBS by 20 to 50 percent, asthma by 8 to 25 percent, and other respiratory illnesses by 26 to 75 percent.[3]

**Impact on productivity.** Efficiency-related upgrades in commercial buildings can increase worker productivity directly, as well as indirectly through reduced sick leave. SBS costs the nation an estimated $60 billion annually in sick days, medical costs, and reduced productivity.[4] A study by Lawrence Berkeley National Laboratory suggests higher indoor air quality itself can increase worker productivity by as much as 5 percent. Occupants of green buildings report themselves to be more satisfied with thermal comfort and air quality in the workspace than occupants of non-green buildings,[5] and may also benefit from the additional use of natural light.[6] Furthermore, worker productivity is higher at certain temperatures, which can be maintained more consistently throughout a building with higher-efficiency HVAC systems.[7] In all, improvements in worker health and productivity due to improved air quality may total $37 billion to $210 billion annually according to some sources.[8]

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[1] "Home Energy Saver," LBNL, 2009. <http://hes.lbl.gov>.

[2] "The Inside Story: A Guide to Indoor Air Quality," EPA, April, 2009.

[3] William J. Fisk, "How IEQ Affects Health, Productivity," ASHRAE Journal, May 2002.

[4] William J. Fisk, "Health and Productivity Gains from Better Indoor Environments and their Implications for the U.S. Department of Energy", LBNL, February 2002.

[5] S. Abbaszadeh Fard et al. "Occupant Satisfaction with Indoor Environmental Quality in Green Buildings," Proceedings of Healthy Buildings 2006, Lisbon, Vol. III, 365-370.

[6] Joseph J. Romm., "Successfully Daylighting a Large Commercial Building: A Case Study of Lockheed Building 157," Progressive Architecture, November 1990.

[7] Olli Seppänen et al., "Effect of Temperature on Task Performance in Office Environment," Helsinki University of Technology and LBNL, July 2006.

[8] William J. Fisk, "How IEQ Affects Health, Productivity," ASHRAE Journal, May 2002.

**Impact on poverty alleviation.** While energy efficiency can result in substantial savings for the average household, these savings can have an even larger impact on the quality of life of low-income households. While the average household spends approximately 5 percent of its income on energy bills, the average low-income household spends about 15 percent, and some households on fixed incomes spend as much as 35 percent. After home weatherization, the average spending for energy drops to 10 percent among low-income households and 21 percent for fixed-income households. These savings materially increase the household standard of living and can be put to other uses, including setting the thermostat to more a comfortable temperature, as well as for food, clothing, or education.

### Deploying energy efficiency measures on a national scale will require a significant capital outlay

Deploying NPV-positive energy-saving technologies on a scale commensurate with the savings potential identified in this report, while generating benefits of $1.2 trillion, would require initial, upfront investments totaling $520 billion in present value terms through 2020 (Exhibit 6), representing an investment of $50 billion per year (in present-value terms) for
10 years. Some observers estimate that the U.S. invests $20 billion to $35 billion per year in energy consuming devices and building insulation to support a price "premium" to fund improved efficiency.[15] To compare these investments to the incremental efficiency investments described in this report we subtracted the business-as-usual level purchases of building insulation to meet present building codes and the base cost of less efficient devices to obtain a market size of $10 billion to $12 billion.[16] This implies that capturing the full efficiency potential identified in this report would require a sustained four- to five-fold increase in spending for efficiency improvements beyond today's levels. Overhead and administration costs would be in addition to this amount and would vary by the policy or market mechanism used to capture the potential. Those costs are discussed in Chapter 5.

The cost of the energy efficiency measures, expressed in dollars per million BTUs (MMBTU) saved over their lifetime, varies greatly. Exhibit 7 arrays the most economically attractive solution strategies in each of 49 energy efficiency measures in our central result from least to highest cost per MMBTU of end-use energy saved. The height of each bar shows the average cost per MMBTU saved; its width corresponds to how much energy in trillion BTUs could be saved annually with that strategy for its corresponding end-use in 2020. This chart highlights the diversity of end-uses that would provide savings, but demonstrates that there are few large and simple opportunities to pursue: capturing 80 percent of the opportunity would require deploying 58 percent of the upfront investment.[17]

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[15] Karen Ehrhardt-Martinez and John A. Laitner, *The Size of the U.S. Energy Efficiency Market: Generating a More Complete Picture*, ACEEE, May 2008. Expert interviews.

[16] Annual efficiency spend of $10 billion to $12 billion includes spending on utility programs ($2.5 billion), ESCO efficiency ($3.5 billion), and incremental investment in insulation and devices ($4–6 billion), but excludes business-as-usual insulation spend ($8–$10 billion) to satisfy building codes and standard practices.

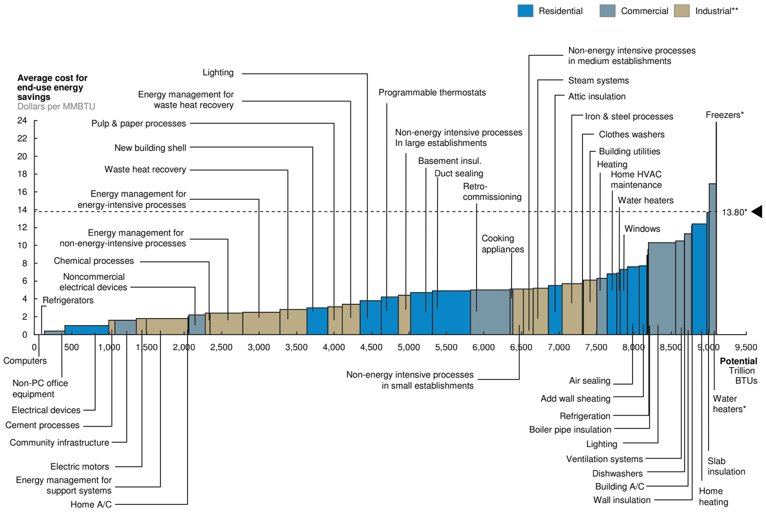
[17] Alternatively, 35 percent of the investment would correspond to 60 percent of the energy efficiency potential.

### Financial value of energy savings outweigh its cost

While not all actions that decrease the consumption of energy represent an NPV-positive investment relative to alternatives, by definition of our methodology all the energy efficiency actions included in this report represent NPV-positive investments. The upfront deployment cost of these NPV-positive efficiency measures ranges upward from $0.40 per MMBTU saved, and averages $4.40 per MMBTU saved (not including program costs). This "price" for efficiency is 68 percent below the forecasted price of energy in 2020, $13.80 per MMBTU (Exhibit 7), and 24 percent below the lowest delivered natural gas price in the United States in 2020, $5.76 per MMBTU. Put another way, even the most expensive opportunities selected in this study are attractive over the lifetime of the measure and represent the least expensive way to provide for future energy requirements.

The difference between the average cost of efficiency measures and value of the energy savings represents a conservative view of the financial benefits of energy efficiency because it includes only direct energy savings.[18]

Exhibit 7: U.S. energy efficiency supply curve – 2020



* Average price of avoided energy consumption at the industrial price; $35.60/MMBTU represents the highest regional electricity price used; new build cost based on AEO 2008 future construction costs

** Our 49th source of savings, refining processes, offers no NPV-positive savings

Source: EIA AEO 2008, McKinsey analysis

The width of each column on the chart represents the amount of efficiency potential (in trillion BTUs) found in that group of measures, as modeled in the report. The height of each column corresponds to the average annualized cost (in dollars per million BTUs of potential) of that group of measures.

## PREVIOUS EFFORTS HAVE IMPROVED ENERGY EFFICIENCY

Over the past 35 years, national interest in energy efficiency has risen and fallen following changes in energy prices (Exhibit 8). The global oil crises of the 1970s catalyzed substantial action at the federal and state levels: efficiency standards for appliances and buildings, tax credits for investment in efficiency measures, and the creation of the Department of Energy and special-purpose state entities.

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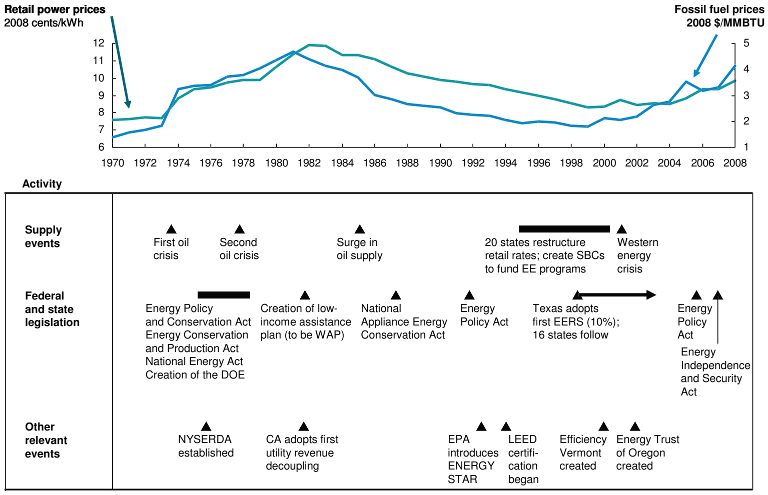
[18] Additional financial benefits include lowered commodity risk, impact on the cost of fuel and improved efficiency of electricity generation, job creation, and health improvements. These benefits are described as special topics in the report where appropriate, but are not included in the calculation of the efficiency potential.

Exhibit 8: Milestones in the pursuit of energy efficiency

The line chart across the upper portion of the exhibit shows fluctuations in retail power prices (2008 cents per kWh) and fossil fuel prices (2008 dollars per MMBTU) over the past 40 years, with power prices tracking to the vertical axis on the left and fossil fuel prices tracking to the vertical axis on the right. The box across the lower part of the exhibit displays a timeline of key events that have affected the capture of energy efficiency potential in the United States over the same period.



Source: DOE, EPA and Alliance to Save Energy; McKinsey analysis

A surge in the global oil supply in the mid-1980s, however, brought a sharp decline in oil and power prices, with relatively stable or declining fossil fuel and power prices following for more than a decade. In this environment, sustaining momentum at the national level for efforts to improve energy efficiency became increasingly difficult.[19] At the same time, national energy policy shifted toward greater reliance on markets to better balance supply and demand of energy resources. Over the past 10 years, however, with an energy crisis in western states, supply disruptions from events overseas and natural disasters domestically, and rising concerns about the effects of climate change, interest in a coordinated approach to capturing energy efficiency has reemerged.

In this period, various government agencies and contractors, non-government agencies, and academics have explored the potential for energy efficiency and the reasons it so often remains an untapped resource. As early as the late 1970s, academics and advocates began identifying the available efficiency potential and the barriers to the capture of that potential. Within the past decade, four efforts stand out at the national level, with more than 20 others at the regional or state level, that generally align with the methodology suggested in the "Guidelines for Conducting Energy Efficiency Potential Studies" published by the EPA. These studies report some subset of technical, economic, or achievable potential, with seven economic potential findings ranging from 10 to 30 percent, presenting an average (and median) value of 21 percent, broadly in line with the results of this report. This report is also in agreement with the finding of our previous work on greenhouse gas abatement in the United States, which identified "mid-range" efficiency savings of 1,284 TWh of electricity and 1,424 trillion BTUs of gas in 2030 with an estimated upfront outlay of $280 billion.[20] Differences in baseline, timing, and nature (i.e., "mid-range" focus on GHG emissions versus focus on NPV-positive energy efficiency) of the reports account for the difference between

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[19] Robert Bamberger, *Energy Policy: Conceptual Framework and Continuing Issues*, Congressional Research Service, March 2007.

[20] Noteworthy differences between the reports, expressed as the figures to add to the greenhouse gas report's 2030 result to obtain this report's 2020 result include the following: baseline (-$27 billion, -264 TWh, -1,638 end-use TBTUs of gas), timing (-$75 billion, -249 TWh, -303 end-use TBTUs of gas), and methodology, including accelerated retirement (add $200 billion, 235 TWh, and 1,320 end-use TBTUs of gas) and penetration ($150 billion, 74 TWh, 2,210 end-use TBTUs of gas).

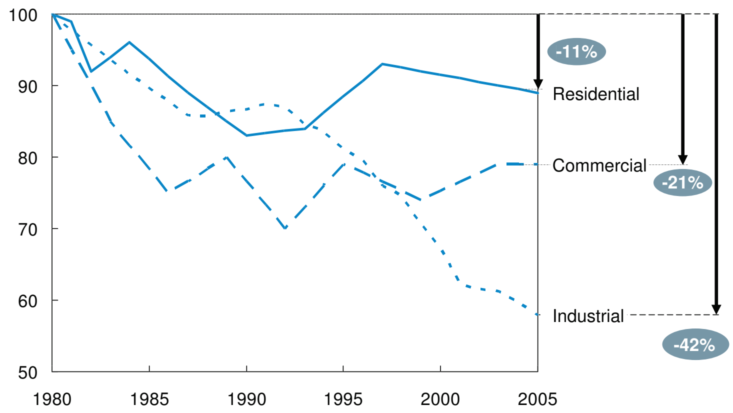
the earlier findings and the 1,080 TWh of electricity, 3,010 trillion BTUs of gas savings, and $520 billion in upfront investment in 2020 that is identified in this report.

## Efficiency has improved and is expected to accelerate

Energy intensity, expressed as the energy consumption per unit of floor space or per dollar of GDP, has decreased steadily over the past 25 years through 2005 especially in the industrial sector (Exhibit 9). Increased energy efficiency is partly responsible for this decrease in energy intensity. However, decades-long trends toward faster economic growth, national migration toward warmer regions of the country (which require more use of air conditioning), increasing home size, and greater use of electrical appliances and devices in most homes and businesses complicate this picture. The contemporaneous decline in industrial-sector energy intensity derives in large measure from improvements in process efficiency, as well as the shift of some energy-intensive manufacturing activity overseas. Thus one cannot attribute the entire increase in energy productivity to efficiency improvements, though various estimates indicate it plays a significant role in this trend.

Exhibit 9: Change in energy intensity in the U.S. economy – 1980-2005

Normalized and indexed, 1980 = 100%*



* Residential and commercial indexing is based on BTUs per square foot; industrial indexing is based on BTUs per real dollar of GDP output

Source: EIA AEO 2008, BEA

The three lines present indexed values of energy intensity for the three sectors in this report, with each year from 1981 through 2005 compared to the value in 1980. Residential and commercial energy intensity are normalized based on BTUs per square foot of space, while industrial intensity is based on BTUs per real dollar of GDP output.

Further, comparing the 20-year intensity forecast from Annual Energy Outlook (AEO) 2004 to AEO 2008 shows accelerating improvements in energy intensity. The AEO 2004 forecasts a 20-year intensity improvement in the residential sector of -5.5 percent while the AEO 2008 forecasts an improvement of -15.7 percent; this change represents a 10 percentage point improvement in energy intensity. Similarly commercial intensity shows a 5 percentage point improvement in intensity as the forecast improved from a 7.4 percent increase to a 2.2 percent increase. Industrial intensity improvements remain high with an expected 23 percent improvement in both forecasts.[21] These facts may indicate both recent progress in driving energy efficiency and renewed national interest in stewardship of our national resources, an observation supported by earlier comments highlighting the annual spend on energy efficiency, which, for example, increased from $1.3 billion in 2003 to $2.1 billion in 2006 in the utility sector.

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[21] We use 20-year expected intensity expressed in primary BTUs per square foot in residential and commercial and primary BTUs per dollar of output for industrial.

### Some success stories highlight what is possible

Economic actors as diverse as utilities, government agencies, special purpose entities, and the private sector have driven equally diverse programs targeted at improving energy efficiency. These programs include appliance standards, building codes, financial incentives, financing, and direct installation, to name a few. Several examples of varying scope warrant discussion, as they represent the significant, documented impact of a subset of approaches, namely national mandatory standards, a state's concerted effort, a national labeling program, and a special purpose entity:

**Federal Equipment Efficiency Standards.** Since 1987, when President Ronald Reagan signed the National Appliance Energy Conservation Act, mandatory national efficiency standards have been an accepted and effective manner for the government to help consumers reduce their energy consumption in a range of household appliances. According to analyses done by the DOE and ACEEE, standards reduced U.S. electricity use by 88 TWh annually and total energy use by 1.2 quadrillion primary BTUs annually in 2000. These savings represent 2.5 percent and 1.3 percent reduction of total electricity and energy use respectively. From 1987 through 2000 appliance standards saved consumers approximately $50 billion in reduced energy bills at an incremental appliance cost of $15 billion. These savings are expected to grow to 250 TWh in 2010 as standards have become more strict since data were last available.[22]

**State of California.** From 1977 through 2007, per-capita electricity consumption in California remained nearly flat, growing at 0.07 percent annually, compared to 1.3 percent in the nation overall. Adjusting for such structural differences as climate, demographics, and industry and commercial business mix, and incorporating measurement uncertainty,[23] reveals that California consumes approximately 11 to 19 percent[24] less energy per capita than the U.S. average. One notable structural difference is that California's lighter industry mix accounts for 38 percentage points of an apparent 60 percent lower per capita industrial consumption. The state's strategy for energy resources has emphasized utility-led energy efficiency programs, significant building code and appliance standard initiatives, and a range of other innovative efforts. Some observers have identified benefits of this energy efficiency, including gross state product of approximately $1,000 per capita and reduced energy burden on the low-income population.[25] It is worth noting that electricity prices in California are 35 percent higher than the national average, partly due to the public-benefit charge of $0.0054 per kWh (6 percentage points of the difference) to fund energy efficiency. This price difference may play a role in decreasing demand through microeconomic supply-demand dynamics, especially in the industrial sector.

**ENERGY STAR®.** The United States Department of Energy (DOE) and Environmental Protection Agency (EPA) jointly operate this nationwide voluntary standards and labeling program. Since its inception in 1992, ENERGY STAR has become a leading international brand for energy efficient products. It covers more than 60 product categories across nine broad product classes, including major appliances, office equipment, and consumer electronics. It also addresses new home construction, residential retrofit, and commercial and industrial energy management. Through 2007, the program has helped save 1,790 trillion BTUs of primary energy (159 TWh). There is substantial opportunity,

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[22] "Appliance and Equipment Efficiency Standards: One of America's Most Effective Energy-Saving Policies," ACEEE, 2009.

[23] Anant Sudarshan and James Sweeney, *Deconstructing the Rosenfeld Curve: Understanding California's Low Per Capita Electricity Consumption*, Stanford University, September 30, 2008.

[24] At first glance the relative per capita consumption of 11,900 kWh per capita for the U.S. vs. 6,400 kWh for California shown in this report and the "Rosenfeld Curve" suggests California consumes approximately 40 percent less energy per capita than the U.S. average.

[25] Mark Bernstein, et al., *The Public Benefit of California's Investments in Energy Efficiency*, RAND Corporation, March 2000.

however, with some new products added to the program, such as commercial food service, while many appliances and devices remain unaddressed. Furthermore, the program is only in the early stages of deploying program models to address sizeable needs in the commercial and residential retrofit segments.

**Efficiency Vermont.** The state legislature and Vermont Public Service Board created Efficiency Vermont in 2000 to help state residents save energy, reduce energy costs, and protect the state's environment. Efficiency Vermont is the nation's first state-wide "energy efficiency" utility. It is funded by a surcharge on customer electricity bills and is operated by an independent, non-profit organization under contract to the Public Service Board. In Efficiency Vermont's first 8 years of operation, businesses and homeowners who worked with the organization saved approximately 398 GWh of electricity. In 2007, Efficiency Vermont's energy savings were approximately 94 GWh, or 1.6 percent of the state's 5,865 GWh of retail sales, completely offsetting business-as-usual electric load growth forecasts in the state.[26] Load-serving entities and other special-purpose and government entities have made similar efforts, notably, but not exclusively, in New England, New York, New Jersey, and the West Coast states.

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[26] *Year 2007 Annual Report*, Efficiency Vermont, October 2008.

## DEMAND-SIDE MANAGEMENT

Opportunities in demand-side management (DSM) are prompting utilities to invest in smart grid and advanced metering infrastructure. DSM's main goal is to reduce peak loads, which allows utilities to flatten their power demand curves, shifting load from expensive peaking units to lower-cost base-load plants. Reducing peak consumption increases reliability of the electric grid, reducing outages for customers and operations and maintenance costs for utilities. Furthermore, some DSM measures can decrease total energy consumption while delivering the same value to customers.

Since the 1980s, DSM has focused primarily on commercial and industrial (C&I) customers, with more than 165 utilities in North America having programs for these customers, including direct load control (DLC) and tiered-pricing programs. However, emerging smart grid technology is shifting the focus in DSM from direct load control to dynamic pricing and making programs possible for residential and small-to-medium business segments. Residential DSM programs have so far achieved mixed results: pilots in California and Nevada have demonstrated strong potential, though other high-profile pilots, such as Puget Sound Energy in 2001, reported high implementation costs and insufficient peak reduction. Larger residential DSM deployments will be needed to better understand its actual savings potential.

Four types of DSM programs warrant discussion:

- **Direct load control and incentive-based programs.** DLC programs are one of a range of incentive-based DSM approaches that include interruptible/curtailment rates, demand bidding/buyback programs, emergency demand response programs, and capacity market programs.[1] DLC programs allow utilities to control specific energy-intensive loads, such as air conditioners, in exchange for a billing discount to the customer. DLC programs are wide-spread; about one-third of utilities cycle residential air conditioners, with average participation rates of 15 percent, and roughly 60 percent of utilities offer load-management programs for C&I customers.[2]

  DLC programs have proven cost effective and have yielded substantial savings: A survey of 24 programs showed average peak load savings of 29 percent for participating customers with minimal reduction in total energy consumed.[3] Con Edison, for example, offers its residential and small commercial customers a free programmable thermostat in exchange for the ability to cycle their air conditioning load, although the customer can override the decision if it occurs at an inconvenient time. Con Edison has installed more than 24,000 thermostats with a peak load reduction of 29 MW.[4] Furthermore, Con Ed's DLC program appears to be cost effective, with costs estimated at $455 to 626 per KW saved,[5] compared to $500 to $1,400 per KW for additional peak generation capacity.[6]

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[1] "Assessment of Demand Response and Advanced Metering," Federal Energy Regulatory Commission, Staff Report, August 2006.

[2] "Utility Load Control Programs," Chartwell, March 2006.

[3] "Residential Electricity Pricing Pilots," eMeter Strategic Consulting, July 2007.

[4] New York State Public Service Commission, "Energy Efficiency Portfolio Standard Working Group 2 – Program Summaries: Direct Load Control," September 2005.

[5] New York State Public Service Commission, "Consolidated Edison Company of New York, Inc's Direct Load Control Program," September 2005.

[6] According to World Bank report on equipment prices in the power sector, a gas turbine simple cycle plant costs $530/KW for a 5 MW plant, $970/KW for a 25MW plant and $1380 for a 5 MW plant. "Study of Equipment Prices in the Power Sector." The International Bank for Reconstruction and Development, The World Bank Group. 2008.

Because DLC programs are used primarily for air conditioning loads in the residential sector and inductive loads in C&I, its potential is limited; other programs will be needed to reduce peak loads further. In addition, DLC programs are perceived to be heavy-handed, because they give control of devices inside homes and businesses to utilities.

- **Dynamic pricing.** Dynamic pricing programs create energy prices that more closely reflect the utility's actual cost of power at the time of consumption. Use of these programs has been limited mostly to large C&I customers; however, residential pilots have emerged recently in many states. Almost one-third of utilities offer dynamic rates,[7] including Time of Use, Critical Peak Pricing (CPP) and Real Time Pricing.[8] Pilots show an average residential reduction in peak consumption due to price signals of approximately 22 percent, although results vary significantly by pilot, with overall consumption dropping by around 4 percent.[9] California's 2,500-participant Statewide Pricing Pilot suggests CPP can reduce California's peak load by 1,500 MW to more than 3,000 MW.[10] Because results have varied significantly by pilot, more large-scale pilots and roll-outs will be necessary to better understand the energy savings potential.
- **Consumption information and transparency.** Other DSM programs provide customers with greater transparency into their consumption, thereby encouraging them to reduce demand. Methods include bill-related signals, in-home displays, and home automation. Bill-related signals provide more frequent and easier-to-understand billing with clear indications of relative consumption levels. When done monthly, these programs can reduce consumption by up to 6 percent, while weekly or daily billing offers savings of 10 to 13 percent.[11] Early pilots suggest that in-home displays, devices that provide real-time information on home energy consumption, could provide savings of 4 to 15 percent.[12] Home automation, including programmable thermostats and smart appliances, are in the earliest development phase of all DSM programs; however, early results indicate peak reduction of up to 46 percent, with reductions in total consumption of 11 percent.[13]

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[7] "Utility Load Control Programs," Chartwell, March 2006.

[8] Time of Use (TOU) rates: electricity rates are set in tiers for different times of the day and typically do not change more than twice per year. Many large commercial and industrial customers already have TOU pricing. Critical Peak Pricing (CPP): during times of extreme peak, prices will increase dramatically. Real-Time Pricing (RTP): prices change on an ongoing basis to reflect closely the utility's cost of generating or purchasing electricity.

[9] "Residential Electricity Pricing Pilots," eMeter Strategic Consulting, July 2007.

[10] Roger Levy, "California Statewide Pricing Pilot (SPP) Overview and Results 2003-2004," 2005.

[11] Sarah Darby, "The Effectiveness Of Feedback On Energy Consumption," Environmental Change Institute, Oxford University, April 2006.

[12] Sarah Darby, "The Effectiveness of Feedback on Energy Consumption, "Environmental Change Institute, University of Oxford, April 2006.

[13] "Residential Electricity Pricing Pilots," eMeter Strategic Consulting, July 2007.

## THE CHALLENGE OF CAPTURING ENERGY EFFICIENCY

Although the U.S. economy has captured measurable and important amounts of energy efficiency since the oil crises of the 1970s, many attractive opportunities remain available. The fundamental challenge for the nation is, therefore, how to bring programs like these to scale and capture the full NPV-positive potential that exists today.

### Both the nature of energy efficiency and attributes of consumer behavior present challenges to efficiency capture

The nation's mixed success in improving energy efficiency stems in part from the significant barriers that surround every cluster of potential and in part from system-level challenges associated with pursuing energy efficiency opportunities at scale in our economy. Four fundamental attributes of energy efficiency, some of them the legacy of how we have approached the opportunity over time, make the task of capturing these savings truly challenging:

- **Initial outlay.** Energy efficiency measures will require upfront investment of capital with savings that will accrue over sometimes lengthy periods. Despite the NPV-positive nature of the investments identified in this report, behavioral barriers to upfront capital outlays and historically low savings rates have prevented consumers from capturing substantial amounts of efficiency. Issues of capital allocation and risk of business termination have challenged the commercial and industrial sectors. Access to capital remains an issue in all sectors.
- **Fragmentation.** As mentioned before, energy efficiency opportunities are scattered across the economy: no single industry, building type, population cluster, climate region, or end-use alone can unlock the opportunity nationwide. The dispersion means that while the NPV-positive energy efficiency potential is collectively large, individually each efficiency opportunity is of relatively low priority. The level of penetration needed to capture something approaching the full potential has rarely been achieved by any technological advancement in society, and even less frequently in as short a time frame as a decade.
- **Low awareness and attention.** Improving energy efficiency is rarely the primary focus or responsibility of any major agent in the economy: businesses have other areas of strategic focus, energy providers focus on reliability, and residential end-users typically face competing needs for their funds and attention. Few businesses targeting these opportunities have existed before, apart from the energy services company (ESCOs) industry which represent a small part of the energy industry. Additionally, energy efficiency is often a lower priority in the selection of energy-consuming devices than functionality, form, or reliability.
- **Difficult to measure.** Reduced energy consumption is not a physical product and frequently difficult to measure. Given the diverse factors that affect energy consumption, including weather, economic activity, and consumer behavior, energy savings require measurement and verification methods more challenging than the meter reading required to accurately measure consumption. Furthermore, saving energy is a more abstract concept than consuming energy, because it expresses a difference relative to what would have happened had consumers made different choices.

Since the late 1970s economists have tried to understand why consumers diverge from classical economic decision criteria through a better understanding of behavioral economics. Several heuristics have emerged which may explain from a behavioral standpoint how these attributes arise or why some of the barriers they present persist.

Given the volume of decisions consumers make daily and the time it would take to rationally analyze each and every one, consumers default to avoiding action on less interesting opportunities. This behavior (termed status quo bias) manifests as consumers hesitating to upset their current situation. For example, a study revealed most investors do not adjust the asset allocation of their retirement funds even in the face of significant market fluctuations.[27] In a similar manner, consumers are unwilling to invest money in energy efficiency upgrades that are financially beneficial as it disrupts their current finances.

When consumers do think about the economics of a decision though, there are other apparently "irrational" components to their decision making. Many consumers are prone to value current or short-term value much higher than longer-term value, and thus attach a higher discount rate to investments that pay back more slowly (termed hyperbolic discounting).[28] This is likely one reason the slower payback of energy efficiency manifests as a high discount factor in customer behavior. In addition the context in which consumers make decisions (termed framing) can influence those decisions. Studies have shown that people are much more likely to act when confronted with a potential loss rather than a potential savings.[29] Currently efficiency investments are typically framed as a savings and are thus prone to this effect. Representing them as avoiding a loss may make them more appealing.

Studies have also shown that when consumers must incur a loss to receive a potential gain, that gain must significantly outweigh the loss (termed loss aversion). For example, when placing a bet with even odds most gamblers demand a $200 reward to place a wager of $100.[30] Thus, even if an energy efficiency measure is strongly NPV-positive, consumers may require the reward of future savings to more than double the upfront investment "wager" (i.e., a cost to benefit ratio of 2 or higher). However, this aversion to investing decreases when consumers have already decided to spend money. Consumers become much less sensitive to incremental costs as they become a smaller percentage of the total cost (diminishing sensitivity).[31] The incremental cost of an efficient air conditioner, for example, appears more palatable to consumers when compared to the price of a new home than when compared to the price of an alternative air conditioner.

The nature of energy efficiency and attributes of consumer behavior combine to create a series of opportunity-specific barriers that the market must overcome to unlock energy efficiency on a national scale (Exhibit 10). These barriers require comprehensive, opportunity-specific solution strategies to unlock the potential, as well as system-level actions to address regulatory barriers and enable broader market impact.

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[27] William Samuelson and Richard Zeckhauser, "Status Quo Bias in Decision Making," *Journal of Risk and Uncertainty,* 1988.

[28] George Ainslie, "Specious Reward: A Behavioral Theory of Impulsiveness and Impulse Control," *Psychological Bulletin*, 1975.

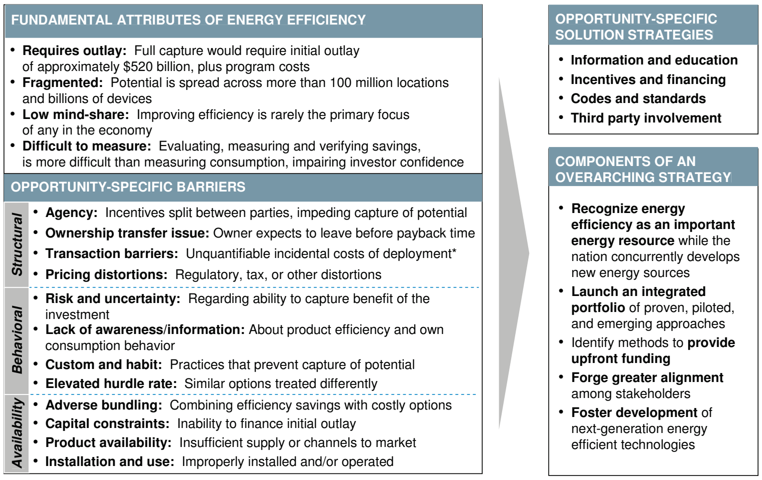
[29] Amos Tversky and Daniel Kahneman, "The Framing of Decisions and the Psychology of Choice," *Science*, 1981.

[30] Amos Tversky and Daniel Kahneman, "Advances in Prospect Theory: Cumulative Representation of Uncertainty," *Journal of Risk and Uncertainty*, 1992.

[31] Daniel Kahneman and Amos Tversky, "Prospect Theory: An Analysis of Decision Under Risk," *Econometrica*, 1979.

Exhibit 10: Multiple challenges associated with pursuing energy efficiency

On the left, this exhibit summarizes the fundamental difficulties of pursuing greater energy efficiency and the opportunity-specific barriers that affect and help define clusters of efficiency potential. On the right, it shows opportunity-level solution strategies to overcome barriers and suggests the essential elements of an overarching strategy for capturing energy efficiency potential.



FUNDAMENTAL ATTRIBUTES OF ENERGY EFFICIENCY

- **Requires outlay:** Full capture would require initial outlay of approximately $520 billion, plus program costs
- **Fragmented:** Potential is spread across more than 100 million locations and billions of devices
- **Low mind-share:** Improving efficiency is rarely the primary focus of any in the economy
- **Difficult to measure:** Evaluating, measuring and verifying savings, is more difficult than measuring consumption, impairing investor confidence

OPPORTUNITY-SPECIFIC BARRIERS

*Structural*

- **Agency:** Incentives split between parties, impeding capture of potential
- **Ownership transfer issue:** Owner expects to leave before payback time
- **Transaction barriers:** Unquantifiable incidental costs of deployment*
- **Pricing distortions:** Regulatory, tax, or other distortions

*Behavioral*

- **Risk and uncertainty:** Regarding ability to capture benefit of the investment
- **Lack of awareness/information:** About product efficiency and own consumption behavior
- **Custom and habit:** Practices that prevent capture of potential
- **Elevated hurdle rate:** Similar options treated differently

*Availability*

- **Adverse bundling:** Combining efficiency savings with costly options
- **Capital constraints:** Inability to finance initial outlay
- **Product availability:** Insufficient supply or channels to market
- **Installation and use:** Improperly installed and/or operated

OPPORTUNITY-SPECIFIC SOLUTION STRATEGIES

- **Information and education**
- **Incentives and financing**
- **Codes and standards**
- **Third party involvement**

COMPONENTS OF AN OVERARCHING STRATEGY

- **Recognize energy efficiency as an important energy resource** while the nation concurrently develops new energy sources
- **Launch an integrated portfolio** of proven, piloted, and emerging approaches
- Identify methods to **provide upfront funding**
- **Forge greater alignment** among stakeholders
- **Foster development** of next-generation energy efficient technologies

* Financial transaction barriers and actual quality trade-offs are factored into the initial NPV-positive potential calculation as real costs.

Source: McKinsey analysis

## Opportunity-specific barriers pose significant hurdles to capturing clusters of energy efficiency potential

Achieving meaningful energy savings will require a variety of approaches tailored to the specific barriers that have inhibited capture of individual efficiency opportunities. Identifying and understanding these barriers has been a focus of energy efficiency research for decades; our investigation drew upon the considerable body of work on the topic. Most sources refer to a consistent set of barriers and point to the need for a comprehensive mix of policies, due to the presence of multiple, sometimes overlapping barriers. Our research additionally suggests that unlocking the potential of a given cluster requires addressing all major barriers that affect that cluster. Many traditional approaches (e.g., monetary incentives or awareness campaigns) have focused on removing the most significant or most addressable barriers, but have often fallen short of a holistic solution that comprehensively addresses all barriers.

**Barriers to greater efficiency.** To simplify the discussion, we have grouped well-known barriers into the following three categories:

- **Structural.** These barriers arise when the market or environment makes investing in energy efficiency less possible or beneficial, preventing a measure that would be NPV-positive from being attractive to an end-user:
  - **Agency issues** (split incentives), in which energy bills and capital rights are misaligned between economic actors, primarily between landlord and tenant
  - **Ownership transfer issues**, in which the current owner cannot capture the full duration of benefits, thus requiring assurance they can capture a portion of the future value upon transfer sufficient to justify upfront investment; this issue also affects builders and buyers

  - **"Transaction" barriers**, a set of hidden "costs" that are not generally monetizable,[32] associated with energy efficiency investment; for example, the investment of time to research and implement a new measure
  - **Pricing distortions**, including regulatory barriers that prevent savings from materializing for users of energy-savings devices.
- **Behavioral.** These barriers explain why an end-user who is structurally able to capture a financial benefit still decides not to:
  - **Risk and uncertainty over the certainty and durability of measures and their savings** generates an unfamiliar level of concern for the decision maker
  - **Lack of awareness**, or low attention, on the part of end-users and decision-makers in firms regarding details of current energy consumption patterns, potential savings, and measures to capture those savings
  - **Custom and habit**, which can create an inertia of "default choices" that must be overcome
  - **Elevated hurdle rates**, which translates into end-users seeking rapid pay back of investments – typically within 2 to 3 years. This expectation equates to a discount rate of 40 percent for investments in energy efficiency, inconsistent with the 7-percent discount rate they implicitly use when purchasing electricity (as embodied by the energy provider's cost of capital). It is beyond the scope of this report to evaluate the appropriate risk-adjusted hurdle rate for specific end-users, though it seems clear that the hurdle rates of energy delivery and energy efficiency are significantly different.
- **Availability.** These barriers prevent adoption even for end-users who would choose to capture energy efficiency opportunities if they could:
  - **Adverse bundling or "gold plating,"** situations in which the energy efficient characteristic of a measure is bundled with premium features, or is not available in devices with desirable features of higher priority, and is therefore not selected
  - **Capital contraints and access to capital**, both access to credit for consumers and firms and (in industry and commerce) competition for resources internally within balance-sheet constraints
  - **Product (and service) availability** in the supply chain; energy efficient devices may not be widely stocked or available through customary purchasing channels, or skilled service personnel may not be available in a particular market
  - **Installation and use issues**, where improper deployment or use eliminates savings.

In practice, nearly all clusters reflect a mix of barriers, with "awareness and information" and "access to capital" the most frequently observed. In fact, 10 of our 14 clusters face both of these barriers. "Product or service availability" is the third-most common, with all three of these barriers impacting six of our 14 clusters. The relative importance of these barriers is broadly in agreement with other work.[33] The mixture of barriers complicates the energy efficiency landscape enormously. We can draw several general conclusions from our analyses:

- **Unlocking the full potential of energy efficiency requires a holistic approach.** Such an approach would address all barriers within a given cluster. None of

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[32] We have included direct transaction costs in our calculation of the NPV-positive potential where present and calculable (e.g., the cost of running a new connection to a gas pipeline, if a user switches from electric to gas heating and piping is not in place at that address).

[33] Steve Sorrell, et al., *The Economics of Energy Efficiency: Barriers to Cost Effective Investment*, Edward Elgar, 2004.

the 14 clusters offers a simple one-step approach as all clusters face at least two barriers, 11 clusters face three or more barriers, and eight clusters face four or more barriers.

- **Agency issues, in the sense of landlord-tenant issues, are not as widespread as often thought.** The industrial sector faces this barrier relatively little. Its effect is only somewhat prevalent in the residential sectors, with 8 percent of residential potential affected. Impact varies in the commercial sector, with roughly 5 to 25 percent of the potential impacted in most commercial subsectors. However, agency issues are concentrated in a few commercial subsectors, with the retail, office, and food service subsectors having up to 75 percent of their energy efficiency potential affected. In total, approximately 9 percent of potential across all sectors is affected by this type of agency issue.
- **Ownership transfer issues, sometimes considered a variant of agency issues, pose a more significant challenge.** Though the benefits of energy efficiency measures in residential homes have an average lifetime of 17 years and pay back within 7 years, 40 percent of households will have moved in that time. This issue is less significant for commercial buildings that have longer tenancy periods, though in some commercial buildings, such as retail or food service, tenancies tend to be significantly shorter than the 15 year average lifetime of commercial-sector energy efficiency measures. Thus current owners are likely to capture only a portion of available savings; for many investments to make financial sense however, owners must be confident they can capture enough of the value of future savings at the time of building sale to warrant the upfront investment.
- **Access to capital and elevated hurdle rates affect 43 percent of the NPV-positive efficiency potential.** These issues tend to cover different segments and technologies than principal-agent issues. If hurdle rates are decreased from the 40 percent typical of residential end-users (equivalent to a 2- to 3-year payback) to 7 percent, 3.9 quadrillion end-use BTUs become NPV-positive. However, even the 5.2 quadrillion end-use BTUs that remain available at a 40-percent discount factor represent an attractive and unseized opportunity.

### Opportunity-specific solution strategies can overcome these barriers

Our review of previous and proposed programs designed to encourage greater energy efficiency suggest that four categories of measures can aid in unlocking the clusters of efficiency potential in the residential, commercial, and industrial sectors. To fully overcome the barriers that affect a single cluster of potential, a combination of solution strategies will likely be needed, though in some clusters a single targeted solution strategy may be sufficient.

- **Information and education.** Increasing awareness of energy use and knowledge about specific energy-saving opportunities would enable end-users to act more swiftly in their own financial interest. Options include providing more information on utility bills or through the use of in-building displays, voluntary standards, labeling schemes, audits, assessments, and awareness campaigns. Such solutions will likely prove insufficient to drive broad adoption on their own, but they represent a necessary part of most holistic solutions.
- **Incentives and financing.** Given the large upfront investment needed to capture efficiency potential, various approaches could reduce the financial hurdles that end-users face. Options include traditional and creative financing vehicles (such as energy efficiency mortgages), monetary incentives or grants, including tax and cash incentives, and price signals, including tiered pricing and pricing of externalities (e.g., carbon prices).
- **Codes and standards.** In several clusters, some form of mandate may be warranted to expedite the process of capturing potential, particularly where end-user or manufacturer awareness and attention are particularly low. Options include

equipment standards, building codes (including improving code enforcement), and mandatory audits or assessments. Such mandates can often yield high "adoption" because they bypass the consumer decision-making process, but they can face a challenging political process and must be kept up to date to capture the full potential.

- **Third-party involvement.** A private company, utility, government agency, or non-governmental organization could support a "do-it-for-me" approach by purchasing and installing energy efficient improvements directly for the end user, thereby essentially addressing all non-capital barriers. When coupled with monetary incentives covering potentially the full cost, this solution strategy could address all barriers and unlock almost the entire potential, though some portion of end-users might opt out of such a program, thereby preventing full capture.

The challenge with every cluster of efficiency potential is to identify appropriate solution strategies that will address existing barriers with sufficient force to unlock the savings. Through an extensive review of the literature on energy efficiency and interviews with experts in this and related fields, we have attempted to identify which solution strategies address which barriers within each cluster. Some solution strategies are "proven" to work at the national level; some have been "piloted" at the scale of large cities, counties, or even states but likely need further refinement before being scaled to a national effort; and others are "emerging" and seem plausible enough to warrant a trial or may have been tried on a sub-metropolitan scale. We categorize each of the 47 solution strategies by these three levels of historical experience relative to a nationally scaled deployment: proven, piloted, and emerging.

In addition, continued progress against the full potential would require careful monitoring of strategies to identify unaddressed barriers, refining the approach to address those barriers, and determining when to discontinue a strategy once the NPV-positive potential is exhausted or is on a self-propelling trajectory to full capture.

Our objective is to expose a promising range of solution strategies that could contribute to a more aggressive scaled-up pursuit of the national efficiency potential. In Chapters 2 through 4 we will describe the potential in each cluster based on its distinguishing characteristics, outline the important barriers that challenge the capture of that potential, and map possible solutions against those barriers. We have attempted to quantify the impact of various measures wherever possible; however, that has not been feasible in every case, often due to the qualitative nature of persistent barriers (e.g., information). In Chapter 5 we discuss the importance of developing a holistic implementation strategy that incorporates five observations from this research.

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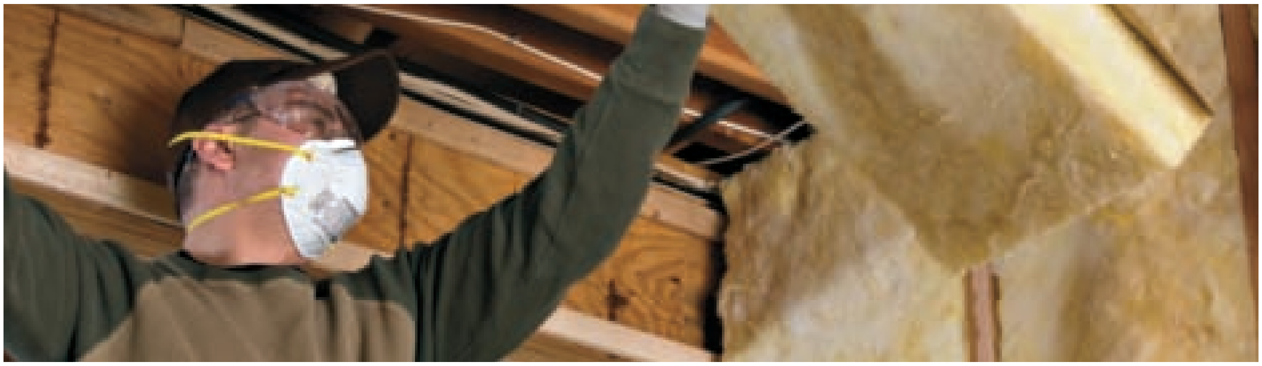
If the U.S. were to progress through 2020 in line with the EIA's projections for energy consumption – the nation would have expanded substantially the energy infrastructure, captured a relatively low level of energy efficiency above and beyond that legislated in the Energy Independence and Security Act of 2007, and constructed many more inefficient commercial and residential buildings and appliances. If this were to occur, the U.S. will have foregone a significant opportunity to improve its energy productivity and, thus, its international competitiveness.

# 2. Approaches to greater energy efficiency in the residential sector



The residential sector will consume 29 percent of the baseline energy in the United States in 2020, accounting for 11.4 quadrillion BTUs of end-use energy (Table 1). These tables, present at the introduction to each sector and cluster, show the end-use and primary energy consumption in 2008 and 2020 and potential savings in 2020, each split out by fuel. We provide the same metrics for GHG emissions and abatement. Finally, the boxes at the bottom show the financial impact: the present value of the investment, the present value of the savings, and the annual savings. With an annual growth rate of 0.4 percent, consumption is forecast to reach 11.4 quadrillion end-use BTUs in 2020, driven by population growth, larger homes, and more electronic devices in each household.[34] Relative to the business-as-usual forecast, deploying all NPV-positive energy efficiency improvements in the residential sector would reduce its energy consumption in 2020 by 28 percent, saving the U.S. economy an estimated $41 billion in annual energy costs and avoiding some 360 million tons of $CO_2$e emissions in that year. Exhibit 11 illustrates energy efficiency measures of a typical household, ranging from improvements in the house's building shell to upgrading to more energy efficient electrical devices. The upfront investment associated with this level of improvement – involving efficiency upgrades for 129 million homes, their appliances and HVAC systems,[35] and 2.5 billion electronic devices – would necessitate some $229 billion in incremental investment and provide present value savings of $395 billion.

Table 1: Overview of energy use in the residential sector

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | **Savings** Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 10,880 | 11,410 | 3,160 | 28 |
| ▪ Electricity TWh | 1,410 | 1,510 | 390 | 26 |
| ▪ Natural gas | 4,960 | 5,200 | 1,460 | 28 |
| ▪ Other fuels* | 1,130 | 1,060 | 370 | 35 |
| PRIMARY ENERGY Trillion BTUs | 21,190 | 22,480 | 6,020 | 27 |
| ▪ Electricity | 14,910 | 16,010 | 4,130 | 26 |
| ▪ Natural gas | 5,150 | 5,400 | 1,520 | 28 |
| EMISSIONS Megatons $CO_2$e | 1,270 | 1,350 | 360 | 27 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $229 billion | PV of energy savings – 2009-2020: $395 billion | Annual energy savings – 2020: $41 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

Considering the dominant barriers to energy efficiency and selected attributes of energy consumption, we organized the efficiency potential in the residential sector into five clusters (Exhibit 12). Some 71 percent of the end-use potential (53 percent of primary

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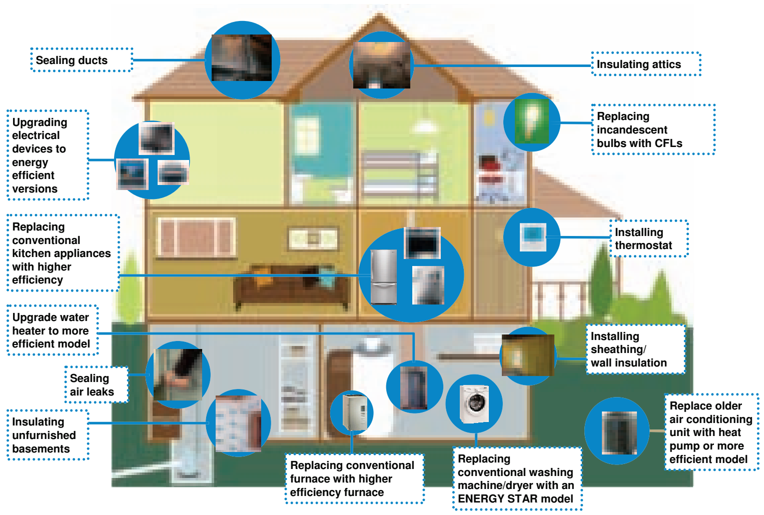
[34] AEO 2008, NEMS.

[35] We refer to home heating and cooling systems generically as HVAC systems (heating, ventilation, and air conditioning), whether a home has a heating system, a cooling system, an air exchanger or all three systems. We group changes to building shell and HVAC systems together because they work in tandem to determine the conditioning of the living space.

energy potential) resides in improving the building shell and heating and cooling equipment, mostly in existing homes. The remaining 29 percent of end-use potential (47 percent of primary energy potential) is split between electrical devices and small appliances, and lighting and appliances.

Exhibit 11: Potential energy efficiency measure for a typical home

Each of the callouts represents some of the measures that are modeled to drive residential energy efficiency in the report.



For each cluster, we will outline the energy efficiency potential, describe the barriers that have prevented its capture in the past, and explore possible solution strategies.

1. **Existing non-low-income homes (1,300 trillion end-use BTUs):** Low consumer awareness and demand, fast payback requirements, ownership transfer issues, high transaction costs, and inconsistent installation practices pose the most formidable and persistent barriers. Possible solution strategies to address these barriers include home energy assessments, creative financing solutions, monetary incentives, and mandatory upgrades.

2. **Existing low-income homes (610 trillion end-use BTUs):** This cluster in particular suffers from capital constraints, though the barriers that apply to the previous cluster apply here as well. Low-income weatherization programs scaled up from today's levels are a potentially powerful measure to address all barriers in this cluster, including the capital constraint.

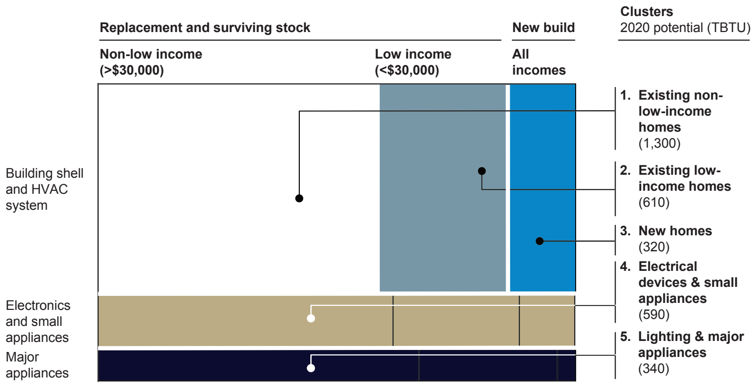
3. **New homes (320 trillion end-use BTUs):** Potential in this cluster reflects the lack of incentives for builders to construct high-efficiency homes. Solution strategies to secure this potential include greater penetration of voluntary building labeling, incentives to builders or home buyers, and improved, standardized, and enforced building codes.

4. **Electrical devices and small appliances (590 trillion end-use BTUs):** Potential is highly fragmented across 2.5 billion consumer electronics devices and small appliances (e.g., computers, televisions, coffee makers, battery chargers). For most device classes, energy efficiency has received little attention from consumers and manufacturers. Promising solution strategies include voluntary labeling and mandatory standards addressing both active and standby consumption.

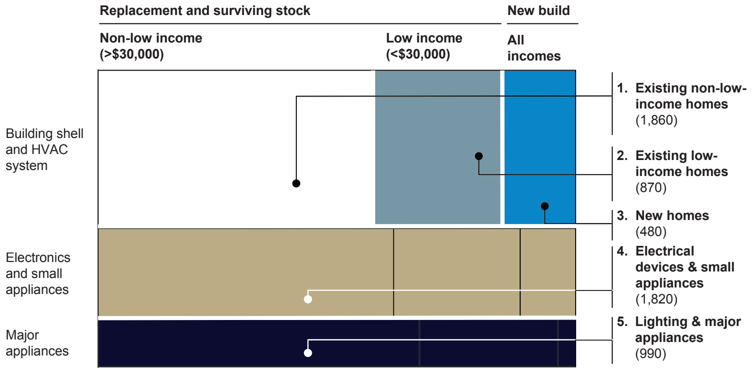
5. **Lighting and major appliances[36] (340 trillion end-use BTUs):** Lighting dominates the potential in this cluster, with lack of consumer information and quality trade-offs representing the most significant barriers. Solutions involve voluntary standards and labeling, monetary incentives, and mandatory standards.

Exhibit 12: Clusters of energy efficiency potential in the residential sector

End-use energy, avoided consumption; total = 3,160 trillion BTUs



Primary energy, avoided consumption; total = 6,020 trillion BTUs



Source: EIA AEO 2008, McKinsey analysis

The upper and lower charts break out the energy efficiency potential in 2020 for the residential sector in end-use and primary energy respectively. Each area represents a cluster of efficiency potential: area is proportional to the relative share (of total potential in the sector) associated with that cluster, while the number next to the cluster name provides the efficiency potential, measured in trillion BTUs.

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[36] Appliances include water heater, dishwashers, clothes washers, clothes dryers, refrigerators, freezers, and cooking equipment.

## WHOLE-BUILDING DESIGN

By viewing a building as a system that can be optimized within a specific site – rather than as a set of independent end-uses – whole-building design achieves additional energy savings in a cost-effective manner. Though it requires a fundamental change in how end-users interact with energy, this approach offers four opportunities:

- **Optimizing building design for the local environment.** Design decisions, including building orientation, landscaping, and exterior design, can reduce demand for heating and cooling. For example, surface-to-volume ratio of the structure, awning use, day lighting, total window area, roof color and pitch, and even wall color and chemistry of the pigment used will affect a building's energy needs. Optimal designs vary by climate and latitude but typically save 10 percent of energy use and as much as 40 percent in some cases.[1] This approach requires that energy use be included as a parameter in the design and construction processes.
- **Minimizing energy consumption.** Energy consumption can be reduced by modifying the building size, shape, and interior layout, as well as by using passive means for heating, cooling, and water heating. The average size of a new single family home in the U.S., for example, increased from 1,500 square feet in 1970 to 2,480 square feet in 2007[2]—a 65 percent increase—with a parallel increase in energy needed for space conditioning; over this period, the average household shrank from 3.0 to 2.6 persons.[3]
- **Pursuing holistic designs.** Due to specialization in education and building trades, contractors tend to design each mechanical system in isolation. Holistic system design would reduce energy consumption and capital investment by, for example, recovering furnace waste heat for water heating or upgrading the building envelope and using passive heating and cooling systems to reduce space conditioning load, enabling the HVAC system to be reduced by as much as half, or even eliminated.[4]
- **Improving design and installation practices.** Improper design and installation of HVAC equipment and building insulation can reduce their efficiency by as much as 30 percent.

Though many of these measures qualify as NPV-positive, their deployment would require a shift in the way end-users interact with and think about energy use. In some cases, these measures could represent a tradeoff with aesthetics or building use that end-users might find unacceptable, leading to a change in utility.

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[1] Dianna Lopez Barnett and William Browning, A Primer on Sustainable Building, Rocky Mountain Institute, 2007.

[2] "Housing Facts, Figures and Trends", NAHB, 2008. <www.nahb.org>.

[3] U.S. Census Bureau,.<www.Census.gov>.

[4] Right-size heating and cooling equipment," EERE, January 2002.

## REBOUND EFFECTS

Rebound effects explain why actual energy savings fall short of expected savings. Studies have confirmed the existence of four effects we classify as rebound:[1]

- **Technical estimation.** "Shortfall" occurs when actual savings fall short of engineering estimates. There are two potential causes: improper installation, which can reduce savings by 20 to 30 percent, and necessary simplifications in engineering models, which can result in overestimating savings by as much as 50 percent, especially for space conditioning.
- **Direct rebound effect.** "Take-back" involves increased energy use concurrent with deployment of an energy efficiency measure. Studies have found average interior temperatures were reset 1 to 3 degrees Fahrenheit higher in homes receiving insulation upgrades, representing a 15 to 30 percent decrease in energy savings.[2,3] This effect can be as much as 50 percent in some settings.
- **Indirect rebound effect.** If end-users redeploy money saved through energy efficiency to purchase (or consume) energy in another form, overall energy consumption will not decrease, though users clearly do more work or capture more utility with the same investment.
- **Macroeconomic effect.** Energy efficiency may paradoxically increase long-term consumption by improving access to energy among populations that previously had limited access to it and by increasing economic growth. Opinions are divided on this point and the impact of increased efficiency on energy prices in regulated and restructured markets remains uncertain.[4]

Our research addressed the issue of technical estimation by matching our building modeling output to consumer survey data. Direct and indirect rebound effects represent improvements in consumer utility (i.e., amount of work or comfort per-unit of energy) and by extension energy productivity. Finally, it is likely that legislative changes or regulatory dynamics will result in price adjustments that offset the potential downward pressure of efficiency on energy prices.

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[1] Steve Sorrell, "The Rebound Effect: An Assessment of the Evidence for Economy-wide Energy Savings from Improved Energy Efficiency," UK Energy Research Centre, October 2007.

[2] Chris Martin and Martin Watson, "Measurement of Energy Savings and Comfort Levels in Houses Receiving Insulation Upgrades," Energy Monitoring Company for Energy Saving Trust, June 2006.

[3] Geoffrey Milne and Brenda Boardman, "Making Cold Homes Warmer: The Effect of Energy Efficiency Improvements in Low-Income Homes" Energy Action Grants Agency Charitable Trust, 2000.

[4] The effect is known as the Khazzoom-Brookes postulate. See, for example, Horace Herring, "Does Energy Efficiency Save Energy: The Implications of accepting the Khazzoom-Brookes Postulate," EERU, 1998.

## 1. EXISTING NON-LOW-INCOME HOMES

Heating and cooling the 55 million single family, 12 million multi family and 3 million manufactured existing non-low-income homes in the U.S. consumes 3.3 quadrillion end-use BTUs of energy in the 2020 reference case. This cluster offers the largest savings potential in the residential sector, accounting for 41 percent (1,300 trillion BTUs) of total residential end-use potential in 2020 (Table 2). The barriers in this cluster are among the most intractable in the residential sector, and the relevant solution strategies as a set are relatively untested at scale, suggesting that the cluster requires further development of solution strategies. Assuming solutions to the barriers are put in place, capturing this potential would require $153 billion of incremental capital and provide present value savings of $167 billion.

Shell improvements can be either low- or high-capital. Low-capital maintenance, includes installing programmable thermostats, sealing home air leaks and ducts, and performing HVAC equipment maintenance. These measures offer 60 percent of the potential in this cluster for 49 percent of the cost. Higher-capital improvements, including the remaining measures listed in Exhibit 13, provide 40 percent of the potential for 51 percent of the cost.[37] Older homes have significantly greater potential per household. Homes built before 1940 have more than twice the potential per household than homes built after 1970. Sixty-four percent of the retrofit opportunity resides in the 51 percent of homes built before 1970.[38]

Table 2 Existing non-low-income homes

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | **Savings** Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 3,830 | 3,330, | 1,300 | 39 |
| ■ Electricity TWh | 220 | 200 | 70 | 38 |
| ■ Natural gas | 2,410 | 2,100 | 820 | 39 |
| ■ Other fuels* | 670 | 550 | 230 | 41 |
| PRIMARY ENERGY Trillion BTUs | 5,510 | 4,850 | 1,860 | 38 |
| ■ Electricity | 2,330 | 2,120 | 780 | 37 |
| ■ Natural gas | 2,500 | 2,180 | 860 | 39 |
| EMISSIONS Megatons $CO_2e$ | 320 | 280 | 110 | 38 |

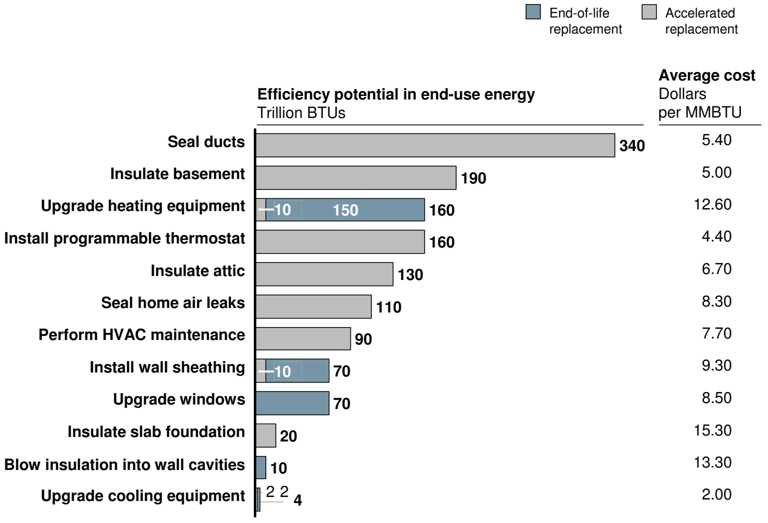
| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $153 billion | PV of energy savings – 2009-2020: $167 billion | Annual energy savings – 2020: $14 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA, AEO 2008, McKinsey analysis

Exhibit 13: Efficiency opportunities in existing non-low-income homes

The bars represent the energy efficiency potential in 2020, in trillion BTUs, for various measures to improve the performance of the building shell of non-low-income homes, with the savings associated with end-of-life and/or accelerated replacement for each of the measures. The prices on the right represent the respective average cost in dollars per million BTU saved for each of the measures.



Source: McKinsey analysis, EIA AEO 2008, RECS, Home Energy Saver model

## Barriers to retrofitting building shells and HVAC systems in most homes

This cluster exhibits the most intractable set of barriers in the residential sector, because it is deeply involved with homeowners' decision-making processes. To organize the discussion, we have divided the process into five stages: awareness, agency and ownership, decision to pursue, ability to pursue, and savings capture:

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[37] The impact and cost of measures were developed and scaled nationally through Lawrence Berkeley National Laboratory's Home Energy Saver, EIA's RECS 2005, RSMeans, U.S. Census, and other publicly available data. These savings and cost estimates represent the average across all households, and savings opportunities vary significantly by household, requiring a personal energy assessment to identify specific opportunities.

[38] Some older homes have been upgraded previously; therefore, opportunities will need to be identified on a per-home basis prior to deployment; these statistics draw on RECS and our modeling of potential as described in Appendix A.

- **Awareness.** Homeowners typically do not understand their home's energy consumption and are unaware of energy-saving measures. Half of homeowners consider recycling and energy efficient appliances as ways to reduce GHG emissions, though only 15 percent indicated that improving insulation would be a preferred means.[39] People also tend to underestimate retrofit savings. A recent survey asked how much consumers expect to save from projects such as adding insulation, caulking and sealing their homes. Although these measures provide savings of 10 to 25 percent nearly three-fourths of respondents underestimated their potential utility bill savings at 10 percent or less.[40] Similarly, fewer than 2 percent of homes in the United States have had an energy efficiency rating or energy assessment to identify savings opportunities in their homes.
- **Agency and ownership.** Both the principal-agent problem in the sense of landlord-tenant issues, and the ownership transfer problem, affect this cluster. Ownership-transfer arises when the payback period on an improvement is longer than the future period of home ownership, as the current owner will not capture savings commensurate with the upfront cost and would be unsure about the increase in home value from the measures implemented. This affects 40 percent of retrofit potential (520 trillion end-use BTUs).[41] The landlord-tenant issue, which arises where renters pay the utility bills, affects 4 percent (50 trillion end-use BTUs) of potential in this cluster.[42]
- **Decision to pursue savings.** Two issues affect the decision itself:
  - **Competing uses for capital** in homeowner budgets inhibit allocation of money to energy-saving investments. Core spending accounts for approximately 90 percent[43] of the average household's budget, forcing retrofit spending to compete for the remaining 10 percent with other categories, including sometimes more appealing options like entertainment and more visible home improvements,[44] such as kitchen and bathroom remodeling.[45] A "typical" residential energy efficiency retrofit costs $1,500 for the average non-low-income single family household, representing approximately 27 percent of their annual discretionary spend (based on a median U.S. household income of $50,740).
  - **Rapid payback**, i.e., inconsistent discount rates, arise from elevated expectations on the use of personal funds. Empirical research suggests U.S. consumers typically expect payback within 2.5 years.[46] This expectation affects 60 percent (780 trillion end-use BTUs) of the potential in this cluster.
- **Ability to pursue savings.** Assuming homeowners decide to pursue the savings, two issues emerge that affect their ability to proceed. **High transaction barriers** arise as consumers incur significant time "costs" in researching, identifying, and

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[39] *2007 Business in Society Survey*, McKinsey & Company, 2007. Number of respondents: 2,002.

[40] "As Energy Costs Rise, Survey Finds Oklahoma Homeowners Are Concerned about Home Energy Efficiency – and Many Are Taking Action to Reduce Heating and Cooling Bills," Johns Manville, *Company News* web site, October 7, 2008.

[41] Inhibited potential includes that not NPV-positive for a home owner's expected stay in their home. This is calculated for each year of expected stay then summed while weighting by the number of people who move after each duration of occupancy (as calculated by the National Association of Home Builders using data from the American Housing Survey) to find the total potential affected.

[42] RECS 2001, NEMS.

[43] Includes food, housing, transportation, health, apparel, education, and insurance (see *Consumer Expenditure Survey 2007*, Bureau of Labor Statistics, Table 2, "Income before taxes: Average annual expenditures and characteristics").

[44] Electrical equipment, kitchen equipment, hardware, painting and flooring provides 78 percent of Home Depot sales, implying that less than 22 percent of sales derive from insulation. "Home Depot 2009 Annual Report." http://www.sec.gov/Archives/edgar/dta/354950/000095014409002875/x17422e10vk.htm#102.

[45] "Special Remodeling Report," NAHB, January 2007.

[46] *Energy Savings Potential of Solid State Lighting in General Illumination Applications: Final Report*, Office of Energy Efficiency and Renewable Energy, Department of Energy, December 2006.

procuring efficiency upgrades, as well as preparing for, and enduring lifestyle disruption during the improvement process.[47] In addition, the **availability of credible, whole house contractors** remains limited. Most contractors do not train in holistic building science, rather they specialize in a single construction procedure (e.g., HVAC or windows). Furthermore, the contractor market is highly fragmented; industry annual revenue of $75 billion is scattered across more than 40,000 businesses consisting mostly of privately held companies with less than $2 million in annual revenue, making it difficult for homeowners to identify which contractors perform relatively well compared to others and have the capabilities to complete the full retrofit.[48]

- **Savings capture.** Even after committing to pursue the savings, challenges remain. **Inconsistent quality of installation** and infrequent retro-commissioning of equipment can increase space conditioning costs by 20 to 30 percent.[49] Experts estimate that contractors install some 90 percent of HVAC equipment and insulation sub-optimally, reducing efficiency by 20 to 30 percent.[50] **Improper use** of programmable thermostats, such as overriding their programming to hold a constant temperature, can reduce or eliminate their savings that, in total, represent 12 percent of retrofit potential.

### Solution strategies to unlock potential

Most solutions in this cluster remain unproven, with the exception of financial incentives that have proven successful through tax credits. This suggests the need for more thorough pilots of innovative approaches including labeling, on-bill or property-tax linked financing, retrofit mandates, and whole building contractor training. Exhibit 14 depicts how each of these solution strategies addresses the barriers each cluster faces. Reading from left to right, the first column, "barriers", depicts all barriers discussed in Chapter 1 with the dominant barriers colored and bolded. The next column, "manifestation of barrier", briefly describes how that barrier prevents capture of potential in this cluster. Next, reading right to left, the rightmost column, "solution strategies" depicts all general types of solution strategies discussed in Chapter 1. The boxes shaded and in bold are those most relevant to this cluster. The next column to the left, "potential approach" describes briefly how to apply that solution strategy to this cluster. Finally, the colored lines connect each potential approach to the barriers it can overcome.

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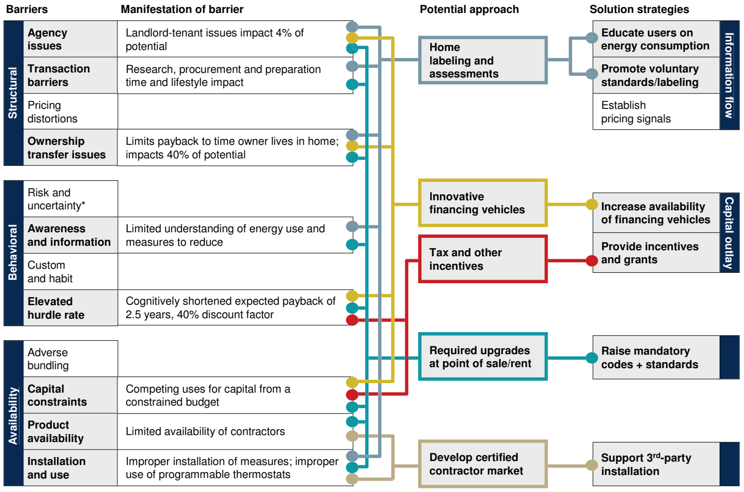
[47] Quantifiable transaction costs including those for refinishing walls after insulation or adding distribution piping for natural gas lines are explicitly included in our efficiency potential calculations.

[48] "HVAC and Plumbing Contractors," First Research, April 2009. <www.firstresearch.com/Industry-Research/HVAC-and-Plumbing-Contractors.html>.

[49] This is mostly in addition to the potential identified in this report; aside from 4 percent savings from retro-commissioning of heating and cooling units our analysis assumes installation continues to proceed as customary practice today.

[50] "A Guide to Heating and Cooling Efficiently," ENERGY STAR web site. <www.energystar.gov>.

Exhibit 14: Addressing barriers in existing non-low-income homes



* Represents a minor barrier
Source: McKinsey analysis

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

- **Public awareness, home labeling, and voluntary standards** *(piloted).* Rating systems and labeling programs (e.g., Home Energy Rating System (HERS), ENERGY STAR, LEED), combined with broad public awareness campaigns, or campaigns targeted at realtors, could increase transparency of home energy use and catalyze action to capture efficiency opportunities. Labeling and voluntary standards have proven effective in the new home market and may be promising for the existing home market, though full penetration of the market will take years. Fewer than 2 percent of existing U.S. homes have ratings,[51] because most homes are evaluated and rated only at time of construction.[52] Therefore we expect share to increase through the new homes market where, for example, ENERGY STAR captured 17 percent of new construction in 2008 and is expected to grow to 25 percent in 2009. With sufficient penetration through broad market adoption or mandates, this measure overcomes many barriers, with the notable exceptions of capital constraints, rapid payback, and product availability. In addition to increasing awareness, reducing some transaction costs, and instructing in the proper use of thermostats, this measure could address the ownership-transfer barrier: some evidence suggests green home owners expect a market premium, as 73 percent of green homeowners[53] report their expectation of a higher resale value was an important factor during their purchase process.
- **Innovative financing** *(piloted).* New forms of financing can reduce capital constraints and agency issues by tying loan payments to the property or utility meter, instead of the homeowner, and by assuring cash flow from the investment is always positive to the home owner (i.e., monthly energy savings are greater than the loan payment). Mechanisms such as Pay As You Save (PAYS),[54] other utility on-bill

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[51] ENERGY STAR from Environmental Protection Agency and Department of Energy, LEED from U.S. Green Building Council, HERS Index from Residential Energy Services Network.

[52] ENERGY STAR and LEED labeling for new homes have not penetrated the existing home market. However, ENERGY STAR has a program called “Home Performance with ENERGY STAR” to address the market for existing homes, which is discussed later in this chapter.

[53] *The Green Homeowner: Attitudes and Preferences for Remodeling and Buying Green Homes*, McGraw Hill Construction, 2007.

[54] PAYS program is a type of on-bill utility financing that ties the loan payment to the home instead of the homeowner and also ensures that loan payments are less than energy savings from month to month.

financing, or loans tied to property taxes, such as Long Island Green Homes in Babylon, New York or BerkeleyFIRST in Berkeley, California could overcome both the principal-agent and ownership-transfer barriers, high discount rate, and capital constraints. Despite promising local pilots, these mechanisms have not yet achieved high penetration rates or been broadly applied. Conventional forms of financing, such as energy efficient mortgages or home equity lines can also provide funding, however they do not address agency barriers and have not penetrated the market to a significant degree, despite 30 years of availability.

- **Rebates and incentives** *(proven).* Monetary incentives for energy assessments and upgrades to residential customers historically have come through tax incentives or utility-sponsored programs. Under the American Recovery and Reinvestment Act (ARRA), 2009, homeowners can access up to $1,500 – but no more than 30 percent of the total installed cost – in tax credits for energy efficient home improvements, covering a wide array of efficiency measures. If incentive and rebate programs were to be expanded dramatically to reach all homes on a national level and buy down all NPV-positive measures to a 2.5-year payback, the outlay would total approximately $105 billion. Another approach involves programs offered by utilities or other organizations to provide low-cost or no-cost energy assessments. These programs, however, have tended to be on a small scale, providing only gradual impact, due to low funding levels, measurement and verification challenges, and low participation rates.
- **Building mandates** *(emerging).* Mandates can capture a large percentage of the potential, effectively removing all barriers; however, they would be a more significant intervention in the market. Authorities could require prescriptive or performance-based improvements at the point of sale, during a major renovation, or over a specified interval. The City of Berkeley, California's Residential Energy Conservation Ordinance (RECO) mandates minimum energy efficiency upgrades at the point of sale and major renovation. RECO has been in existence since the 1980s and leads to upgrades in approximately 500 homes annually at a typical cost of $400 to $1,300, which is borne by the home seller.[55] Because of changing ownership and inhabitant behavior, performance measurement and enforcement is challenging.

  A similar, but milder mandate would require home assessments, rather than improvements. The City of Austin, Texas, among others, is in the process of implementing such a mandatory assessment program. Such a program should recommend upgrades and provide referrals to approved contractors to address the service availability barrier; however, it would not guarantee savings. In fact, the success of the program would depend entirely on the rate at which participants choose to make the upgrades, because the amount of energy savings must justify the assessment cost, which typically runs between $300 and $600, given current operational scale, in addition to the cost of the energy efficiency measures themselves. In addition, about half of homes would not be covered by a point-of-sale audit by 2020 because they will not have changed ownership.[56] Covering all homes under such a program would likely require an additional mandated inspection within a specified time period. One important design aspect for a mandatory assessment program would be that it provide recommendations, not exact prescriptions, to minimize the possibility that differences in recommendations and savings estimates could cause a homeowner to defer or cancel the upgrade.[57]

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[55] Expert interviews. City of Berkeley, California website. <www.ci.berkeley.ca.us>.

[56] Paul Emrath, "How Long Buyers Remain in Their Homes," NAHB, February 12, 2009. <www.housingeconomics.com>

[57] Interviews with contractors revealed that homes that have been already rated before an assessment by a contractor have a lower chance of being upgraded, likely due to homeowners' confusion from conflicting assessments.

- **Larger market of home performance contractors** *(emerging).* This solution strategy would overcome existing workforce constraints. Given the current pace of roughly 200,000 retrofits annually,[58] capturing the full efficiency potential of 70 million homes within ten years would require a 30- to 40-fold increase in certified contractors, from approximately 40,000 to 1.5 million. To overcome the barrier of homeowner risk and uncertainty, contractors would likely need training and certification, in building science, potentially combined with certification and facilitated through government-funded training programs. Home Performance with ENERGY STAR (HPwES), where regional managers connect consumers with qualified Building Performance Institute (BPI)-certified contractors,[59] completed 50,000 upgrades from 2001 through 2008[60] and could serve as a potential model. A recent DOE summit recommended using HPwES as the preferred mechanism to deploy BPI certified contractors using RESNET certifications. This is a significant step toward deploying this solution strategy.

## 2. EXISTING LOW-INCOME HOMES

With 24 million single family, 16 million multifamily, and 5 million manufactured homes, low-income homes (building shells and HVAC) account for 1,540 trillion end-use BTUs of energy consumption in the 2020 reference case (Table 3). Capital constraints and a history of government and policy solutions distinguish this cluster,[61] which represents 19 percent of the residential energy savings potential in 2020 (610 trillion end-use BTUs).[62] Some 92 percent of the opportunity consists of shell upgrades, with the remaining 8 percent in the HVAC system. Capital required to achieve this potential could total an estimated $46 billion and provide present value savings of $80 billion. Sixty-eight percent of the potential is in single family homes, with 23 percent in multifamily and 9 percent in manufactured homes.

Table 3: Existing low-income homes

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 1,770 | 1,540 | 610 | 40 |
| ▪ Electricity TWh | 100 | 90 | 30 | 37 |
| ▪ Natural gas | 1,110 | 970 | 390 | 40 |
| ▪ Other fuels* | 320 | 260 | 110 | 41 |
| PRIMARY ENERGY Trillion BTUs | 2,530 | 2,240 | 870 | 39 |
| ▪ Electricity | 1,060 | 970 | 360 | 37 |
| ▪ Natural gas | 1,150 | 1,000 | 400 | 40 |
| EMISSIONS Megatons CO$_2$e | 150 | 130 | 50 | 39 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $46 billion | PV of energy savings – 2009-2020: $80 billion | Annual energy savings – 2020: $7 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA, AEO 2008, McKinsey analysis

Per square foot, low-income homes have a higher consumption (29,000 end-use kBTUs per sq. ft) and higher potential (9 end-use kBTUs per sq. ft) than other homes (25 end-use kBTUs per sq. ft and 7 end-use kBTUs per sq. ft respectively). They are also on average smaller: 1,480 square feet compared to 2,462 square feet for the average non-low-income home, driving lower per house consumption.

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[58] Expert interviews.

[59] The Building Performance Institute (BPI) certifies holistic home performance contractors. <www.bpi.org>.

[60] "ENERGY STAR Overview of 2008 Achievements," EPA Climate Protection Partnerships Division, March 2009.

[61] In this report, low-income households are defined as households with less than $30,000 in annual income.

[62] Public housing accounts for approximately 3 percent of all low-income homes and 3 percent of the low-income energy savings potential. There are approximately 1 million public homes in the United States, making up less than 1 percent of total U.S. housing.

## Barriers to greater energy efficiency

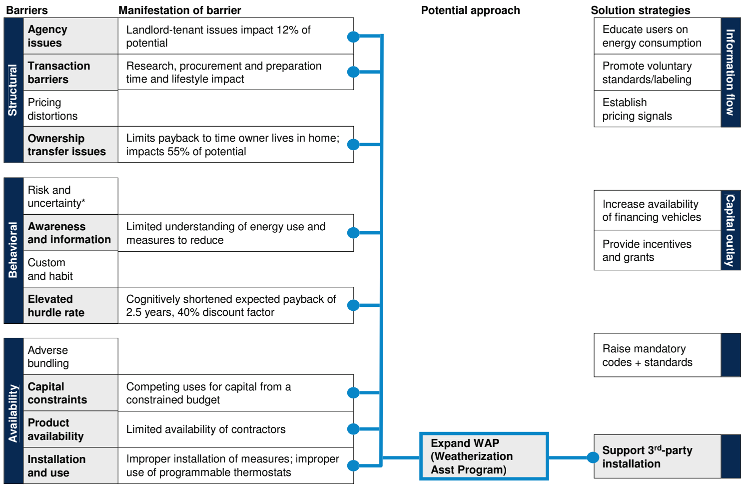
The barriers to improving the efficiency of low-income homes are similar to those in other residential retrofits, though capital concerns are far more pronounced. Allocating capital to a typical shell retrofit, which would cost $910 for the average low-income home ($1,820 for the average low-income single family home), would require spending roughly half of a household's annual non-core budget,[63] making funding through cash savings extremely challenging. Additionally, this cost compares poorly to the value of some older, poorly maintained homes[64] and the savings expected from shortened occupancy. Debt financing, while available, is often at higher interest rates, especially for lower-income households. Financing a retrofit through credit cards, if those were even avaialble to this segment, with an average interest rate of 18 percent,[65] would reduce the NPV-positive energy efficiency potential by 110 trillion end-use BTUs.

## Solution strategies to unlock potential

Solutions suitable for the previous cluster (i.e., non-low-income homes) would also be relevant in the low-income retrofit cluster, given the consistency among most of the barriers.

Exhibit 15: Addressing barriers in existing low-income homes

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.



* Represents a minor barrier
Source: McKinsey analysis

The success of the government-sponsored Weatherization Assistance Program (WAP), however, warrants specific attention (Exhbiit 15). Traditionally, WAP has prioritized the lowest income homes with energy-savings potential: 66 percent of homes weatherized have annual household incomes below $8,000, with 90 percent having less than $15,000, but the program could be extended to focus on energy savings more broadly and address higher-income homes. WAP fully funds and deploys energy-saving measures in low-income houses, effectively bypassing all barriers. These programs have weatherized more than 6.2 million homes over the past 32 years, generating annual savings of approximately 100 trillion end-use BTUs. These retrofits typically reduce heating and cooling bills by

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[63] Core expenses include housing, food, apparel, transportation, health care, education, insurance and pensions. Non-core expenses include entertainment, alcohol, tobacco, and miscellaneous expenses (Bureau of Labor Statistics website, <www.bls.gov/cex/2007/Standard/income.pdf>).

[64] In particularly troubled areas housing values can be highly depressed: currently there are several hundred homes available in Detroit for under $2,000 total cost.

[65] "Historical Monthly Credit Card Tables," Carddata Financial Surveillance, 2009.

32 percent and carry a fully loaded cost of approximately $3,200,[66] which includes measures addressing appliance and lighting potential. As with retrofits for other residential buildings, large-scale WAP deployment is constrained by the availability of resources: capturing all cost-effective potential from 45 million homes by 2020 would require increasing the annual output – currently 100,000 homes – by a factor of almost 40. Under the ARRA, 2009, the plan is to weatherize 1 million homes per year – 10 times the current pace – but, even if sustained, this would not be enough to reach all homes by 2020.

## 3. NEW HOMES

New buildings (i.e., constructed after 2009) are expected to consume 970 trillion end-use BTUs in 2020, representing 10 percent (320 trillion end-use BTUs) of total residential potential (Table 4). The incremental capital associated with this level of improvement would total $16 billion through 2020.

Table 4: New homes

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | **Savings** Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | n/a | 970 | 320 | 33 |
| ▪ Electricity TWh | n/a | 70 | 20 | 31 |
| ▪ Natural gas | n/a | 650 | 210 | 33 |
| ▪ Other fuels* | n/a | 80 | 30 | 37 |
| PRIMARY ENERGY Trillion BTUs | n/a | 1,510 | 480 | 32 |
| ▪ Electricity | n/a | 750 | 230 | 31 |
| ▪ Natural gas | n/a | 650 | 210 | 33 |
| EMISSIONS Megatons $CO_2e$ | n/a | 90 | 30 | 32 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $16 billion | PV of energy savings – 2009-2020: $41 billion | Annual energy savings – 2020: $4 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

New residential buildings represent a modest portion of the 2020 potential for two reasons: the 21.6 million new homes added to the national stock through 2020 are forecast to account for a relatively small share (17 percent) of all homes in 2020, and homes built after 2009 are expected to be more efficient, consuming only 19.7 end-use kBTUs per sq. ft. – 25 percent lower than the average (26.2 end-use kBTUs per sq. ft) for existing homes. Despite its moderate size in 2020, this cluster is important for two reasons. First, its share of potential grows with time: from 2020 to 2030, the share of homes built after 2009 would grow from 17 to 28 percent of U.S. homes[67] and the NPV-positive reduction potential offered correspondingly increases from 320 to 520 trillion end-use BTUs. Second, upgrades installed when a home is being built save energy at $4.30 per MMBTU, less than half the price of the $8.80 per MMBTU average for retrofit upgrades. This difference exists because all new-build potential comes at an incremental, rather than full deployment cost, unlike costs for many retrofit measures.

### Barriers to capturing efficiency potential in new buildings

The new building cluster faces three noteworthy barriers:

- **Ownership transfer concerns between builders and future owners.** Builders are often unsure about their ability to earn a return on efficiency investments. Because builders do not typically benefit from future energy savings, they must cover their incremental costs through a price premium on the efficient home. Home builders perceive high costs[68] as the most important obstacle to building energy efficient homes.
- **Low consideration at time of purchase.** Customers are typically unaware of the savings energy efficient homes offer and value other home attributes, such as location, school district, or home size, above energy efficiency, and it is unclear whether a large population of home buyers will consistently pay a premium for more efficient homes.

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[66] The amount of $3,200 includes approximately $2,500 of installation costs and $700 of administrative costs. Martin Schweitzer, *Estimating the National Effects of the U.S. Department of Energy's Weatherization Assistance Program with State-Level Data: A Metaevaluation Using Studies from 1993 to 2005*, Oak Ridge National Laboratory, U.S. Department of Energy, September 2005; 2005 dollars converted to 2009 dollars.

[67] AEO 2008, NEMS.

[68] Some industry experts indicate that if a builder redesigns his/her business model he or she could construct efficient homes at no additional cost.

- **Inconsistent installation quality.** This issue applies as much to the new building cluster as it does to the existing residential homes cluster. Problems with installation quality stem from incorrect sizing, improper duct sealing and refrigerant charge, and low compliance with building codes, partly due to low code enforcement.
  - **Sizing:** Properly sizing HVAC equipment for a home involves a trade-off between sufficient size to maintain the home at desired temperatures when facing climate extremes (i.e., the hottest and coldest days of the year) and energy savings that come with operating an appropriately sized system. A unit large enough to meet cooling needs in even the most extreme climates will repeatedly cycle on and off on more temperate days significantly reducing efficiency. Furthermore, larger air conditioners tend to be more expensive, more prone to maintenance problems, noisier, and less effective at removing humidity. Reducing air conditioner over-sizing beyond maximum-efficient operation could yield 20-percent savings.[69] The Air Conditioning Contractors of America and the Air Conditioning and Refrigeration Institute have jointly developed guidelines to help contractors properly size air conditioners and heat pumps.
  - **Duct sealing and refrigerant charge:** As many as 90 percent of air conditioning units have incorrectly sized and/or sealed ducts, and 70 percent of homes have inadequate air flow. Over- or undercharging refrigerant can also reduce equipment efficiency: half to three-quarters of air conditioners are estimated to have improper charges.[70] Improper air flow and refrigerant charge together can reduce efficiency by 12 to 32 percent.
  - **Code compliance and enforcement:** Code compliance varies significantly by type of measure, with full compliance ranging by state from 40 percent to 60 percent.[71] Many consumer-advocates report that builders have limited incentive to ensure proper installation, and inspectors may lack proper training to evaluate energy efficiency, because their primary focus is on health and safety. Furthermore, building officials are typically paid less than the market rate for skilled efficiency assessors, making recruitment of the required skill set difficult.

Other barriers affecting this potential include risk and uncertainty about the quality of construction, adverse bundling of efficiency features with uneconomic "green" measures, such as more expensive insulation products with a lower lifecycle carbon content or claims of auxiliary benefits, and unavailability of green homes. Sixty-three percent of homebuyers report that green homes are not available in areas they want to live.[72]

### Solution strategies to unlock potential

Three principal solution strategies appear suitable for the new building cluster. Developing and adopting higher performance standards in building energy and HVAC codes on a national scale would raise the floor for energy efficiency in new buildings (Exhibit 16). Voluntary specifications, such as ENERGY STAR and LEED, enable developers to differentiate buildings that exceed the code. However, it has not been fully proven that customers will pay the commensurate price premium necessary to increase builder confidence in the ability to earn a return on the incremental investment. Incentives for builders and HVAC manufacturers or prospective home buyers could stimulate the market for these higher-efficiency buildings.

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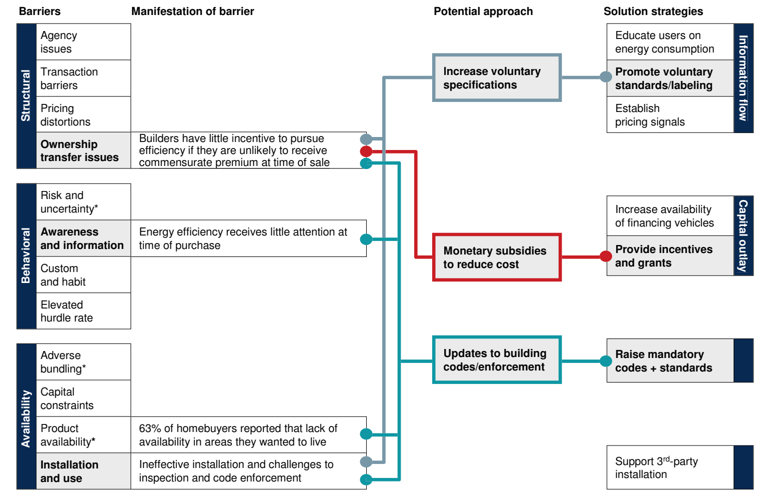
[69] Chris Neme, et al., "National Energy Savings Potential from Addressing Residential HVAC Installation Problems," ACEEE, February, 1999.

[70] "Energy Savings Impact of Improving the Installation of Residential Central Air Conditioners," Cadmus Group, 2005.

[71] Expert interviews.

[72] "The Green Homeowner: Attitudes and Preferences for Remodeling and Buying Green Homes," McGraw Hill Construction, 2007.

Exhibit 16: Addressing barriers in new homes



* Represents a minor barrier
Source: McKinsey analysis

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

Given the relatively lower cost of capturing energy efficiency in the design and construction of buildings – and the perishability of these options – this cluster merits more immediate attention than its share of 2020 potential suggests.

- **Mandatory building codes** *(proven).* State and local residential building codes are often based on the International Energy Conservation Code (IECC) model code, which is evaluated by the DOE to determine energy savings. If the DOE makes a positive determination, states are required to consider adopting the new code; they are not, however, obligated to adopt it. Codes typically contain prescriptive (i.e., specific measures to include in a home) and performance (i.e., minimum efficiency levels that builders must verify, regardless of measures employed) options. Prescriptive codes may be easier for builders to implement because they provide explicit stipulations. Performance codes allow builders to trade-off between measures, allowing for innovation and lowest-cost compliance, but are more complicated, because a range of measures are possible and savings would need to be quantified. Most analysis indicates that building codes have demonstrated savings over time, though some critics raise concerns about the code-writing process, unintended consequences on builders, and the proper trade-off between regionality and uniformity. Our research suggests solution strategies to capture potential through codes involve three complementary actions: 1) spreading high-efficiency codes to all states, 2) raising efficiency levels in existing codes, and 3) improving code compliance.
  - **Spreading high-efficiency codes to all states:** Since IECC model codes are not mandatory, states and municipalities are free to adopt or not adopt updated codes. As of early 2009, 21 states had adopted the 2006 or 2009 IECC codes or the equivalent; 13 had adopted IECC 1998 or 2003, and 16 had not adopted codes as stringent as IECC 1998 (Exhibit 17). If all states adopted the 2009 IECC code starting in 2009, annual energy savings in 2020 would be approximately 130 trillion end-use BTUs, with cumulative savings through 2020 reaching 850 trillion end-use BTUs.[73]

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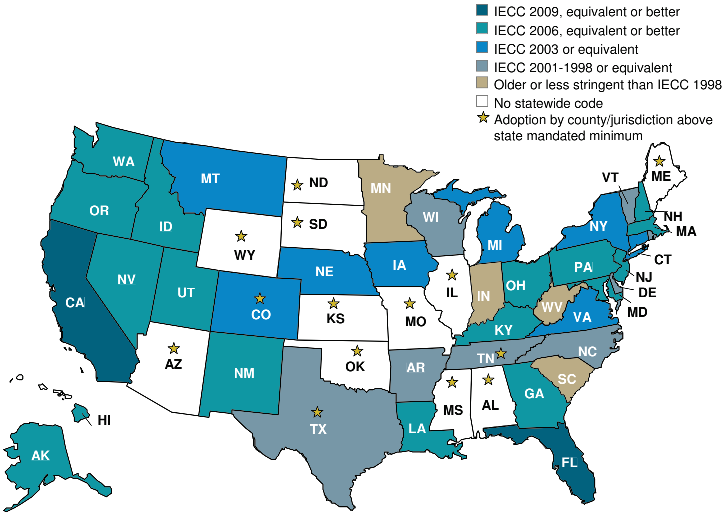
[73] Expert interviews.

Exhibit 17: Inconsistency of residential building codes

The map displays the variation in residential new building codes in place across the United States. In general, darker shades indicate higher standards, and lighter shades indicate less stringent standards, in line with the legend in the top right of the exhibit.



Source: Buildings Energy Databook, US Department of Energy, Office of Energy Efficiency and Renewable Energy

Two interesting options could be used to drive larger code adoption. The first focuses on education for state officials and building departments, e.g., through such mechanisms as the Building Codes Assistance Project (BCAP)[74] or utility-funded code assistance projects. The second method would employ incentives to encourage adoption, such as having the federal government make the accessibility of certain funds contingent on building code stringency. This approach has worked in the past in other contexts: when changing the legal drinking age to 21, the federal government linked highway funding to adoption of that limit, and all fifty states complied within three years.[75] The federal government enacted a similar measure in the February 2009 American Recovery and Reinvestment Act under the State Energy Program; it provides $3.1 billion in grants for state energy efficiency programs on the condition that the state plans to adopt residential and commercial codes that meet or exceed the 2009 IECC and ASHRAE Standard 90.1-2007 and comply with these codes in 90 percent of new and renovated residential and commercial buildings within 8 years.[76]

— **Raising efficiency levels in current codes:** Most of the recent improvements in the IECC code – which is updated every three years – have resulted in 1 to 3 percent improvements; from 1992 to 2006 code efficiency increased approximately 8 percent.[77] However, the 2009 IECC code is estimated to provide a 12 to 16 percent efficiency improvement compared to the 2006 IECC code.[78] In addition, the DOE and others are seeking to improve efficiency in the 2012 IECC code a further

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[74] BCAP was established in 1994, as a joint initiative of the Alliance to Save Energy, ACEEE, and the Natural Resources Defense Council. BCAP is largely funded by the DOE and the Energy Foundation.

[75] "Sanctions are effective," Advocates for Highway and Auto Safety, 2009. <http://www.saferoads.org/sanctions-are-effective>.

[76] "2009 Recovery Act and State Funding," EERE, DOE, 2009. <http://apps1.eere.energy.gov/state_energy_program/recovery_act.cfm>.

[77] "Energy Efficiency Trends in Residential and Commercial Buildings," DOE, October 2008.

[78] The 2009 prescriptive code is estimated to be 12.2 percent more efficient than the 2006 code, and the performance code is estimated to be 15.7 percent more efficient. ICF analysis suggests 2009 IECC could save roughly $235 in energy costs per household per year compared with IECC 2006. "Energy and Cost Savings Analysis of 2009 IECC Efficiency Improvements," ICF International, September, 2008.

15 percent beyond 2009 IECC. This level is very close to the NPV-positive value for new residential buildings calculated in this report.[79] If IECC 2009 were adopted through 2011 and a 30 percent improved code were adopted in 2012, 250 trillion end-use BTUs could be saved in 2020.[80]

  - **Improving code compliance:** To increase enforcement of building codes, states and municipalities could consider four complementary measures: 1) managing performance of building inspectors with third-party verifiers to spot-check buildings;[81] 2) hiring more building officials; 3) increasing the pay of building officials and requiring training in building science to attract those with building assessment skills; and 4) increasing the objectivity of performance-based code compliance, particularly for energy modeling.

    The Building Codes Assistance Project estimates that improving code compliance significantly above current levels would cost $210 million per year: $75 million for local building departments to hire and train building officials and $135 million for state governments to increase education and compliance.[82] Other experts have estimated the cost required to increase building code compliance, for new residential and commercial buildings, at a higher level of $1 billion per year.[83] This estimate includes hiring and training officials; adding equipment; creating an inspected building database; training contractors, plumbers, and electricians on code compliance and best practices; and re-inspecting 2 percent of buildings. Even at this higher annual cost, which (if incurred for 10 years and divided equally between commercial and residential sectors) adds $3.5 billion present value to the cost of capturing the new building potential, the energy efficiency potential of the cluster remains over $21 billion NPV-positive (in fact providing a roughly 20 percent rate of return).

- **Voluntary building standards, home labeling, and benchmarking** *(proven).* Labeling can address builder-buyer agency issues by fostering a market premium for energy efficiency due to increased awareness of efficient buildings. If installation quality receives continued attention, labeling could also circumvent the installation and inspection challenges. While no large-scale study of price premiums for efficient homes has been conducted to date, a number of regional analyses suggest that efficient homes are beginning to command a premium in some markets. In Portland, Oregon and Seattle, Washington, for example, new homes that were certified to be energy efficient were selling at a 3- to 5-percent premium and 10-percent faster rate.[84] (Note: this research was conducted prior to the recent collapse in the housing market). Voluntary standards could also drive builder training and increase use of best practices, indirectly increasing energy efficiency. There are various labeling mechanisms in use today that could address these concerns, if brought to scale:

  - The current ENERGY STAR specification covers total home energy use, including space conditioning and appliances, and is 20 to 30 percent more efficient than

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[79] It should be noted that very few retrospective studies on the energy savings impact of building codes exist and ones that do exist were conducted at the state or local level. Making the case for improving and funding building codes will likely require retrospective studies measuring the energy savings impact on a nationwide level.

[80] Expert interviews.

[81] This could be through utility or federally led programs (such as Austin Energy's), where funding is contingent on documentation of a proper inspection.

[82] "Code Enforcement Cost Estimates," BCAP, 2009. Expert Interviews.

[83] David Goldstein and Cliff Majersik, "NRDC/IMT Proposal for Improved Building Energy Code Compliance through Enhanced Resources and Third-Party Verification," NRDC, 2009. $1 billion is across both residential homes and commercial buildings.

[84] "Green Certified Homes Sell for More in Portland Real Estate Market," Earth Advantage Institute and the Green Building Value Initiative, May 6, 2008.

the average new home.[85] ENERGY STAR homes had a 17 percent share of the new home market in 2008 and together save 2 TWh of electricity and 15 trillion BTUs of natural gas per year.[86]

- The U.S. Green Building Council developed the LEED building certification system that targets energy savings, water efficiency, greenhouse gas emissions reduction, and improved indoor environmental quality. The system allows trade-off between these goals but sets the minimum efficiency level for LEED certification at 15 percent more efficient than the latest IECC code.[87]
- The Energy Efficient Codes Coalition is making its comprehensive package, called "The 30 Percent Solution," available to state and local governments as a code.[88]

- **Builder incentives** *(piloted).* There are various tax incentives for builders written into law, such as those in the Federal Energy Policy Act of 2005. Certain programs run by utilities or other organizations can accelerate adoption of these incentives. Efficiency Vermont, for instance, in its new residential housing program, provides builder training and assistance in securing incentives. For a total cost of $2.8 million in 2007, this program helped 35 percent of all homes qualify for ENERGY STAR rating, double the national average.[89] Incentives to builders are more likely to drive efficiency, because they directly offset incremental costs without requiring buyer awareness.[90]

## 4. ELECTRICAL DEVICES AND SMALL APPLIANCES

Electrical devices and small appliances, sometimes loosely called "plug load," consist of hundreds of smaller electricity-consuming devices and represent an area of sustained consumption growth: the U.S. consumer electronics industry, for example, grew from revenues of $94 billion in 2001 to $162 billion in 2007.[91] In 2008, the average household spent $330 on energy for these devices, with the expenditure growing at an annual rate of 2 percent. EIA forecasts that increased penetration of electronic devices will drive consumption from 500 TWh of electricity in 2008 to 630 TWh by 2020, rising from 35 percent of end-use residential electricity consumption to 40 percent in 2020. By 2020, there will be 2.5 billion devices consuming power in residential homes. TVs, DVD players and PCs made up 32 percent of electrical device and small appliance consumption in 2008, while another 9 categories tracked by the EIA made up an additional

Table 5: Electrical devices and small appliances

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 1,690 | 2,140 | 590 | 27 |
| ■ Electricity TWh | 500 | 630 | 170 | 27 |
| ■ Natural gas | n/a | n/a | n/a | n/a |
| ■ Other fuels* | n/a | n/a | n/a | n/a |
| PRIMARY ENERGY Trillion BTUs | 5,270 | 6,640 | 1,820 | 27 |
| ■ Electricity | 5,270 | 6,640 | 1,820 | 27 |
| ■ Natural gas | n/a | n/a | n/a | n/a |
| EMISSIONS Megatons $CO_2e$ | 330 | 410 | 110 | 27 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $3 billion | PV of energy savings – 2009-2020: $65 billion | Annual energy savings – 2020: $11 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

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[85] "Methodology to Calculate Energy Savings for ENERGY STAR Qualified New Homes," ENERGY STAR, 2007.

[86] "ENERGY STAR market share," EPA, April 2009.

[87] The energy efficiency portion of a LEED certification is based on ENERGY STAR. A new residential building must earn an 85 or lower on the ENERGY STAR scale, which is indexed at 100 to the IECC 2006 code and each percent below 100 indicated 1 percent savings. LEED specifications focus on sustainability of the home, including energy efficiency as well as water and sustainability, and it is therefore difficult to determine the exact efficiency improvement of a LEED home compared to the average home.

[88] "Energy and Cost Savings Analysis of 2009 IECC Efficiency Improvements," ICF International, 2008.

[89] *Year 2007 Annual Report*, Efficiency Vermont, 2008.

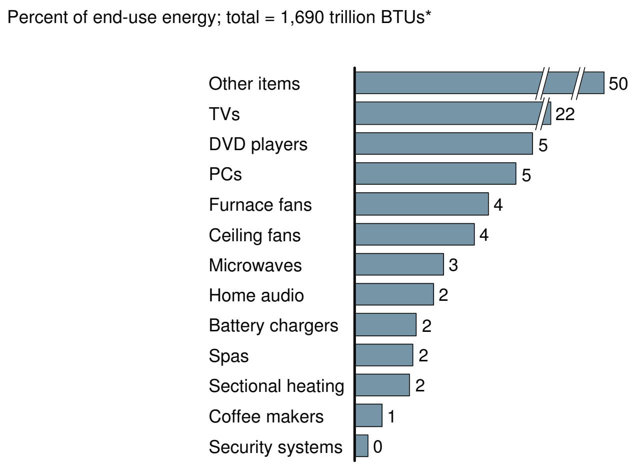
[90] One challenge brought on by the recent economic downturn is that tax credits are effective only if builders have taxes to pay.

[91] "Consumer electronics market research reports," CEA, April 2006 and 2008.

18 percent. The remaining 50 percent of consumption is divided across hundreds of other electric devices (Exhibit 18).

Electrical devices and small appliances provide 590 trillion end-use BTUs of NPV-positive potential, accounting for 19 percent of residential energy efficiency potential and 44 percent of residential electricity potential in 2020 (Table 5). Incremental capital required to capture this potential in 2020 would be approximately $3.4 billion,[92] and provide present value savings of $65 billion, resulting in a per-MMBTU cost of $1.00. This potential is highly cost effective – 90 percent of this potential would have payback period of less than two years.

Exhibit 18: Energy consumption of electrical devices and small appliances – 2008



* Does not equal 100% due to rounding
Source: NEMS 2008

Each bar represents the share of total electrical-device-related energy consumption in 2008 associated with the listed category of devices.

## Barriers to capturing potential in plug-load devices

Energy efficiency of plug-load devices has historically received little attention from consumers and manufacturers, giving rise to both demand- and supply-side barriers:

- **Lack of consumer awareness and associated habit and transaction cost barriers.** Each plug-load device occupies an extremely small part of a consumer's electric bill or a device's purchase price. Even TVs, the largest energy consumers in the cluster, cost consumers an average of $40 per TV per year ($100 on average per house) – only 5 percent of their total energy bill. Furthermore, consumers tend to underestimate plug-load consumption; residents believe these devices drive 13 percent of electric bills, much lower than their actual 35 percent share.[93] Research shows that many end-users do not know that devices consume electricity even when not in use.[94] Surveys also indicate that consumers tend to value other attributes, including price, features, device size, and warranty quality, above energy efficiency and that only 10 percent of consumers rate energy savings as the most important feature when purchasing a device.[95]

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[92] These costs reflect premiums of energy efficient consumer electronic devices currently in the market and do not account for manufacturer retooling costs, discussed more in detail later.

[93] Based on results from McKinsey / Burke market research; data represents weighted average of responses.

[94] Brahmanand Mohanty, "Perspectives for Reduction of Standby Power Consumption in Electrical Appliances," United Nations Economic and Social Commission for Asia and the Pacific. <www.unescap.org/esd/energy/publications/psec/guidebook-part-two-standby-power.htm>.

[95] "Going Green: An Examination of the Green Trend and What it Means to Consumers and the CE Industry," Consumer Electronics Association, 2008.

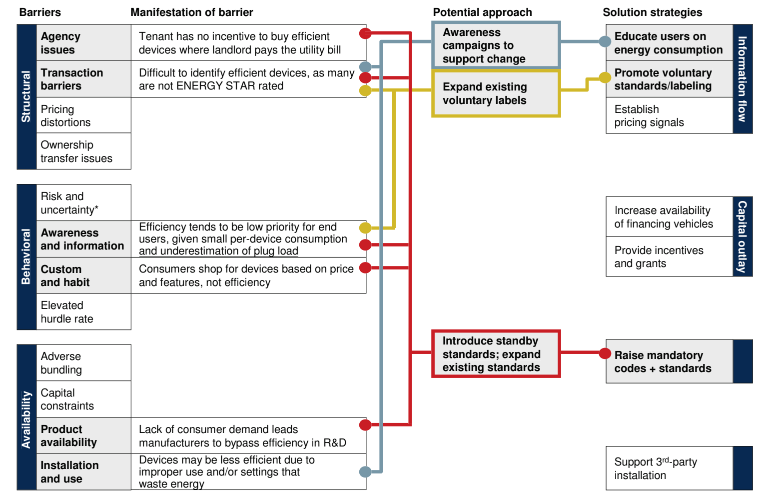
- **Limited technology availability and low manufacturer mindshare.** Lack of demand for energy efficient devices and an absence of mandatory efficiency standards for consumer electronics lead manufacturers to make efficiency improvements a low priority during product development. Because consumer electronics is a competitive market with low margins, manufacturers generally choose to minimize costs over developing features for which they are not sufficiently rewarded.
- **Failure to use efficient settings.** Many consumer devices, such as PCs and TVs, have energy-saving features, for example, entering standby after a period of disuse. A study in 2007 showed that only 15 percent of computers in home offices had power management enabled, as manufacturers don't necessarily enable settings at the point of sale, and consumers sometimes disable settings.[96] Technologies for power management are improving, becoming more user-friendly and less likely to interfere with consumer utility, thus helping to reduce the frequency at which people disable the functions.
- **Agency issues in rented homes.** Where the property owner pays a tenant's utility bill, the tenant has no incentive to choose energy efficient devices, which impedes capture of 19 percent of this cluster's potential.

### Solution strategies to unlock potential

Particularly low attention to electrical device and smaller appliance energy consumption among consumers and manufacturers points to solution strategies that either increase consumer awareness of potential savings or bypass consumer and manufacturer awareness and decision-making requirements (Exhibit 19).

Exhibit 19: Addressing barriers in electrical devices and small appliances

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.



* Represents a minor barrier
Source: McKinsey analysis

- **Mandatory standards** *(proven).* Mandatory standards would bypass consumer and manufacturer decision-making, offering a high certainty of capture.
  - **Specific product standards.** For the largest categories, it may be feasible to create specific standards (as there are for battery chargers and power adapters), though other factors including product differentiation and incremental cost are important to consider. As an example, setting mandatory standards at the NPV-

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[96] K. Roth and K. McKenney, "Residential consumer electronics electricity consumption in the United States," European Council for an Energy Efficient Economy Summer Study, June 2007.

positive level identified in this report for the five largest plug-load categories[97] would save 210 trillion end-use BTUs (36 percent of this cluster's potential). To go beyond the most energy-consuming categories and create standards for the hundreds of remaining product classes would be difficult and costly.

— **Standby standard.** A cross-cutting "standby" standard could capture a large portion of the potential across a range of devices, both high consumption devices that have specific product standards and devices that have too little consumption to warrant a specific standard of their own. Standby power consumes an estimated 6 to 8 percent of residential electricity,[98] equivalent to 130 to 170 TWh per year. Standby power accounts for 10 to 90 percent of a device's total consumption, depending on the product.[99] A standby standard could reduce standby consumption by roughly two-thirds,[100] yielding 90 to 110 TWh in savings. Such a standard could produce an additional savings of 80 to 100 TWh in commercial office equipment, which chapter 3 discusses further. In addition, because the U.S. makes up 34 percent of the global consumer electronics market,[101] a U.S. standby standard has the potential to stimulate significant change in global electronics manufacturing. Finally, anecdotal evidence suggests that reducing standby consumption may stimulate design changes that reduce active mode energy consumption.[102] The Federal Energy Management Program (FEMP) is tasked to implement the "1-Watt Standby" plan requiring federal agencies to select products with low-standby energy consumption and has released the FEMP Standby Levels for agencies to follow.[103] While direct impact of this mandate is difficult to measure, it did raise manufacturer awareness of standby power. There are a number of examples from outside the U.S. of standby standards that drive energy savings:

  □ Japan's Top Runner program, which reduced annual per-household standby consumption from 437 kWh in 2002 to 308 kWh in 2005.[104]

  □ Korea's 1-Watt Program, which will progress from a voluntary program to a mandatory standard in 2010. Average standby power per device is projected to decline from 3.66 Watts in 2003 to 1.54 Watts in 2020, saving 6.8 TWh per year (more than $70 million in electricity cost) by 2020.[105]

  □ Australia's standby power regulation, which covers a number of devices, is expected to introduce cross-category regulations for all electric appliances by 2012.

  Standby standards do present some concerns:

  □ Manufacturers may oppose a standby standard, owing to the incremental cost to their products. However, many plug-load devices could meet a standby standard with little incremental cost, likely to be less than 50 cents per unit.[106]

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[97] The five largest electricity consuming categories in National Energy Modeling System are TVs, PCs, microwaves, ceiling fans, and DVD players.

[98] The majority of the 6 to 8 percent estimate for standby power consumption is from plug-load devices, but it includes some from other appliances. Expert interviews.

[99] "2006 ACEEE Summer Study on Energy Efficiency in Buildings," ACEEE, 2006.

[100] Expert interviews.

[101] "Consumer Electronics Global Statistics," Growth from Knowledge, 2008.

[102] Benoit Lebot, et al., "Global Implications of Standby Power Use," IEA, 2000. Expert interviews.

[103] "U.S. Executive Order 13221 – '1-Watt Standby' Order," Power Integrations, 2001. <www.powerint.com/node/201>.

[104] Joakim Nordqvist, "Evaluation of Japan's Top Runner Programme," Energy Intelligence for Europe Program, 2006.

[105] "Korea's Market Transformation Plan," Korea Energy Management Corporation, October 2008.

[106] Expert interviews.

At that level, the cost of avoided power for all devices would be $2.10 per MWh.[107]

  - Standards must balance energy savings with delivered functionality, often making it difficult to craft a policy that adequately captures savings while preserving consumer appeal. As a result, there will likely need to be multiple standby standards, because certain devices require higher power levels than others. Set-top boxes, for example, require greater functionality and energy use while in standby and may require a higher minimum level than other products.

- **Voluntary standards and labeling** *(proven).* Voluntary standards can reduce transaction “costs” associated with identifying efficient devices and raise awareness of plug-load consumption. ENERGY STAR has created voluntary standards for nine device categories that fall into residential electrical devices, among them TVs, DVDs, and PCs, which saved 63 TWh of electricity in 2007.[108] Voluntary standards would facilitate implementation of future mandatory standards by developing testing procedures and building manufacturer relationships. Voluntary standards can also be developed and updated faster than mandatory standards, allowing greater flexibility in a rapidly changing marketplace.
- **Education and awareness** *(piloted).* Programs to educate the public about plug-load consumption and how individuals can reduce it could overcome transaction and usage barriers. A representative campaign could 1) encourage people to unplug unused devices and turn off devices when not in use, 2) increase awareness of efficiency settings and passive controls, such as smart switches and power strips, and 3) generate demand for efficient consumer electronic devices. Research shows that 22 percent of residential PC users leave their computers running at night[109] and 64 percent of office PCs run overnight;[110] changing these behaviors alone could unlock significant savings.

## 5. LIGHTING AND MAJOR APPLIANCES

Lighting and major appliances, which include water heaters, refrigerators, freezers, clothes washers, clothes dryers, dishwashers, stoves and ovens, constitute 30 percent (3,420 trillion end-use BTUs ) of 2020 residential consumption (Table 6). Consumption is expected to decline at 0.3 percent over the next ten years, which reflects provisions in EISA 2007 that address lighting consumption, effectively phasing out today’s incandescent bulbs in 2012 for more efficient lighting.

The lighting and major appliances cluster accounts for 11 percent of total residential potential in 2020 (340 trillion end-use BTUs). Ninety-six percent of appliance potential are from replacement purchases, with four percent driven by new appliance purchases. Total incremental capital required to purchase higher-efficiency appliances between 2009 and 2020 would be $11 billion and provide present value savings of $42 billion at an average per-MMBTU cost of $4.50 (Table 6).

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[107] Calculated as $0.50 for each of 2.5 billion consumer electronic devices divided by the energy savings of approximately 100 TWh over an average 8-year lifetime.

[108] “Table 8, Consumer Electronic, Residential & Commercial Office Equipment,” *2007 Annual Report*, ENERGY STAR, 2007.

[109] K. Roth and K. McKenney, “Residential consumer electronics electricity consumption in the United States,” European Council for an Energy Efficient Economy Summer Study, June 2007.

[110] Judy Roberson, et al., “After-hours power status of office equipment and energy use of miscellaneous plug-load equipment,” Lawrence Berkeley National Laboratory, LBNL-53729 Rev, May 2004.

Lighting constitutes 15 percent of energy consumption in this cluster but 82 percent of its savings potential, representing 9 percent (80 TWh) of total residential potential (Exhibit 20). Deployment of general use LED lighting, which becomes the lowest cost lighting technology between 2013 and 2017, presents much of this potential. Even today, the average home could save more than $180 per year by switching from incandescent to CFLs,[111] though CFLs become the business-as-usual lighting technology of choice by 2012 in accord with the Energy Independence and Security Act of 2007. Water heating constitutes 50 percent of consumption in this cluster and 13 percent (40 trillion end-use BTUs) of potential. Clothes washers are another 4 percent of consumption and 4 percent (20 trillion BTUs) of cluster potential, with the remaining 31 percent of consumption and 1 percent of potential shared among dryers, dishwashers, refrigerators, freezers, and cooking appliances.[112]

Table 6: Lighting and major appliances

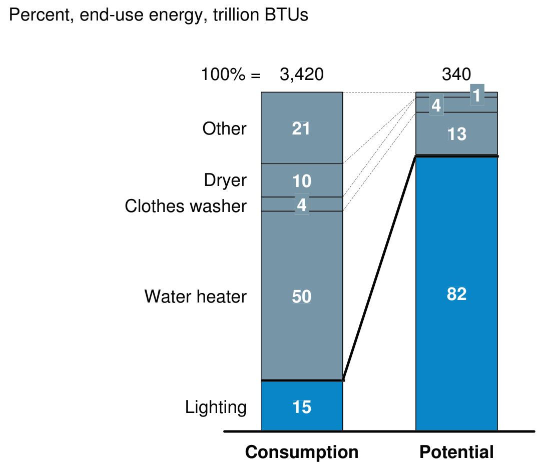
| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 3,540 | 3,420 | 340 | 10 |
| ▪ Electricity TWh | 580 | 520 | 90 | 17 |
| ▪ Natural gas | 1,380 | 1,490 | 40 | 2 |
| ▪ Other fuels* | 180 | 160 | 10 | 6 |
| PRIMARY ENERGY Trillion BTUs | 7,770 | 7,230 | 990 | 14 |
| ▪ Electricity | 6,150 | 5,520 | 940 | 17 |
| ▪ Natural gas | 1,430 | 1,550 | 40 | 2 |
| EMISSIONS Megatons $CO_2e$ | 470 | 430 | 60 | 14 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $11 billion | PV of energy savings – 2009-2020: $42 billion | Annual energy savings – 2020: $6 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

Exhibit 20: Efficiency opportunities in lighting and major appliances – 2020



Source: EIA AEO 2008, McKinsey analysis

The two columns break out energy consumption and efficiency potential in 2020 for the listed appliance categories modeled in the report.

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[111] Assuming 30 light bulbs per house used 3 hours per day. (Susan Williams and Bill McNary, "Change a Light, Change the World 2007 Facts and Assumptions Sheet," ENERGY STAR, 2007.)

[112] Significant energy efficiency is already included in EIA business-as-usual projections for appliances through inclusion of existing appliance standards as well as assumed penetration of high-efficiency devices above the standard.

### Barriers to capturing appliance efficiency potential

Lighting and major appliance efficiency faces barriers common to both electrical devices and new building potential. The most relevant barriers are:

- **Lack of awareness and certainty of savings.** Knowledge of efficient appliances is relatively high among consumers – 93 percent for lighting, 86 percent for kitchen appliances, 84 percent for clothes washers and dryers, and 74 percent for water heaters.[113] However, consumers seem to be less clear about the potential monetary savings. For instance, 75 percent of consumers believed that CFLs had longer than a one year payback or did not know what the payback was.[114]
- **Quality trade-offs.** End-users retain preconceived and often inaccurate ideas about differences in functionality that limit the acceptance of certain products. Forty-two percent of consumers, for example, believe that CFLs have significantly lower-quality light than incandescent bulbs.[115]
- **Supply chain availability.** Sixty-eight percent of water heaters fail before they are replaced, and more than 50 percent are emergency replacements, leaving these consumers dependent on the stock of water heaters available on contractors' trucks. When given purchasing options, however, consumers place the highest importance on energy efficiency, followed by unit size; surprisingly, price ranks fifth of nine possible responses.[116] Thus, if given the time and selection often denied by emergency replacement, consumers would likely select more efficient devices than they are currently able to select.

Other minor barriers include allocation of capital for more costly appliances; adverse bundling in some appliances, such as clothes washers where manufacturers bundle higher efficiency with sophisticated options and cycle settings; ownership transfer issues as home builders have unclear ability to recover their investment in efficient devices; and to a lesser extent transaction barriers associated with identifying efficient devices, which is significantly mitigated by the prevalence of labeling.

### Solution strategies to unlock potential

Solutions to capture the energy efficiency potential in appliances include education, voluntary standards and labeling, codes and standards, and incentives and grants (Exhibit 21).

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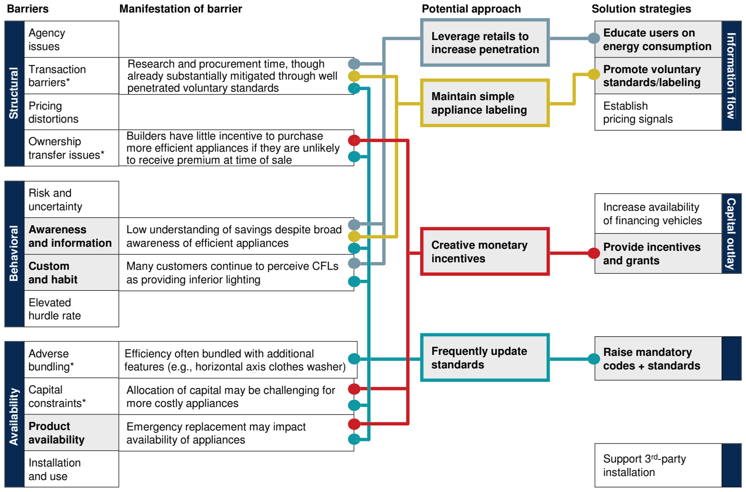
[113] *2007 Business in Society Survey*, McKinsey & Company; Number of respondents: 2,002.

[114] *2007 Business in Society Survey*, McKinsey & Company; Number of respondents: 995.

[115] Note that technologies with real, rather than perceived, quality differences are excluded from substitution in our analysis; we consider CFLs interchangeable for most lighting, as they have overcome most challenges (e.g., slow start up). 2007 Business in Society Survey, McKinsey & Company; Number of respondents: 2,002.

[116] "Residential Water Heater Market," KEMA, July 2006.

Exhibit 21: Addressing barriers in lighting and major appliances



* Represents a minor barrier
Source: McKinsey analysis

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

- **Mandatory appliance standards** *(proven)*. Between 1990 and 2000, mandatory appliance standards saved U.S. consumers roughly $50 billion in energy bills, with consumer savings outpacing additional consumer expenditures by a ratio of 2.5 to 1.[117] Taxpayer funds to support DOE's appliance standards program since 1987 total $200 million to $250 million. According to Lawrence Berkeley National Laboratory, appliance standards will reduce energy consumption in 2020 by 8 percent relative to a scenario with no standards.[118] Refrigerators and clothes washers account for over 50 percent of this savings, followed by water heaters and central air conditioners as the next largest energy saving categories.[119] Challenges to increasing mandatory standards include passing legislation and the speed of implementation. Standards typically take 3 years from inception to implementation.[120] Systematic, periodic reviews to update the standards are essential to their success. Japan's Top Runner program, which includes mandatory labeling, is a case in point. In 21 product categories, the standard is set based on the most efficient model in the market; all products must comply with that standard within 3 to 10 years, depending on the product category. Thus the program eliminates low-efficiency products from the market and encourages manufacturers to develop models with higher efficiency. It is estimated that by 2010, this program will annually save 56 TWh of electricity in Japan's residential and commercial sectors.
- **Voluntary appliance standards and labeling** *(proven)*. Voluntary appliance standards have had a significant impact on energy savings in appliances. In 2008, EPA reported savings of 159 TWh through its appliance standards (in both residential and commercial), over a third of which is due to lighting. In 2008, 76 percent of households were aware of the ENERGY STAR brand. ENERGY STAR continues to raise its efficiency bar through a continual updating process. When setting a

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[117] "Appliance and Equipment Efficiency Standards: One of America's Most Effective Energy-Saving Policies," ACEEE, 2009.

[118] Steve Meyers, et al.

[119] Steve Meyers, et al.

[120] The standards process begins with a "Framework Workshop," with an Advanced Notice of Proposed Rulemaking (ANOPR) 18 months later, a Proposed Rule (NOPR) 12 months after that, and a Final Rule an additional 6 months later. "DOE standards due between late 2008 and 2014: Key dates and energy savings," Appliance Standards Awareness Project, 2008.

specification, ENERGY STAR aims to set it to a level that 25 percent of the products on the market can meet, guaranteeing a high level of efficiency but also ensuring that consumers have a variety of products from which to choose. While many factors drive updates in ENERGY STAR specifications, including technological innovation and regulatory changes, having 40 to 50 percent of the market compliant with ENERGY STAR specifications triggers an update of the specification. One factor driving success of ENERGY STAR may be its simple messaging. Finally, voluntary standards can be particularly cost effective: according to National Renewable Energy Laboratory, ENERGY STAR has saved energy at a cost of roughly $0.09 per end-use MMBTU. [121]

- **Monetary incentives and rebates** *(proven).* While incentives to consumers primarily address barriers in capital availability and ownership transfer (i.e., appliances in new buildings), incentives to suppliers can overcome the product availability barrier as well. A number of utilities and other organizations offer rebates, or even free efficient appliances, and the government has offered tax incentives. Many such programs have focused on lighting, due to its high energy-savings potential. For example, the Illinois Department of Commerce and Economic Opportunity Residential ENERGY STAR Lighting Program (2003 to 2004) partnered with over 140 retailers to provide 164,000 instant rebates on CFLs and 60,000 mail-in rebates on ceiling fans and CFLs in the 2 years of the program. In Efficiency Vermont's CFL buy-down program, consumers purchased 580,000 CFLs in 2007 – 74 percent of all CFLs sold in the state. The program reported a cost of about $1.0 million, with savings of approximately 263 GWh, for a per-kWh cost of $0.004.[122] One consumer incentive includes refrigerator and freezer "swap out" programs, where utilities bear the cost of extracting old equipment and replacing it with a new unit, thus encouraging people to accelerate adoption of efficient technology. Providing a financial rebate to contractors to stock efficient water heaters can overcome the technology availability barrier for that appliance.
- **Retailer's role in energy efficiency** *(piloted).* Retailers could play an important role in driving adoption of energy efficient appliances. A flagship example is Wal-Mart's focus on CFLs, with 100 million bulbs sold in 9 months, helping double CFL penetration from 5 percent to 10 percent. ENERGY STAR has effectively partnered with retailers to leverage their relationships with consumers, providing information and advertising material for stores for ENERGY STAR products, as well as promoting efficiency incentives. While still largely unproven, retailers' strong position with consumers make retailers a natural partner for this type of energy efficiency measure.

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[121] "Estimates of Administrative Costs for Energy Efficiency Policies and Programs," NREL, 2000. <www.nrel.gov/docs/fy01osti/29379.pdf>. The ENERGY STAR 2007 Annual Report indicates even higher cost effectiveness recently, with primary energy savings of $0.023 per MMBTU.

[122] *Year 2007 Annual Report*, Efficiency Vermont, 2008.

# 3. Approaches to greater energy efficiency in the commercial sector

The commercial sector will consume 20 percent of the 2020 baseline end-use energy in the United States, equivalent to 8.0 quadrillion BTUs of end-use energy (Table 7).[123] Consumption is forecast to grow by 1.5 percent per year, from a base of 6.7 quadrillion BTUs of end-use energy in 2008, driven by increases in commercial floor space and consumption intensity of end-use energy per square foot.

Relative to the business-as-usual baseline for 2020, deploying all NPV-positive efficiency improvements in the commercial sector would reduce energy consumption in 2020 by 29 percent, require $125 billion in upfront investment, and provide present-value savings of $290 billion in energy costs while avoiding some 360 million tons of GHG emissions that year.

Although most of the efficiency potential exists in buildings (87 percent, 2,010 trillion end-use BTUs), 13 percent (290 trillion end-use BTUs) is in such community infrastructure as water purification and treatment, water distribution, street and traffic lighting, and telecommunications. The opportunity in the commercial sector is diverse, characterized by 10 types of buildings (4.9 million in total), multiple ownership structures, governmental and private tenants, and more than 100 end-use applications (Exhibit 22).

Table 7: Overview of energy use in the commercial sector

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 6,680 | 8,010 | 2,290 | 29 |
| ■ Electricity TWh | 1,330 | 1,660 | 510 | 31 |
| ■ Natural gas | 1,930 | 2,140 | 510 | 24 |
| ■ Other fuels* | 200 | 220 | 50 | 23 |
| PRIMARY ENERGY Trillion BTUs | 16,330 | 20,010 | 5,970 | 30 |
| ■ Electricity** | 14,110 | 17,570 | 5,390 | 31 |
| ■ Natural gas | 2,010 | 2,220 | 530 | 24 |
| EMISSIONS Megatons $CO_2e$ | 990 | 1,220 | 360 | 30 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $125 billion | PV of energy savings – 2009-2020: $290 billion | Annual energy savings – 2020: $37 billion |

* End-use energy is approximated as equivalent to primary energy

** Does not include CHP savings of 490 trillion BTUs

Source: EIA AEO 2008, McKinsey analysis

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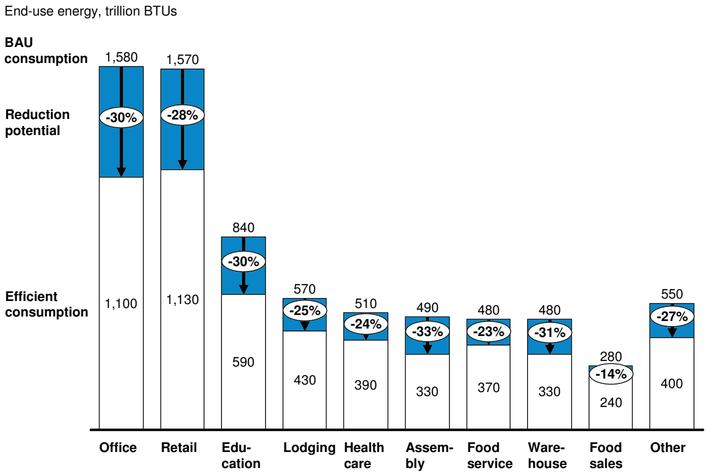
[123] This excludes natural gas and distillate fuel oil consumption (1,350 trillion BTUs in 2020) attributed to miscellaneous load and unspecified sources in *AEO 2008* due to lack of information about the sources of consumption and the efficiency opportunities.

Exhibit 22: Efficiency potential in commercial subsectors – 2020

The exhibit displays energy consumption in 2020 associated with various building types in the commercial sector with and without energy efficiency measures implemented.



Source: EIA AEO 2008, McKinsey analysis

We organized the potential into five clusters, based on shared barriers and attributes (Exhibit 23). Although specific barriers manifest themselves within commercial subsectors (e.g., the relative importance of agency in the food service subsector), we have focused on cross-cutting solutions that can apply with minor modification across subsectors.

For continuity, we will discuss clusters that involve the building shell and HVAC systems, which together provide habitable and conditioned space, then we will examine commercial energy use inside and outside those spaces.

1. **Existing private buildings (810 trillion end-use BTUs):** Notable barriers include split agency, expectations of short payback period, upfront capital constraints, and lack of awareness or information. Solution strategies to address these barriers include requiring energy benchmarking for buildings, establishing a public-private partnership through a government loan guarantee fund, enabling creative financing solutions, and/or introducing mandatory assessments and upgrades.
2. **Government buildings (360 trillion end-use BTUs):** This cluster faces barriers in access to capital, lack of awareness, and regulatory challenges. Possible solution strategies include requiring energy benchmarking for buildings, setting binding energy efficiency targets for state and local jurisdictions, and adjusting regulations to expand access to performance contracting.
3. **New private buildings (270 trillion end-use BTUs):** Barriers resemble those in new residential buildings: lack of incentives for developers to construct high-efficiency buildings, ineffective installation, and limited commissioning. Relevant solution strategies also resemble those for new residential buildings: improving efficiency levels in building codes and greater use of those standards, increasing penetration of voluntary specifications, and linking incentives to developers or buyers through voluntary specifications.
4. **Office and non-commercial devices (570 trillion end-use BTUs):** Potential is spread across a variety of electronic equipment and miscellaneous commercial load, for which energy efficiency has historically been of relatively little concern among both users and manufacturers. As with residential plug-load, the primary

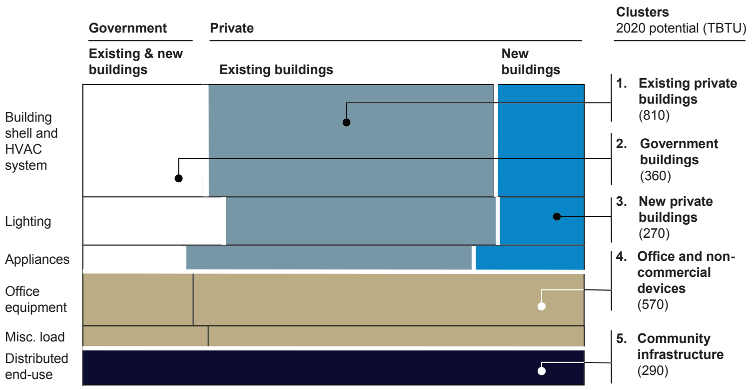
measure appears to be equipment-specific and category-level standards for active and standby power consumption.

5. **Community infrastructure (290 trillion end-use BTUs):** This cluster suffers from capital constraints, low awareness, and risk aversion. Solution strategies for government-owned facilities could include requiring energy benchmarking, setting binding energy efficiency targets for state and local jurisdictions, and enabling effective performance contracting. Several additional solutions will apply to specific end-uses in this cluster.

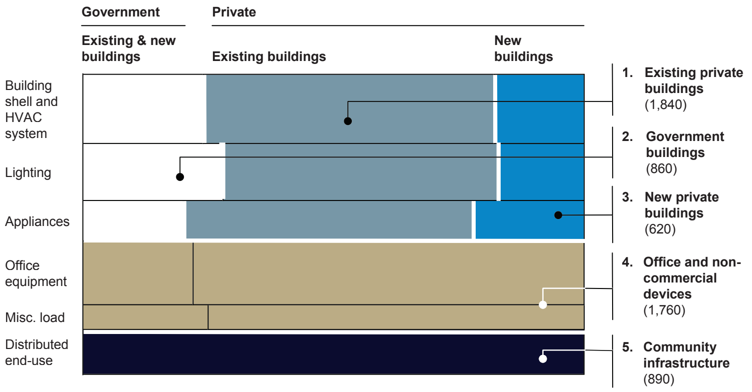
Exhibit 23: Clusters of energy efficiency potential in the commercial sector

The upper and lower charts break out the energy efficiency potential in 2020 for the commercial sector in end-use and primary energy respectively. Each area represents a cluster of efficiency potential: the area is proportional to the relative share (of total potential in the sector) associated with that cluster, while the number next to the cluster name provides the efficiency potential, measured in trillion BTUs.

End-use energy, avoided consumption; total = 2,290 trillion BTUs



Primary energy, avoided consumption; total = 5,970 trillion BTUs



Source: EIA AEO 2008, McKinsey analysis

## 1. EXISTING PRIVATE COMMERCIAL BUILDINGS

Existing privately owned commercial buildings account for 2,860 trillion end-use BTUs of energy consumption in the 2020 reference case (Table 8). These buildings cover a range of types, including educational facilities, office buildings, assembly, retail and service facilities, warehouses, lodging, healthcare, and other buildings. Floor space in this cluster totals approximately 57 billion square feet. This cluster's end-uses include heating, cooling, ventilation, lighting, and water heating, as well as building-related electrical devices including elevators and transformers.[124]

Table 8: Existing private buildings

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY<br>Trillion BTUs | 3,560 | 2,860 | 810 | 28 |
| ■ Electricity TWh | 560 | 450 | 140 | 31 |
| ■ Natural gas | 1,520 | 1,230 | 300 | 24 |
| ■ Other fuels* | 140 | 110 | 30 | 27 |
| PRIMARY ENERGY<br>Trillion BTUs | 7,630 | 6,110 | 1,840 | 30 |
| ■ Electricity | 5,920 | 4,730 | 1,500 | 31 |
| ■ Natural gas | 1,580 | 1,280 | 310 | 24 |
| EMISSIONS<br>Megatons $CO_2e$ | 460 | 370 | 110 | 30 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $73 billion | PV of energy savings – 2009-2020: $104 billion | Annual energy savings – 2020: $11 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

This cluster offers NPV-positive energy efficiency potential of 810 trillion end-use BTUs, representing 35 percent of the potential in the commercial sector. Retail and office buildings together constitute 44 percent of consumption in this cluster and offer 48 percent of the efficiency potential. Capturing the potential in this cluster would require an investment of approximately $73 billion and provide present-value savings of $104 billion.

### Barriers to greater energy efficiency

Capture of NPV-positive potential in existing private buildings is constrained by a wide range of barriers. While different barriers exert themselves to different degrees depending on the context, we have identified several dominant barriers whose removal is essential.

- **Agency issues.** Agency issues affect approximately half (420 trillion end-use BTUs) of the cluster's potential. In leased buildings, financial incentives for the owner to invest in energy efficiency are uncertain, because the owner will likely not capture the energy savings. Owners may benefit from efficiency investments, if lower operating costs increase the rate of tenant renewals and/or command a rental premium.[125]
- **Elevated hurdle rate.** The average payback period expected by commercial customers is 3.6 years.[126] This expectation creates a hurdle for deeper retrofits that typically have longer payback periods. This barrier affects an estimated 170 trillion end-use BTUs or 21 percent of this cluster's potential.
- **Capital constraints.** Capital constraints exist for energy users and their upstream lenders. For the energy end-user, raising and allocating capital for efficiency projects is often confounded by a desire not to increase debt, concern about the opportunity cost of this capital against alternative uses (particularly projects that impact revenue growth), and a reluctance to outsource energy solutions to companies that may charge a financing premium. Upstream financiers may incur increased credit risk when providing capital to privately owned buildings compared to the municipal-university-school-hospital (MUSH) market, because of elevated default risk. In all markets they face difficulty in establishing collateral for the loan, as projects often involve

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[124] We discuss the energy efficiency potential in lighting and appliances in the cluster consisting of new privately owned buildings, though the solutions are equally applicable for lighting and appliances in this and the government buildings clusters.

[125] Based on interviews with commercial building operators.

[126] "Energy Efficiency Indicator, North America," Johnson Controls, March 2008.

specialized equipment, unrecoverable design and installation costs, and high retrieval costs, all of which elevate the financier's risk exposure pending default.[127]

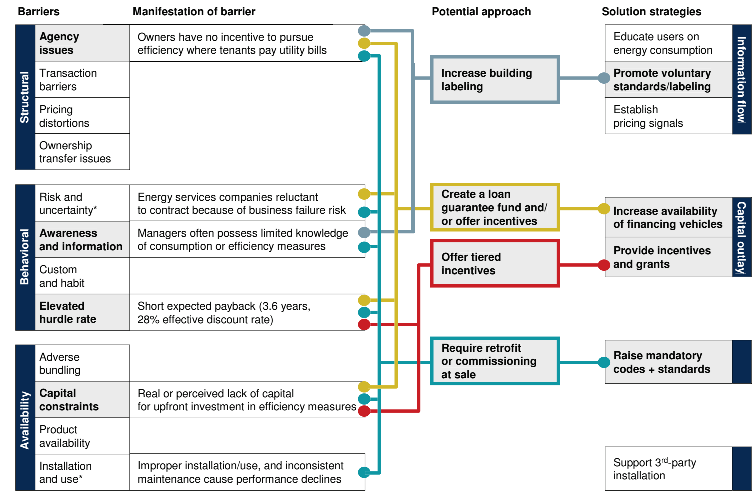
- **Lack of awareness or information.** Many facility managers are unaware of energy efficiency potential with the belief that the building is already energy efficient. Furthermore, they often possess limited knowledge of energy efficiency measures and ways to deploy them within their facilities, including the critical role that proper design and installation play in capturing the savings.[128]

Other barriers affect this cluster to a lesser degree: risk and uncertainty about the financial health and longevity of customers is a barrier for ESCOs considering this market; risk may also take the form of quality tradeoffs (e.g., unwillingness to incur perceived compromises to consumer experiences in retail or food service); and improper installation and inconsistent maintenance of HVAC equipment can lead to suboptimal performance and incomplete realization of efficiency potential.

## Solution strategies to unlock potential

A number of solution strategies could help overcome the principal barriers while addressing many of the additional barriers discussed above (Exhibit 24).

Exhibit 24: Addressing barriers in existing private buildings



* Represents a minor barrier
Source: McKinsey analysis

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

- **Mandate efficiency at time of retrofit** *(emerging).* Local, state, or federal governments could require private buildings to meet an efficiency benchmark at point of sale, major retrofit, or a specified time interval. Such mandates represent a solution that could address all barriers by circumventing the end-user. Creating such a requirement could prove difficult to achieve politically, though recent actions in New York City suggest it may be possible.[129] Results from these programs are as yet unclear as annual turnover is relatively small (2.2 percent of building stock),[130] limiting the speed of improvement.

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127 *Developing Financial Intermediation Mechanisms for EE Projects in Brazil, China and India*, Econoler International, January 2006. < http:// 3countryee.org/public/angraworkshop.pdf>.

128 *Sector Collaborative on Energy Efficiency Accomplishments and Next Steps*, EPA, July 2008.

129 *The Power of Information to Motivate Change: Communicating the Energy Efficiency of Today's Commercial Buildings*, EPA, February 2009. The City of New York's PLANYC Initiative 5. <www.nyc.gov/html/planyc2030>.

130 "US Commercial Building Ownership Turnover," CoStar Group, February 2008.

In addition, point of sale standards do not create a natural opportunity for retrofits, as change in building ownership does not always accompany turnover of tenants; further, some stakeholders are concerned that point of sale regulation could slow transactions. Hence, variants of this approach that link enforcement to changes in tenancy (rather than ownership) may prove more effective. Enforcement of the regulations presents additional concern and would incur added costs.

- **Create value with voluntary standards** *(emerging).* Buildings meeting an efficiency standard show a 6 percent premium in effective rent and a 16 percent premium in valuation over similar non-energy efficient buildings.[131] The benefits provided by adherence to a voluntary standard, applied to both buildings and commercial equipment, could help manage agency issues by offering financial returns for investments through increased rent and raising awareness of the benefits of efficient buildings.
- **Finance through a public-private partnership** *(piloted).* Interviews[132] suggest that creating a credit-enhancement fund that, for a modest premium, shares the risk of default with the lender could enable private capital to flow into the energy efficiency market. Such an approach has proven successful in other markets, namely student loans and mortgages. According to the Congressional Budget Office, federal credit guarantees on student loans cost the government approximately 3 to 5 percent of the capital deployed.[133] At similar subsidy rates, it would cost $2 billion to $4 billion to provide credit guarantees for the $73 billion of capital needed for this cluster. Furthermore, combining this approach with alternative financing solutions, such as on-bill or tax-district financing, would also overcome agency barriers and provide a vehicle for monetary incentives through tax cuts or offsets to the principal amount. Load-serving entities and local distribution companies and utilities may face challenges internally with billing systems and with regulatory involvement in bill design, and it may not be appropriate in all service territories.
- **Provide monetary incentives** *(proven).* Government and non-government entities could provide monetary incentives to owners in several forms – tax credits, tax deductions, rebates, or accelerated depreciation. The federal government offers a tax deduction of up to $1.80 per square foot for new or renovated commercial buildings that are 50 percent more efficient than the ASHRAE 90.1-2001 standard.[134] Providing tiered incentives – a greater percent of initial investment for deeper retrofits – would help make the economics of deeper retrofits more attractive to building owners. Incentives for commercial equipment should be easy to access contemporaneously with building incentives given the connectedness of the decision process.

  Incentives may be effective within an organization as well. The retail chain JC Penney has begun communicating each store's energy performance rating across the management chain. The company ranks each store and region by energy use, sharing this information with store and regional managers, as well as corporate managers. The company has also begun to link management incentives to energy performance.[135]

A number of additional solution strategies could supplement the approaches outlined above but are not proven to work at scale in the market. Benchmarking would increase awareness by revealing relative performance of buildings of similar type, age, and

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[131] *Program on Housing and Urban Policy*, University of California, Berkeley, January 2009.

[132] Expert interviews.

[133] "Subsidy Estimates for Guaranteed and Direct Student Loans," Congressional Budget Office (CBO), November 2005. "Estimating the Value of Subsidies for Federal Loans and Loan Guarantees," CBO, August 2004.

[134] Energy Policy Act of 2005, subsequent legislation in 2008 extended the tax deduction until 2013.

[135] *The Power of Information to Motivate Change: Communicating the Energy Efficiency of Today's Commercial Buildings*, EPA, February 2009.

geography, as well as indicating sources of energy loss. Tools exist that can provide voluntary or mandatory ratings with or without public disclosure. For example, the EPA provides a free-of-charge benchmarking tool called the Portfolio Manager, which allows building owners or managers to track and benchmark several types of commercial buildings. Several utilities have also developed capabilities to directly upload building energy consumption information into the Portfolio Manager to enable benchmarking.[136] The District of Columbia and California currently require benchmarking and public availability of the results.[137]

Establishing policies or business models that encourage ESCOs to aggregate small building retrofits (i.e., less than 5,000 square feet) could address a particularly challenging 10 percent of overall commercial space. Commercial costs (e.g., administration, sales, EM&V) associated with performance contracting for small projects can be high, as much as 20 to 30 percent of project costs.[138] Aggregating smaller buildings under a single performance contract and/or verifying impact with random sampling across a portfolio rather than directly measuring all improved buildings could reduce these expenses to 5 to 10 percent of project costs[139] for MUSH-market or government owners. This approach might face additional challenges with small privately owned buildings due to disparate ownership. Direct-install programs managed by utilities or other third-party providers, for example, could provide a channel for this aggregation.

## 2. GOVERNMENT BUILDINGS

With 21.2 billion square feet of floor space, government buildings account for 1,180 trillion end-use BTUs of energy consumption in the 2020 reference case (Table 9). Offices and educational facilities together make up 63 percent of the space and 53 percent of total consumption in the cluster.

The incremental efficiency potential is greatest in local-level government buildings (260 trillion end-use BTUs), principally because local government buildings, which include a subset of schools, libraries, and administrative offices, hold 62 percent of government floor space. State buildings contain 100 trillion end-use BTUs of efficiency potential (Exhibit 25). Federal buildings, by contrast, offer the least efficiency potential, because they are the smallest in overall size and because the reference case includes a 30 percent reduction in their energy consumption by 2020, as mandated for all federal buildings by The Energy Independence and Security Act (EISA, 2007).[140] Unlocking the potential in local buildings would require $19 billion of upfront investment and provide present value savings of $36 billion. Unlocking the potential in state buildings would require $7 billion of upfront investment and provide present value savings of $13 billion.

Table 9: Government buildings

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | **Savings** Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 1,080 | 1,180 | 360 | 31 |
| ▪ Electricity TWh | 180 | 190 | 70 | 35 |
| ▪ Natural gas | 420 | 450 | 120 | 26 |
| ▪ Other fuels* | 70 | 70 | 10 | 22 |
| PRIMARY ENERGY Trillion BTUs | 2,360 | 2,590 | 860 | 33 |
| ▪ Electricity | 1,870 | 2,050 | 730 | 35 |
| ▪ Natural gas | 430 | 470 | 120 | 26 |
| EMISSIONS Megatons $CO_2e$ | 140 | 160 | 50 | 33 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $26 billion | PV of energy savings – 2009-2020: $49 billion | Annual energy savings – 2020: $5 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

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[136] *Utility Best Practices Guidance for Providing Business Customers with Energy Use and Cost Data*, EPA, November 2008.

[137] The State of California's AB 1103, 2007 legislation: <www.info.nse.ca.gov>. District of Columbia's Clean and Affordable Energy Act of 2008: <www.dccouncil.washington.dc.us>.

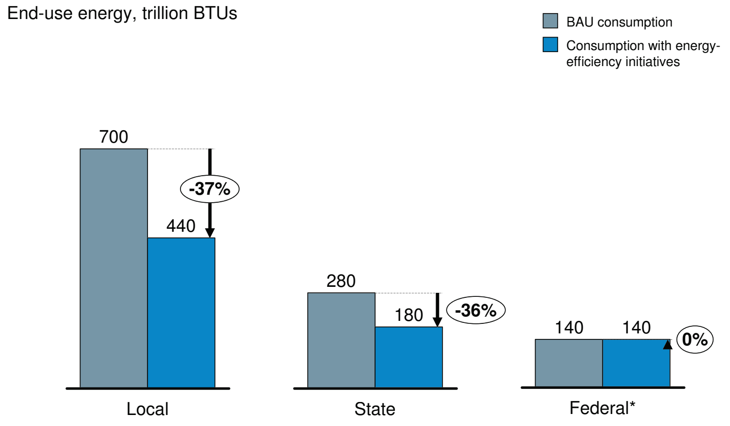
[138] Expert interviews.

[139] Expert interviews; based on aggregating 100 buildings of 5,000 square feet each in one contract.

[140] Energy Independence and Security Act of 2007. Though several state and some local governments have set energy efficiency targets, the reference case does not reflect those targets.

Exhibit 25: Energy potential in government buildings – 2020

The height of the columns represents energy consumption associated with local, state, and federal government buildings in 2020. The left column in each pair shows the BAU consumption forecast for 2020, and the right column displays the possible energy efficient consumption in 2020.



* Federal savings built into BAU
Source: EIA AEO 2008, McKinsey analysis

### Barriers to greater energy efficiency

Though significant efficiency potential exists in state and local government buildings, a few dominant barriers have limited the achievement of this potential:

- **Access to capital.** Public facilities often suffer from inadequate capital budgets for infrastructure improvements.[141] In some cases, demand for capital from state agencies can outweigh the ability of state governments to raise debt.[142] In other cases, administrators refuse to access debt due to concerns about debt ratings, because rating agencies may not provide credit for the savings generated through energy efficiency measures. [143] To warrant such treatment rating agencies require assurance that savings flow to the credit market rather than increased spending.
- **Impediments to performance contracting.** Many states limit the use or effectiveness of building retrofit solutions through performance contracting due to inconsistent regulatory support. Challenges range from constraints on the financial treatment of lifecycle benefits – which can inhibit capture of the full potential,[144, 145] to accounting rules that limit debt payments from operational savings, to inadequate administrative support or expertise to evaluate or manage pursuit of the opportunity.
- **Lack of awareness.** Many facility managers are unaware of current energy consumption, because centralized departments often pay utility bills. Furthermore, they often possess limited knowledge of energy efficiency measures and ways to deploy them within their facilities.[146]

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[141] Nicole Hopper, et al., *Public and Institutional Markets for ESCO Services: Comparing Programs, Performances and Practices*, LBNL, March 2005.

[142] Ranjit Bharvirkar, et al., *Performance Contracting and Energy Efficiency in the State Government Market*, LBNL, November 2008.

[143] Expert interviews.

[144] Nicole Hopper, et al., *Public and Institutional Markets for ESCO Services: Comparing Programs, Performances and Practices*, LBNL, March 2005.

[145] Ranjit Bharvirkhar, et al., *Performance Contracting and Energy Efficiency in the State Government Market*, LBNL, November 2008. In a sample of 12 states, 8 had maximum contract periods less than the federal maximum allowed length of 25 years.

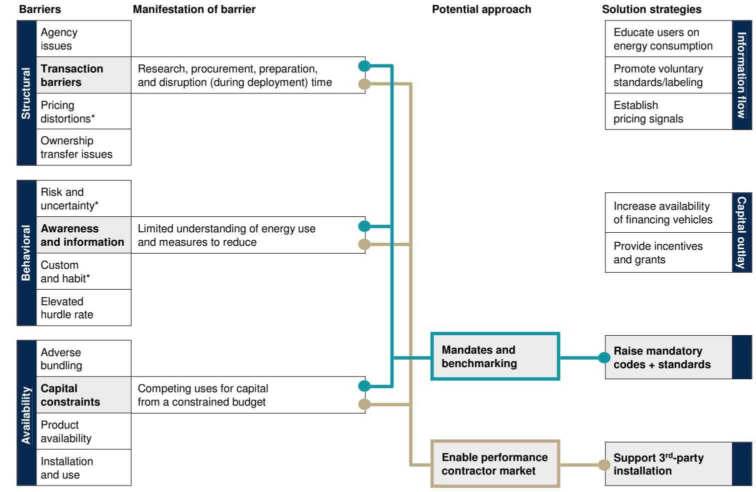
[146] Ranjit Bharvirkar, et al.

Additional barriers include perceptions of risk or uncertainty associated with behavior change or equipment substitution; pricing distortions due to the more favorable rates that are enjoyed by schools and government buildings, making energy efficiency less cost-effective despite its availability; and institutional, allocation, or bureaucratic challenges that limit the ability to act, even when a decision is made to move forward.

### Solution strategies to unlock potential

Addressing the major barriers within this cluster will require increasing the focus on and resources deployed toward energy efficiency at all levels of government, while partnering with the private sector to assist in its capture (Exhibit 26).

Exhibit 26: Addressing barriers in government buildings



* Represents a minor barrier
Source: McKinsey analysis

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

- **Mandate benchmarks or standards** *(piloted)*. Benchmarking performance and setting mandatory standards are a means to increase institutional focus on efficiency capture. To date, twenty-eight[147] state governments have mandated efficiency targets for state government buildings that target up to a 35 percent reduction in energy use over the next decade in an attempt to "lead by example." Drawing on energy performance benchmarking, for example, Council Rock School District in Pennsylvania was able to improve its average EPA energy performance rating from a 16 (fourth quartile) to 55 (second quartile) within 2 years.[148] The District of Columbia has begun requiring that commercial buildings rate their energy performance and disclose their performance to the public.[149]

  Nonetheless, translating these state aspirations to local governments is often a challenge. A process used in Texas could serve as a useful model: bills passed in 2001 and 2007 require all state agencies and "all political sub-divisions" – including counties, public school districts, and higher education institutions – to reduce energy consumption by 5 percent annually for 6 years. Results so far are inconclusive; however, a sampling of sub-divisions suggests an average consumption decrease of

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[147] Expert interviews.

[148] *The Power of Information to Motivate Change: Communicating the Energy Efficiency of Today's Commercial Buildings*, EPA, February 2009.

[149] The District of Columbia's Clean and Affordable Energy Act of 2008: <www.dccouncil.washington.dc.us>.

14 percent.[150] A second model, effectively used by the U.S. Department of Transportation with highway funding, could make the receipt of federal funding (e.g., Weatherization Assistance Program) contingent on state or local action on efficiency targets for government buildings.

- **Address regulations that inhibit performance contracting** *(emerging).* In capturing the full potential of energy efficiency available, state and local governments will benefit from effectively partnering with the private sector. Potential actions include developing a streamlined process for performance contracting, allowing aggregation of multiple buildings in a single contract, clarifying accounting rules, and creating an approved list of eligible service providers. Details of this approach lie in the above cluster's description. In addition, state and local governments could require procurement departments to evaluate bids based on lifecycle costs rather than initial costs. Finally, they could designate champions of performance contracting to provide strong executive support, an approach proven to increase penetration of energy efficiency solution strategies.[151]

Additional solution strategies could play an important enabling role. Collaborating with rating agencies to convey the impact of debt incurred for energy efficiency improvements on the credit ratings of participating governments could facilitate allocation of capital, as would earmarking capital for energy efficiency projects. Further opportunities exist to leverage federal allocations (e.g., State Energy Plan and Energy Efficiency Conservation Block Grants) to maximize the impact of collective funding. Finally, federal matching grants could reduce capital requirements and enable state and local governments to pursue this opportunity.

## 3. PRIVATELY OWNED NEW BUILDINGS

New buildings (i.e., constructed in 2009 and later) will add an average of 1.3 billion square feet per year to the stock of privately owned commercial floor space, representing 27 percent of all privately owned commercial floor space in 2020 and 41 percent in 2030.

Table 10: New private buildings

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | **Savings** Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | n/a | 1,060 | 270 | 25 |
| ■ Electricity TWh | n/a | 160 | 50 | 30 |
| ■ Natural gas | n/a | 460 | 90 | 21 |
| ■ Other fuels* | n/a | 40 | 10 | 25 |
| PRIMARY ENERGY Trillion BTUs | n/a | 2,260 | 620 | 28 |
| ■ Electricity | n/a | 1,750 | 520 | 30 |
| ■ Natural gas | n/a | 470 | 100 | 21 |
| EMISSIONS Megatons $CO_2e$ | n/a | 140 | 40 | 28 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $15 billion | PV of energy savings – 2009-2020: $35 billion | Annual energy savings – 2020: $4 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

Privately owned new buildings offer NPV-positive energy efficiency potential of 270 trillion end-use BTUs (Table 10). The incremental capital cost of capturing this potential is $15 billion but would provide present-value savings of $35 billion. This cluster offers only 12 percent of the commercial-sector efficiency potential in 2020, because buildings constructed between 2009 and 2020 are forecast to account for only 27 percent of all floor space in 2020 and are expected to be more efficient than existing buildings. Nonetheless, new construction will be an increasingly important opportunity through 2030 and beyond, as the share of building stock constructed after 2009 grows. Furthermore, incorporating

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150 Half the subdivisions showed an increase in energy consumption and half showed a decrease. Median value was an increase in consumption of 3 percent; weighted average value was a decrease in consumption of 14 percent; range in percentage change in consumption was +1,514 percent to -77 percent. These results were not normalized for floor space or other changes.

151 Ranjit Bharvirkar, et al., *Performance Contracting and Energy Efficiency in the State Government Market,* LBNL, November 2008.

energy efficiency measures into new buildings during initial design is attractive as it costs five times as much ($3.83 per square foot compared to $0.76 per square foot) to incorporate the same measures as a retrofit. If the nation ignored the opportunity to capture efficiency potential in "new" buildings through 2020, retrofitting the buildings after they are built, capturing the same potential would cost an additional $48 billion and would likely not be cost effective.

Deployment of more energy efficient lighting and appliances accounts for 110 trillion end-use BTUs of potential in this cluster. Though such building codes as ASHRAE 90.1 specify the range of code-compliant HVAC and lighting equipment, developing federal standards for such equipment would facilitate the capture of energy efficiency potential in two ways: it would address the new-build market in states with no building codes and address the replacement (natural end-of-life or accelerated replacement) in existing buildings in all states.

### Barriers to capturing efficiency potential in new buildings

There are two noteworthy barriers that solutions must address:

- **Lack of incentives for developers to build energy efficient buildings.** Because developers do not receive the future energy savings from energy efficient buildings and are often unaware or uncertain of the market premium energy efficient buildings can command, developers have little financial incentive to invest in energy efficiency above the required minimum level.[152] As a result, inclusion of energy efficient options in new buildings may be undermined by tradeoffs in favor of more visible features (e.g., granite flooring, upgraded facilities).
- **Ineffective installation and lack of commissioning.** Developers have little incentive to ensure that contractors install equipment optimally or commission buildings properly. As a result, some buildings perform below the levels called for in building codes: research has found that as many as 20 to 30 percent of buildings designed to meet the ASHRAE 1999 standard did not meet building shell and lighting requirements. However, most buildings designed to meet 1989 standards met or exceeded those specifications.[153] Similarly, non-compliance rates in California for more stringent codes have been reported to be greater than 40 percent.[154]

A range of minor barriers can also inhibit capture of these opportunities. Limited market information to help inform equipment purchasing decisions or floor space selection, concerns over quality of building practices, and limited supply of efficient commercial floor space represent the most encountered minor barriers.

### Solution strategies to unlock potential in new buildings

Given the relative cost-benefit of capturing energy efficiency in the design and construction phases and the perishability of these options, this cluster is among the most important for near-term action (Exhibit 27).

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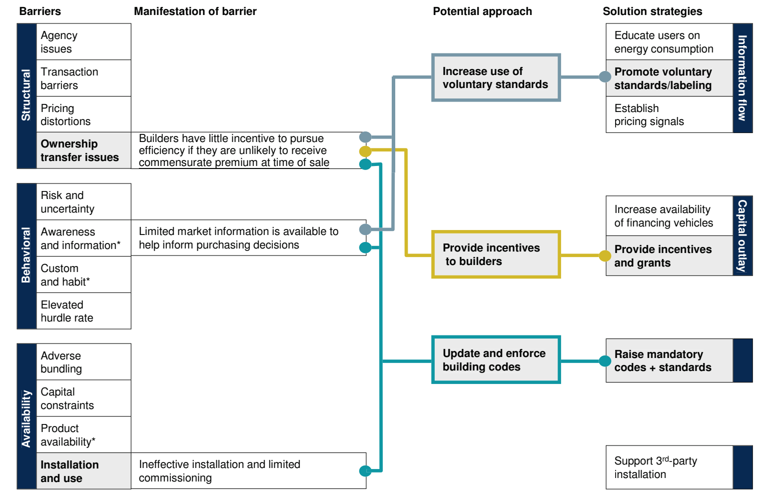
[152] Jens Lausten, *Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings*, International Energy Agency, March 2008.

[153] Eric Richman, et al., "National Commercial Construction Characteristics and Compliance with Building Energy Codes: 1999-2007," *Summer Study on Energy Efficiency in Buildings*, ACEEE, 2008.

[154] M. Sami Khawaja et al., "Statewide Codes and Standards Market Adoption and Noncompliance Rates," Southern California Edison, May 2007.

Exhibit 27: Addressing barriers in new private buildings

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.



* Represents a minor barrier
Source: McKinsey analysis

- **Mandatory building codes** *(proven).* As is true within the residential sector, mandatory codes for new buildings can overcome all barriers by circumventing the end-user's decision-making process. Three complementary actions would increase building code impact:

  — **Adopting the latest energy efficiency building codes.** Only two states have adopted the latest commercial building code, while 13 states have either not adopted a statewide code or continue to use codes that are three or more generations behind (Exhibit 28).[155] The 2007 ASHRAE standard represents a 32 percent efficiency improvement over the 1980 level. States adopting the most recent ASHRAE Standard, 90.1-2007, would reduce energy consumption in new buildings by 11 percent relative to current code levels. In 2020, capturing this improvement would produce 110 trillion end-use BTUs of energy savings, 5 percent of the annual commercial-sector potential that year. Furthermore, if ASHRAE Standard 90.1-2007 were adopted through 2011 and a 30 percent improved code were adopted in 2012, 270 trillion end-use BTUs could be saved in 2020, or 12 percent of annual commercial-sector potential that year.[156] As discussed in the residential section, two options emerge that can overcome the challenge of getting states to adopt the latest codes. Focusing on education for state officials and building departments, and making accessibility of some federal funds contingent on building code stringency could enable increased state adoption of the latest building codes.

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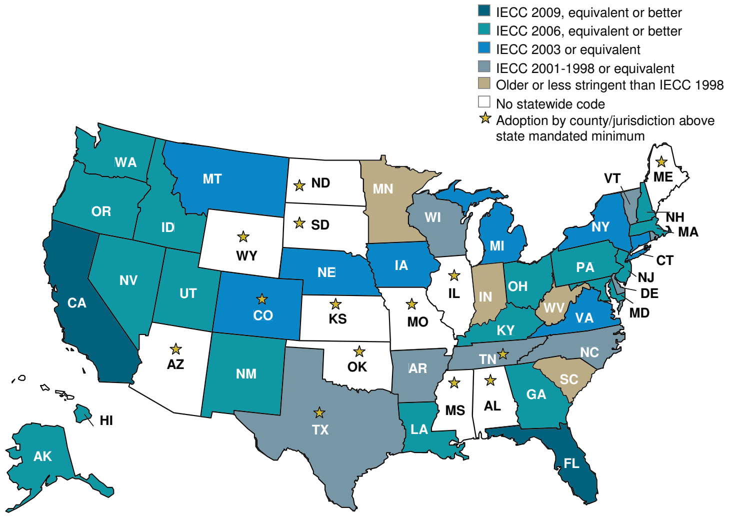
[155] "Building Energy Data Book, Table 5.1.5," EERE, March 2009. < http://buildingsdatabook.eren.doe.gov>.

[156] Expert interviews.

Exhibit 28: Inconsistency of commercial building codes



Source: Buildings Energy Databook, US Department of Energy, Office of Energy Efficiency and Renewable Energy

The map displays the variation in commercial new building codes in place across the United States. In general, darker shades indicate higher standards, and lighter shades indicate less stringent standards, in line with the legend in the top right of the exhibit.

— **Developing more energy efficient codes:** Opportunities exist to advance codes beyond their 2009 levels while maintaining use of cost-effective technology. Current efforts are underway to redesign the ASHRAE code to achieve a 30 percent reduction over 2004 levels – a reduction thought to be cost-effective using existing technologies at current costs.

— **Improving compliance with mandatory codes:** Improving code compliance is an important lever in enabling the effectiveness of mandatory building codes. State support for increased enforcement through various actions as discussed in the residential section would ensure that adopted codes are effective. Experts estimate the incremental annual cost of sufficient enforcement to assure compliance at $1 billion.[157]

- **Broaden mandatory appliance standards** *(proven).* Similar to building codes, equipment standards can overcome all barriers. The Department of Energy provides federal standards for 20 commercial equipment categories, with standards for another seven categories in development.[158] There are no federal energy performance standards, however, for some types of HVAC equipment and some other commonly used appliances.

- **Drive market change through voluntary standards** *(piloted).* Market penetration of voluntary standards in new buildings directly increases awareness and can overcome the agency barrier by increasing the likelihood that a building will gain a premium. Though penetration has been limited,[159] recent trends suggest it is increasing. Targeted awareness programs to educate developers and buyers of commercial buildings would accelerate this process. Universal adoption of these

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[157] David Goldstein and Cliff Majersik, "NRDC/IMT Proposal for Improved Building Energy Code Compliance through Enhanced Resources and Third-Party Verification," NRDC, 2009. The $1 billion is the total for both residential homes and commercial buildings.

[158] Appliance Standard Awareness Project <www.standardsASAP.org>

[159] USGBC has awarded LEED certifications to 14.3 million square feet of commercial building space since 2003 (0.1 percent of the space constructed over this period), while in 2008, 130 new buildings (0.1 percent) achieved the "Designed to earn ENERGY STAR" label.

standards would yield energy savings of 260 trillion end-use BTUs in 2020, some 11 percent of overall commercial-sector potential that year.[160]

- **Provide education and monetary incentives** *(proven).* Builder subsidies would overcome agency issues by allowing builders to recover costs other than through the buyer. The incremental cost of constructing energy efficient buildings is approximately $1.08 per square foot, a 0.5 percent increase over standard practices. Educating developers on the actual incremental costs and the associated building techniques could increase the rate of adoption at relatively low cost. Alternatively, if the government or another agent provides an incentive of $1.08 per square foot to developers, it would cost $1.9 billion annually to capture the full potential.

## 4. OFFICE AND NON-COMMERCIAL DEVICES

Electricity consumption from office and non-commercial devices is growing at a rate of 3.6 percent per year. This cluster is forecast to consume 1,980 trillion end-use BTUs in 2020, consisting entirely of 580 TWh of electricity (Table 11).

The efficiency potential in this cluster is highly fragmented across hundreds of device categories. At $2.70 per MMBTU of end-use energy, however, the opportunity is among the most cost effective. This cluster could contribute 570 trillion end-use BTUs of NPV-positive potential, assuming an estimated upfront investment of $8 billion and provide present-value savings of $57 billion. Equipment groups fall into three broad categories: office equipment, miscellaneous commercial load, and data centers:

Table 11: Office and non-commercial devices

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 1,290 | 1,980 | 570 | 29 |
| ■ Electricity TWh | 380 | 580 | 170 | 29 |
| ■ Natural gas | n/a | n/a | n/a | n/a |
| ■ Other fuels* | n/a | n/a | n/a | n/a |
| PRIMARY ENERGY Trillion BTUs | 4,010 | 6,160 | 1,760 | 29 |
| ■ Electricity | 4,010 | 6,160 | 1,760 | 29 |
| ■ Natural gas | n/a | n/a | n/a | n/a |
| EMISSIONS Megatons $CO_2$e | 250 | 380 | 110 | 29 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $8 billion | PV of energy savings – 2009-2020: $57 billion | Annual energy savings – 2020: $11 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

- Office equipment includes dozens of device categories, in broad terms, PCs (including desktop computers, laptop computers) and non-PCs (such as servers, printers, fax machines, multi-function devices, and phones).
- Miscellaneous commercial load includes some 100 equipment categories, with two broad sub-groups:
  - Commercial equipment including specialized devices such as MRI machines, X-ray machines, other medical and laboratory equipment, cash registers and surveillance systems.
  - Residential devices present in commercial settings including equipment categories such as refrigerators, coffee makers and water coolers.
- Data-centers consist of servers, auxiliary data equipment, and supporting power systems (e.g., uninterruptable power supplies); potential associated with energy efficient cooling and lighting is contained in the private and government building clusters. However they bear special attention as data center energy use is expected to

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[160] ENERGY STAR labeled buildings perform on average 35 percent better than the average building in CBECS 2003 from expert interviews. New buildings are better than CBECS average by 13 percent from B. Griffith et al., *Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector*, NREL, 2007. This leads to net benefits of 24 percent.

grow 9.6 percent per year from a base of 200 trillion end-use BTUs in 2008 to 600 trillion end-use BTUs in 2020.[161]

### Barriers to capturing efficiency potential

The energy consumed by each device in this cluster is small and therefore of relatively little concern to consumers and manufacturers. While there are necessarily many barriers of lesser importance that impact this cluster, we have elevated three for particular consideration:

- **Low awareness.** This cluster may account for as much as 25 percent of total electricity consumption in the commercial sector in 2020; however, each category of devices represents a tiny share of an enterprise's overall electric bill. As a result, the efficiency potential in this cluster receives little attention, as discussed in the section on residential plug-load. Lack of attention is compounded by insufficient or buried information about the energy consumption of these devices, often making the transaction "cost" of identifying lifecycle benefits prohibitively large relative to the savings. Additionally, proper usage of energy efficiency settings presents a minor barrier similar to that facing the electrical devices and small appliances cluster in the residential sector.
- **Manufacturer limitations.** Consumers and businesses tend to value other attributes (e.g., price, screen resolution, print quality) above energy efficiency, thus affecting end-user purchasing processes.[162] This makes manufacturers' ability to receive compensation for energy efficient devices unclear (a type of ownership transfer barrier), which impacts design decisions.
- **Practical availability.** Restricted procurement selection, consumer focus on acquisition rather than lifecycle costs, and distributed budget responsibility within an organization (e.g., separation of upfront purchasing concerns from long-term energy budget responsibility) limit availability of efficient technology. Adverse bundling of efficiency with other features can also present a barrier for some devices.

Data centers face a similar set of barriers. Low awareness of energy usage (and the expertise to capture substantial efficiency potential) persists among operators of smaller data centers, though operators of enterprise-class centers are increasingly focusing on managing power consumption.[163] Furthermore, data centers tend to focus on acquisition cost rather than total lifetime cost, and they may be concerned about perceived quality trade-offs, such as concerns about reliability, due to risk aversion. With this mind-set, developers and data center operators tend to over-invest in servers, resulting in low server utilization, with as many as 30 percent of servers consuming electricity but serving a limited useful business purpose with less than 3 percent average daily utilization.[164]

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[161] "Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431", EPA, Aug 2007. Expert interviews.

[162] "Going Green: An Examination of the Green Trend and What it Means to Consumers and the CE Industry," Consumer Electronics Association, 2008.

[163] Expert interviews.

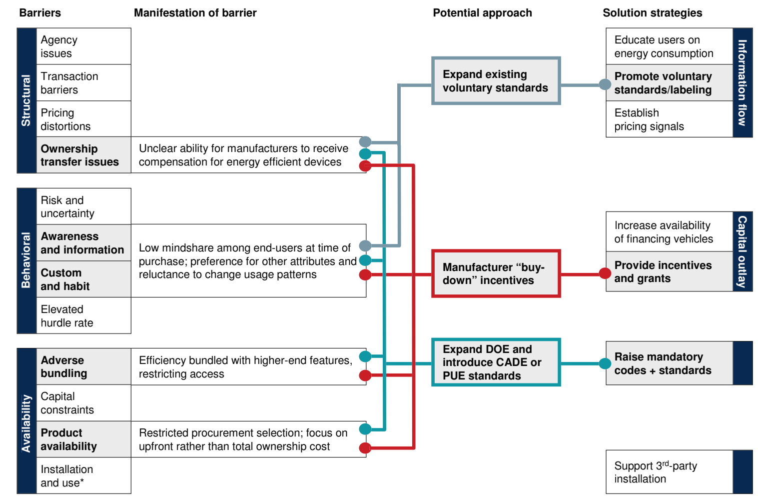
[164] "Revolutionizing Data Center Energy Efficiency," McKinsey & Company, 2008.

## Solution strategies to unlock potential in office and non-commercial devices

Capturing the potential opportunity from a distributed group of actors where energy efficiency is only a minor factor in the decision-making process may require a certain degree of intervention, but it may be supplemented by harnessing competitive market forces to drive improvements over time. Several solutions emerge as possibilities (Exhibit 29).

Exhibit 29: Addressing barriers in office and non-commercial devices

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.



* Represents a minor barrier
Source: McKinsey analysis

- **Introduce or expand mandatory minimum standards** *(proven).* Expanding the equipment categories for which the DOE sets standards would enable greater energy efficiency. Within this cluster, three equipment categories have federal mandatory standards, leaving most categories unaddressed.[165] It is important to note that technology in this area advances rapidly, making the task of setting standards without stifling market innovation quite challenging. It is worth noting that a standby standard for electric devices used in residential settings would have further impact in this cluster. However, due to extremely limited data on commercial office equipment, it is difficult to determine impact of such a standby standard.[166]

  For data centers, one potential approach is to set Corporate Average Data-Center Efficiency (CADE) or Power Usage Effectiveness (PUE) standards. In addition, creation of cross-cutting standby standards, as discussed in the residential section, would have a spillover effect to this cluster.

- **Voluntary standards** *(proven).* ENERGY STAR currently covers 12 product categories in this space and reported energy savings in 2008 of 52 TWh.[167] The EPA is developing a benchmarking tool for data centers through its Portfolio Manager.[168] In addition, the impact of solution strategies considered in residential lighting and appliances and electrical devices would also increase potential in this cluster.

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[165] Expert interviews.

[166] Further research would be required to dimensionalize commercial office equipment and determine potential impact of a standby standard.

[167] Expert interviews.

[168] "ENERGY STAR Data Center Infrastructure Rating," EPA, 2008.

Additionally, supporting solution strategies could include providing manufacturers or distributors incentives to decrease the incremental cost of producing energy efficient equipment or providing procurement departments with more information on lifetime costs.

## 5. COMMUNITY INFRASTRUCTURE

In 2008, 11 percent (750 trillion end-use BTUs) of commercial-sector energy consumption occurred in community infrastructure (Table 12) – settings not normally associated with buildings: street and other outdoor lighting, water services, and telecom infrastructure (including mobile phone base stations).[169] Overall consumption in this cluster is forecast to grow at an annual rate of 1.8 percent.

Community infrastructure could provide 290 trillion end-use BTUs of NPV-positive potential in 2020; unlocking this potential would require upfront investment of $4 billion and provide present-value savings of $45 billion. The potential resides in several sub-categories: street/other lighting (43 percent), water services (12 percent), telecom network (25 percent), and other electricity consumption (20 percent). End-uses and facilities managed by local governments account for 200 trillion end-use BTUs of the potential, while end-uses and facilities managed by private-sector entities make up 90 trillion end-use BTUs of the potential.

Table 12: Community infrastructure

| | Energy use – 2008 | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 750 | 930 | 290 | 31 |
| ■ Electricity TWh | 220 | 270 | 80 | 31 |
| ■ Natural gas | n/a | n/a | n/a | n/a |
| ■ Other fuels* | n/a | n/a | n/a | n/a |
| PRIMARY ENERGY Trillion BTUs | 2,320 | 2,890 | 890 | 31 |
| ■ Electricity | 2,320 | 2,890 | 890 | 31 |
| ■ Natural gas | n/a | n/a | n/a | n/a |
| EMISSIONS Megatons $CO_2e$ | 150 | 180 | 60 | 31 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $4 billion | PV of energy savings – 2009-2020: $45 billion | Annual energy savings – 2020: $5 billion |

* End-use energy is approximated as equivalent to primary energy

Source: EIA AEO 2008, McKinsey analysis

### Barriers to capturing the efficiency potential

The prevailing barriers in this cluster vary by ownership category. Local governments typically own water service facilities and often (but not always) own street lighting, while private-sector entities own telecom infrastructure. Water service facilities and street lighting (when owned by government) face barriers typical of government buildings, namely capital availability and inconsistent regulatory support for performance contracting. Street lighting, when owned by the utility, may encounter agency issues. Common barriers affect all three categories of community infrastructure:

- **Risk aversion.** Many operators are risk averse and put a premium on reliability; they may not be inclined to pursue energy efficiency activities for fear of disrupting essential services.[170]
- **Lack of performance awareness or accountability.** Water operators typically manage to such metrics as discharge level and water quality; energy efficiency is not usually a metric for which they are accountable.[171] Similarly, telecom infrastructure is geographically dispersed and budget ownership within an organization is often fragmented, both of which introduce management challenges. As a result, operators often do not have a consolidated view of the energy consumption they manage.[172] Finally, other considerations, such as equipment features (e.g., flexibility, backward compatibility, vendor compatibility), may take precedence over energy efficiency.[173]

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[169] We have excluded natural gas and distillate fuel oil consumption (1,350 trillion end-use BTUs in 2020) attributed to community infrastructure and miscellaneous load in *AEO 2008* due to lack of information about the sources of consumption and the efficiency opportunities.

[170] Expert interviews.

[171] Expert interviews.

[172] Expert interviews.

[173] Expert interviews.

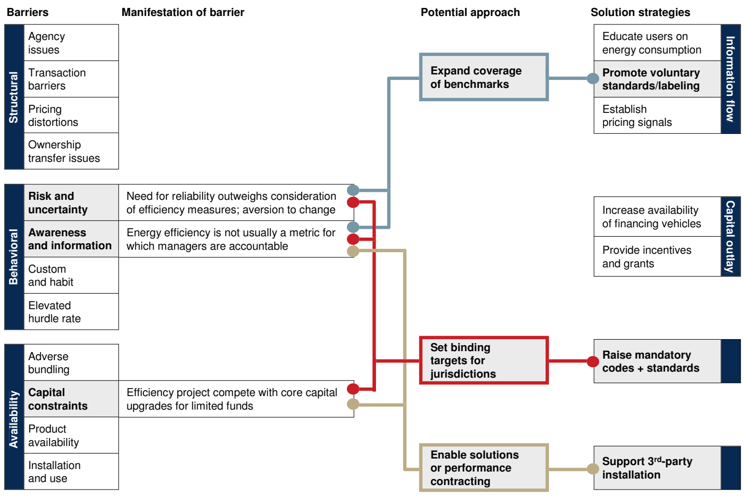
- **Competing uses for capital.** Energy efficiency projects may compete for capital with core business projects, such as upgrades to the next-generation mobile technology[174] or new lighting capacity additions.

### Solution strategies to unlock potential in community infrastructure

Several solution strategies can address one or more of the barriers affecting community infrastructure efficiency potential (Exhibit 30). The relative emphasis for each measure may differ based on the type of community infrastructure addressed.

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

Exhibit 30: Addressing barriers in community infrastructure



Source: McKinsey analysis

- **Benchmark energy consumption** *(piloted).* Expanding existing benchmarking tools, such as the EPS's Portfolio Manager, to include water distribution facilities, street lighting, and distributed telecom infrastructure would help provide a voluntary standard for 230 trillion end-use BTUs of potential or 79 percent of total potential in this cluster. Such benchmarks should normalize for differences, especially if addressing telecom base stations where technology generation, supported bandwidth, voice and data usage, encryption level, and geographical spread of consumers served could significantly impact benchmark definition.
- **Set binding targets** *(piloted).* State and local governments could mandate energy efficiency targets for water services and street lighting, by expanding existing programs.[175] Energy efficiency measures in water services could yield savings of 10 to 30 percent and would include retrofitting facilities with more efficient pumps and motors, incorporating variable frequency motors, installing dissolved oxygen sensors for the aeration process, and installing a system for overall plant monitoring and control.[176]
- **Enable performance contracting** *(emerging).* Water treatment and street lighting would benefit from regulatory changes that would facilitate performance contracting, as discussed for government buildings.

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[174] Expert interviews.

[175] See, for instance, EPA ENERGY STAR Challenge for water systems. <www.energystar.gov>.

[176] Richard Brown, "Energy Efficiency and Renewable Energy Technologies in Wastewater Management," testimony before House Subcommittee on Water Resources and Environment, 4 February, 2009.

Other enabling solution strategies include capturing available funds[177] and improving training by including efficiency within existing EPA guidelines for periodic training and certification. To support these solution strategies, fund regulators could make full access to available funds contingent in part on fulfillment of a training requirement.

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[177] Water treatment facilities can access existing funds for energy efficiency improvements, including State Energy Program, Energy Efficiency Conservation Block Grant, Drinking Water State Revolving Fund, and Clean Water State Revolving Fund.

# 4. Approaches to greater energy efficiency in the industrial sector

The industrial sector will consume 51 percent of the 2020 baseline end-use energy in the United States, equivalent to 20.5 quadrillion BTUs of end-use energy. The industrial sector offers 3,650 trillion end-use BTUs of NPV-positive energy efficiency potential, equivalent to 18 percent of its forecast energy consumption in 2020 (Table 13).[178] Capturing this potential would save $47 billion per year in energy costs, though between 2009 and 2020 it would require present value investment of $113 billion yielding total present-value savings of $442 billion.[179] It is noteworthy that energy consumption and potential in the industrial sector remains considerably more regionalized than in the residential or commercial sectors: the South, for instance, contains 50 percent of consumption and 49 percent of the efficiency potential.

Energy consumption in the industrial sector (as examined in this report) is forecast to grow by 0.5 percent per year, reaching 20,530 trillion end-use BTUs in 2020. This rate is slower than expected GDP growth because of 3 to 14 percent improvements anticipated in energy-intensive industries (i.e., cement, chemicals, iron and steel, pulp and paper, and refining).[180]

Table 13: Overview of energy use in the industrial sector

| | Energy use – 2010*** | BAU energy use – 2020 | Savings due to EE – 2020 | **Savings** Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 19,290 | 20,530 | 3,650 | 18 |
| ■ Electricity TWh | 1,090 | 1,050 | 190 | 18 |
| ■ Natural gas | 5,370 | 5,850 | 1,040 | 18 |
| ■ Other fuels* | 10,200 | 11,090 | 1,970 | 18 |
| PRIMARY ENERGY Trillion BTUs | 27,320 | 28,320 | 5,030 | 18 |
| ■ Electricity** | 11,540 | 11,150 | 1,980 | 18 |
| ■ Natural gas | 5,580 | 6,080 | 1,080 | 18 |
| EMISSIONS Megatons $CO_2e$ | 1,660 | 1,710 | 300 | 18 |

| PV of upfront investment – 2009-2020: $113 billion | PV of energy savings – 2009-2020: $442 billion | Annual energy savings – 2020: $47 billion |
|---|---|---|

* End-use energy is approximated as equivalent to primary energy

** Does not include CHP savings of 910 trillion BTUs

*** 2010 is used throughout this chapter due to data availability

Source: EIA AEO 2008, McKinsey analysis

The energy intensity of production in industrial subsectors varies widely, from 52.3 end-use BTUs per dollar of value added in cement production to 0.4 end-use BTUs per dollar in

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[178] The industrial sector as a whole is projected to consume 25,820 trillion BTUs of end-use energy in 2010. We excluded transport fuel (1,380 trillion end-use BTUs) and asphalt consumed by the construction sector (1,080 trillion end-use BTUs), as well as chemical feedstock (4,080 trillion end-use BTUs), identifying potential efficiency in the remaining 19,290 trillion BTUs of end-use consumption.

[179] This does not include primary energy potential of 1.4 quadrillion BTUs from industrial and commercial CHP, which is discussed later in the chapter.

[180] For the purposes of this report energy-intensive industries include those requiring intensities above 10 BTUs per dollar of value added: cement, bulk chemicals, refining, iron and steel production, and pulp and paper. See Exhibit 28 for a list of sectors. We excluded aluminum and glass products due to their low total consumption and mining as its consumption is primarily driven by transportation.

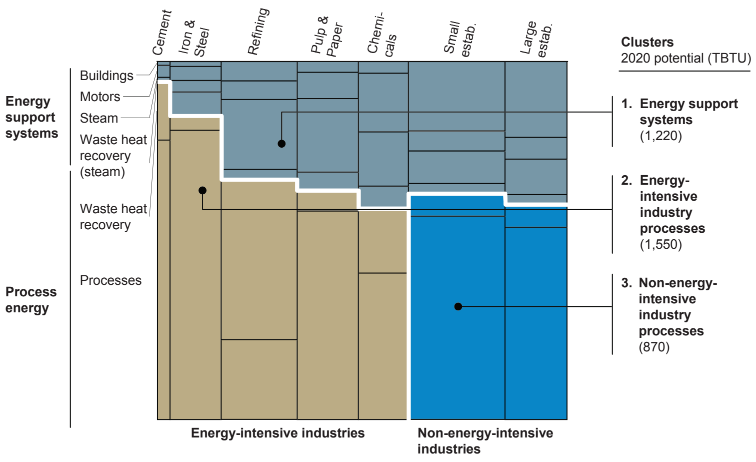
computer assembly. We found that opportunities for energy efficiency are highly fragmented across subsector-specific process steps (e.g., pulping and bleaching in pulp and paper, clinker production in cement, and secondary hot rolling in iron and steel), which represent 67 percent of the potential. Cross-cutting energy support systems, such as steam systems, motors, and buildings, represent the remaining 33 percent of the potential. Sixty-one percent of the total opportunity resides in energy-intensive sectors, with 39 percent in non-energy-intensive sectors. In addition to these energy efficiency initiatives, NPV-positive deployment of combined heat and power systems could increase from 85 GW in 2008 to 135 GW in 2020, representing a substantial opportunity to increase efficiency in primary energy and drive 1,390 trillion BTUs of primary-energy savings, reduce facility-level energy costs by $77 billion, and abate greenhouse gas emissions by 100 megatons of $CO_2$e.

We have divided the industrial sector into four clusters (Exhibit 31). Unlike the residential and commercial sectors, the three end-use clusters in the industrial sector share similar barriers and solutions, while CHP, which generates electricity and thermal energy from a single fuel source, stands apart. Therefore, we will group the three energy-use clusters into a single discussion and address CHP separately.

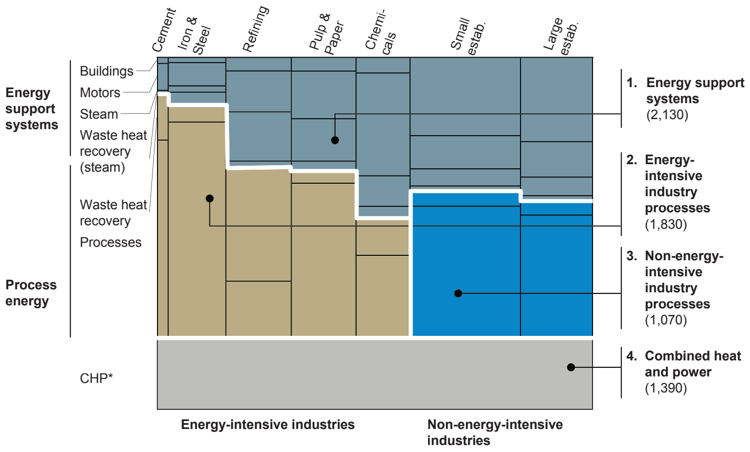
Exhibit 31: Clusters of energy efficiency potential in the industrial sector

The upper and lower charts break out the energy efficiency potential in 2020 for the industrial sector in end-use and primary energy respectively. Each area represents a cluster of efficiency potential: the area is proportional to the relative share (of total potential in the sector) associated with that cluster, while the number next to the cluster name provides the efficiency potential, measured in trillion BTUs.

Enduse energy, avoided consumption; total = 3,650 trillion BTUs



Primary energy, avoided consumption; total = 6,420 trillion BTUs



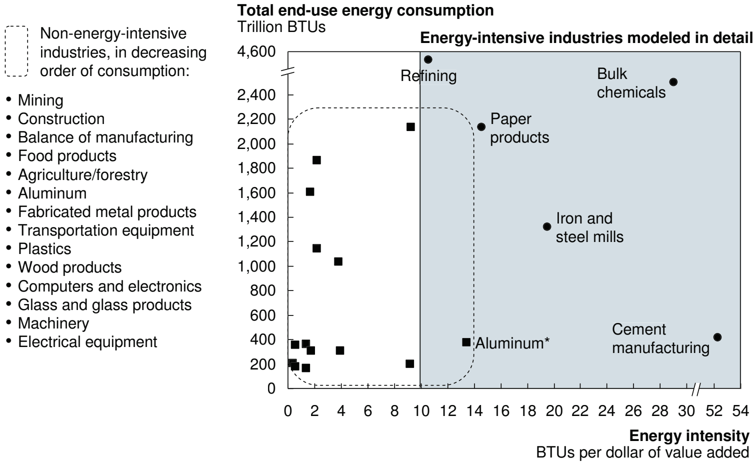
* CHP also includes 490 TBTU of potential from CHP in commercial uses

Source: EIA AEO 2008; McKinsey analysis

## EFFICIENCY POTENTIAL IN INDUSTRIAL ENERGY CONSUMPTION

The energy-savings potential in the industrial sector divides into three clusters: energy support systems, process energy in energy-intensive industries (with 10 or more end-use BTUs per dollar of value added), and process energy in non-energy-intensive industries (with less than 10 end-use BTUs per dollar of value added). The energy support systems cluster (1,220 trillion end-use BTUs of potential) consists of steam systems, motor systems, and buildings that support manufacturing processes (but are not core to those processes) across all industrial subsectors; it also includes waste heat recovery from these systems, specifically steam system waste heat. Energy-intensive industry processes (1,550 trillion end-use BTUs of potential) include process energy and process system waste heat recovery. Non-energy-intensive industry processes account for some 870 trillion end-use BTUs of potential (Exhibit 32).[181] Given differences in the nature of the potential, we will describe the potential for each cluster before describing the barriers to greater efficiency and potential solutions to those barriers.

Exhibit 32: Industries modeled for energy efficiency potential



* Despite presenting an energy intensity above 10 BTU per dollar of value added it is modeled with non-energy intensive given its small total energy consumption of only 370 trillion BTUs

Source: EIA AEO 2008, McKinsey analysis

Each dot represents an industry in the U.S., with its position on the horizontal axis corresponding to the energy intensity (measured in BTUs of end-use energy consumed per dollar of value created) for the industry and its position on the vertical axis corresponding to its total end-use energy consumption in 2008. Industries having a dot (as opposed to a square) within the shaded area were modeled in detail for this report.

### Energy support systems

Industrial energy support systems consist of steam systems, motor systems, and building infrastructure (i.e., lighting and space conditioning). These systems are forecast to consume 8,540 trillion end-use BTUs of energy in 2010, with consumption forecast to grow at 0.3 percent annually to 8,800 trillion end-use BTUs in 2020 (Exhibit 33). These systems offer 1,220 trillion end-use BTUs of NPV-positive efficiency potential in 2020, requiring an estimated upfront investment of $34 billion and generating present value savings of $164 billion (Table 14).

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[181] Though aluminum requires 13.5 BTUs of energy input per dollar of value added, it represents a small subsector in the U.S. economy (370 trillion end-use BTUs) and is therefore grouped among non-energy-intensive subsectors.

- **Steam systems.** These systems (e.g., steam generation [boilers], distribution, and condensate-recovery systems) are projected to consume 5,360 trillion end-use BTUs of energy and provide 460 trillion end-use BTUs of potential in 2020, with petroleum accounting for 35 percent of the potential, natural gas 35 percent, and other fuels 30 percent. Efficiency measures include waste heat recovery (i.e., from boiler exhaust and waste gases and liquids), which would provide an additional 150 trillion end-use BTUs of potential, steam trap maintenance, insulation of distribution systems, and valve and fitting improvements.

Table 14: Energy support systems

| | Energy use – 2010** | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 8,540 | 8,800 | 1,220 | 14 |
| ■ Electricity TWh | 870 | 850 | 120 | 15 |
| ■ Natural gas | 1,920 | 2,040 | 280 | 13 |
| ■ Other fuels* | 3,650 | 3,870 | 520 | 13 |
| PRIMARY ENERGY Trillion BTUs | 14,870 | 14,960 | 2,130 | 14 |
| ■ Electricity | 9,220 | 8,970 | 1,320 | 15 |
| ■ Natural gas | 2,000 | 2,120 | 290 | 13 |
| EMISSIONS Megatons CO$_2$e | 900 | 910 | 130 | 14 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $34 billion | PV of energy savings – 2009-2020: $164 billion | Annual energy savings – 2020: $17 billion |

* End-use energy is approximated as equivalent to primary energy

** Table 14, 15 and 16 include a double-count of steam systems of approximately 5,520 trillion BTUs of 2010 consumption due to difficulties in accuately seperating this consumption into each cluster

Source: EIA AEO 2008, McKinsey analysis

- **Motors systems.** Motor-driven systems are projected to consume 2,330 trillion end-use BTUs of energy, all of it electricity, totaling 680 TWh, which represents 65 percent of total industrial electricity consumption. These systems (e.g., pumps, fans, air compressors and motor-driven industrial process systems) provide 250 trillion end-use BTUs (70 TWh) of potential in 2020. Efficiency improvements include matching component size with load requirements, using speed control, and improving maintenance; together, these improvements represent 77 percent of this potential. Motor-drive upgrades beyond EISA 2007 standards[182] and improved motor management offer the remaining 23 percent.

- **Buildings.** Buildings consume energy for HVAC, lighting, and other support functions. By 2020, buildings are projected to consume 1,110 trillion end-use BTUs, including 160 TWh of electricity, 190 trillion end-use BTUs of natural gas, and 360 trillion end-use BTUs of other fuels. Upgrades to lighting and appliances, plus retro-commissioning of HVAC systems and building shells, would provide 360 trillion end-use BTUs of potential.

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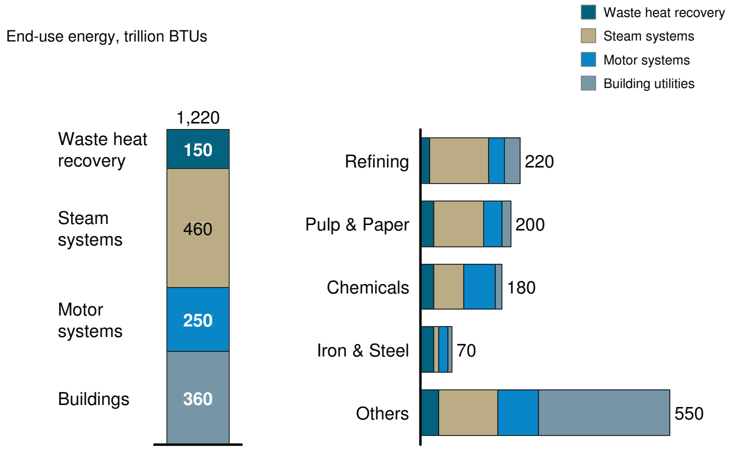
[182] More strict motor efficiency standards included in EISA 2007 address efficiency upgrades for new motors; some potential exists in motors maintained beyond the end of their useful life that should be replaced.

Exhibit 33: Efficiency potential in energy support systems – 2020



Source: EIA AEO 2008; McKinsey analysis

On the left side of the exhibit, the height of each segment and the column itself represent the amount of potential in the industrial support systems modeled, measured in trillion BTUs, with the total at the top of the column and the values for each system in their corresponding segment. The right side of the exhibit displays the amount of potential in select industries for each of these systems.

## Energy-intensive industry processes

Energy intensive industry processes are expected to consume 10,440 trillion BTUs of energy in 2020: this would include process heating and cooling, and such highly specialized process steps as clinker production in cement, blast furnaces in iron and steel manufacturing, hydrocracking in refining, and bleaching in pulp and paper.

The savings potential for this cluster is 1,550 trillion end-use BTUs, consisting of 40 TWh of electricity, 490 trillion end-use BTUs of natural gas, and 940 trillion end-use BTUs of other fuels (Table 15). Savings measures include implementing new processes, incrementally improving current processes, upgrading process monitoring and maintenance, and increasing waste heat recovery in specific process systems. Three forms of waste heat recovery offer savings potential:

- High-quality heat recovery, including sinter plants, annealing lines, and top-pressure recovery turbines, which can be harnessed for such uses as process energy, electricity generation, fuel preheating, and steam generation
- Low-quality heat recovery from cooling water and return lines, which can be used for water heating and space conditioning
- Recovering waste streams for fuel, such as hydrogen in refining, basic oxygen furnace gas, blast furnace gas in iron and steel, and black liquor gasification in pulp and paper.[183]

Table 15: Energy-intensive industry processes

| | Energy use – 2010** | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY | 9,930 | 10,440 | 1,550 | 15 |
| Trillion BTUs | | | | |
| ▪ Electricity TWh | 110 | 100 | 40 | 40 |
| ▪ Natural gas | 3,300 | 3,490 | 490 | 14 |
| ▪ Other fuels* | 6,260 | 6,610 | 940 | 14 |
| PRIMARY ENERGY | 10,810 | 11,290 | 1,830 | 16 |
| Trillion BTUs | | | | |
| ▪ Electricity | 1,120 | 1,060 | 380 | 36 |
| ▪ Natural gas | 3,340 | 3,620 | 510 | 14 |
| EMISSIONS | 650 | 680 | 110 | 16 |
| Megatons $CO_2e$ | | | | |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $51 billion | PV of energy savings – 2009-2020: $182 billion | Annual energy savings – 2020: $19 billion |

* End-use energy is approximated as equivalent to primary energy
** Tables 14, 15 and 16 include a double-count of steam systems of approximately 5,520 trillion BTUs of 2010 consumption due to difficulties in accuately seperating this consumption into each cluster

Source: EIA AEO 2008, McKinsey analysis

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183 N. Martin et al., "Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper industry," LBNL, 2000. Expert interviews.

Measures to capture this potential would require upfront investments of $51 billion, but would generate present value savings of $182 billion; 42 percent of the potential would pay back in less than 2.5 years.

## Non-energy-intensive industry processes

Non-energy intensive industry processes (e.g., food products, plastics, electrical equipment) are expected to consume 6,300 trillion end-use BTUs in 2020.[184] Savings measures available in this cluster include improved maintenance, process energy monitoring, and waste heat recovery.[185]

This cluster contains 870 trillion end-use BTUs of efficiency potential, offering $96 billion in present-value savings with an expected upfront investment of $28 billion (Table 16). This opportunity is highly fragmented across some 330,000 plants in 14 industries. The largest 3 percent of plants (9,500), however, consume 41 percent (2,590 trillion end-use BTUs) of the energy and offer 38 percent (330 trillion end-use BTUs) of the efficiency potential, suggesting that these sites would be the most attractive to pursue first.

## Barriers to capturing energy efficiency

The industrial sector faces five major barriers that together affect the bulk of the available energy efficiency potential:

- **Low awareness and attention.** Energy typically represents a relatively small fraction of operating costs (less than 5 percent), leading to low levels of awareness and attention from senior management at industrial companies.[186] Opportunities often require technical analysis that on-site employees rarely perform because of insufficient training, awareness, or management concern. The savings potential varies considerably by site, ranging from 10 to 40 percent, even for sites within the same subsector, highlighting the need for site-specific analysis.[187] This issue is exacerbated by the lack of focus on energy efficiency by top management, leading to under-prioritization of energy as an important strategic lever or metric to manage, resulting in limited investment in developing the required technical expertise.

Table 16: Non-energy-intensive industry processes

| | Energy use – 2010** | BAU energy use – 2020 | Savings due to EE – 2020 | Savings Percent |
|---|---|---|---|---|
| END-USE ENERGY Trillion BTUs | 6,330 | 6,300 | 870 | 13 |
| ■ Electricity TWh | 110 | 110 | 30 | 24 |
| ■ Natural gas | 2,050 | 2,050 | 270 | 13 |
| ■ Other fuels* | 3,900 | 3,890 | 520 | 13 |
| PRIMARY ENERGY Trillion BTUs | 7,220 | 7,130 | 1,070 | 15 |
| ■ Electricity | 1,200 | 1,120 | 270 | 24 |
| ■ Natural gas | 2,130 | 2,130 | 280 | 13 |
| EMISSIONS Megatons $CO_2e$ | 430 | 430 | 60 | 15 |

| | | |
|---|---|---|
| PV of upfront investment – 2009-2020: $28 billion | PV of energy savings – 2009-2020: $96 billion | Annual energy savings – 2020: $11 billion |

* End-use energy is approximated as equivalent to primary energy

** Tables 14, 15 and 16 include a double-count of steam systems of approximately 5,520 trillion BTUs of 2010 consumption due to difficulties in accuately seperating this consumption into each cluster

Source: EIA AEO 2008, McKinsey analysis

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[184] Given the many processes used in these sub-sectors, we created top-down models to identify the key characteristics of the opportunities based on our extensive experience serving these industries.

[185] See the "ENERGY STAR Guide for Energy and Plant Managers" (2008), a series of papers by LBNL's International Energy Studies exploring "Energy Efficiency Improvement and Cost Saving Opportunities" for many industries, including Pharmaceuticals, Wet Corn Milling, Fruit and Vegetable, and Vehicle Assembly; available at <http://ies.lbl.gov/publications>.

[186] Refining (13 percent total savings, 5 percent process energy savings) and to a lesser extent chemicals, (19 percent total savings, 11 percent process energy savings) often represent an exception to this rule.

[187] Expert interviews.

- **Elevated hurdle rate.** Industrial sites generally receive very tight operational budgets, and plant managers are encouraged to maximize production while keeping near-term quarterly costs low. Furthermore, management tends to focus on quarterly targets, potentially at the expense of projects that pay back over longer periods. Forty-three percent of energy managers indicate that they use a payback period of less than 3 years for energy efficiency projects,[188] while under difficult economic conditions anecdotal evidence suggests many companies require a payback period of 18 months or less on all investments.[189] Requiring a 2.5-year payback would reduce identified industrial potential by 46 percent or 1,690 trillion end-use BTUs.
- **Capital allocation and elevated hurdle rate.** Capital allocation from internal sources faces strict capital budget constraints with non-core projects (e.g., energy efficiency) competing for funding against core projects on unlevel ground. Often energy efficiency projects face an elevated hurdle rate compared to core projects. Furthermore, corporations often separate plant operations and maintenance budgets from capital improvement budgets, creating an organizational challenge for energy efficiency efforts, because the costs reside in one budget while the savings reside in another. Finally, even if projects are attractive by internal standards, corporations may remain reluctant to raise debt for energy efficiency projects for fear of adversely affecting their balance sheets and credit ratings.[190]
- **High transaction "cost."** Transaction "costs"[191] associated with implementing efficiency-related process improvements include space constraints, invested resource time, process disruptions, potential effects on product quality, and safety concerns associated with system integration and energy support system maintenance.[192]
- **Procurement and distributor availability constraints.** Lack of product availability can occur within an enterprise's procurement system, with the distributor, or in the marketplace. Many procurement systems contain limited inventory, typically focus on upfront cost rather than total cost of ownership, and require special processes and additional time to procure non-pre-approved parts. Distributor limitations primarily affect replacement of equipment during urgent situations because inventory carrying costs restrict distributors' ability to respond to immediate needs with the most efficient solutions. Marketplace limitations arise from the risk aversion of plant managers: despite continued ability of manufacturers to improve technology, risk aversion frequently creates demand for in-kind rather than more efficient replacements.

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[188] "Johnson Controls Energy Efficiency Indicator, North America," Johnson Controls and the International Facility Management Association, 2008.

[189] Expert interviews.

[190] Expert interviews.

[191] Quantifiable transaction costs including costs for engineering time and system integration are included in the investment sum; transaction costs considered barriers include those with uncertain incremental financial impact given challenges regarding allocation of marginal employee time, and unclear or misperceived impacts on product quality and safety.

[192] Expert interviews.

### CLEAN-SHEET REDESIGN OF SELECT INDUSTRIES

Recent studies indicate that the technical potential for efficiency reductions in many energy-intensive industries range from 35 to 71 percent with existing – but not necessarily cost-effective – technology. The "theoretical" potential for efficiency reductions (i.e., as limited by thermodynamics) range from 43 to 95 percent.[1] Capturing this technological potential, however, would require a clean-sheet redesign of operations, because retrofitting these measures into existing facilities would be too costly. Greenfield industrial projects are rare in the U.S., and plants are long-lived assets; as a result, experts have not detailed costs of these measures. Many measures, however, would likely be NPV-positive, if designed into greenfield facilities. The range of technical to thermodynamic potential for each industry analyzed includes:

- **Chemicals:** 71 to 88 percent, mostly through process-specific changes
- **Mining:** 60 to 95 percent, mostly related to on-site transportation, reducing what is transported and increasing efficiency of how it is transported
- **Pulp and paper:** 39 to 43 percent, mostly in paper drying
- **Refining:** 38 to 73 percent, mostly in improving crude distillation processes
- **Steel:** 35 to 43 percent, mostly in reducing heating temperatures.

While it would be difficult to achieve the technical limits within the next 5 to 10 years, clean-sheet redesign would enable manufacturers to gradually achieve world-leading levels of energy efficiency as they develop new assets. A long-term industry vision for greater energy efficiency would help direct research and development efforts.

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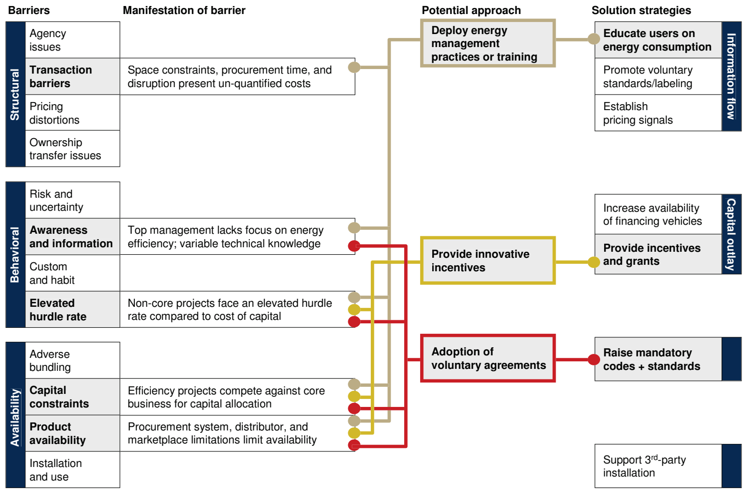
[1] Pulp and Paper Industry Energy Bandwidth Study, prepared by Jacobs Greenville, South Carolina, and Institute of Paper Science and Technology (IPST) at Georgia Institute of Technology Atlanta, Georgia, August 2006; Energy Bandwidth for Petroleum Refining Processes, prepared by Energetics Incorporated, for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Industrial Technologies Program, October 2006; Steel Industry Energy Bandwidth Study, prepared by Energetics, Inc., for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Industrial Technologies Program, October 2004; McKinsey analysis

## Solution strategies to unlock the potential

Solution strategies to address these barriers cut across consumption clusters and fall into four groups: promoting energy management, providing energy assessments and training tools, offering monetary incentives, and establishing efficiency target agreements or equipment standards (Exhibit 34).

Exhibit 34: Addressing barriers in industrial clusters*



* Energy support systems, energy-intensive industry processes, and non-energy-intensive industry processes
Source: McKinsey analysis

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

- **Promoting energy-management practices** *(proven/piloted).*[193] Strong company-wide energy-management practices supported by part-time or full-time on-site energy managers have proven effective in achieving greater energy efficiency. Specifically, energy managers can directly play a decisive role in capturing 1,730 trillion BTUs of end-use energy potential (47 percent of the efficiency potential identified in these clusters or 8 percent of total end-use consumption). They target this potential by implementing process and support system measures categorized as improving monitoring and control, improving operating practices, and assuring timely repair and regular maintenance. Implementing these measures will require $39 billion as upfront investment. Furthermore, this solution strategy directly addresses the awareness and attention and product availability barriers by giving primary responsibility to an individual or group. To address the capital allocation and elevated hurdle rate barriers, management could allocate appropriate funds to the energy manager. As of 2002, fewer than 2 percent of facilities had on-site energy managers,[194] despite clear examples of companies that reduced their energy costs by 20 to 30 percent through effective energy management.[195] Effective programs typically include a corporate-level, multi-year planning horizon; designated accountable energy managers and champions; sufficient capital allocation; process and support system energy auditing; and plant or line-level performance goals and performance tracking.[196]

  — EPA's ENERGY STAR Partnership focuses on helping industrial companies develop and refine corporate energy-management programs. In 2007, nearly 500 U.S. manufacturing partners made a commitment to follow the program's energy management guidelines. The guidelines included assessment, benchmarking, energy management planning, and progress evaluation.

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[193] Proven in two clusters (energy support systems and process improvements in energy-intensive industries) and piloted in one cluster (process improvements in the non-energy-intensive industries).

[194] MECS 2002.

[195] Aimee McKane, et al., "Certifying Industrial Energy Efficiency Performance: Aligning Management, Measurement, and Practice to Create Market Value," ACEEE, 2007. Expert interviews.

[196] Christopher Russell, "Strategic Industrial Energy Efficiency: Reduce Expenses, Build Revenues, and Control Risk," Alliance to Save Energy, July 2003.

  - Plant certifications, similar to OSHA safety programs, can encourage adoption of energy-management programs. Energy-management certification protocols, such as the emerging ISO 50001 standard,[197] will likely strengthen energy-management practices.

- **Providing energy assessment and training tools** *(proven/piloted)*.[198] Subsidized assessments and distribution of training materials can increase awareness of energy-saving opportunities:
  - The DOE Industrial Technology Program "Save Energy Now" represents a national initiative to drive a 25 percent reduction in industrial energy intensity in 10 years. It has already helped 2,100 U.S. manufacturing facilities save an average of 8 percent of total energy costs. They have performed 200 assessments of steam systems and process heat systems across 40 sites in 2006, 257 sites in 2007, and 301 sites in 2008. Surveys 6 months after the assessment showed participants had implemented or were in the process of implementing 60 percent of the recommendations. More than 90 percent of participants found assessments played an influential or highly influential role in their implementation of energy-saving projects.[199] Significant resource requirements would make enlarging programs like this challenging. Assessment of a single establishment costs approximately $10,000, including 2 FTE weeks. Assessing the top 10 percent would require an investment of $300 million, including more than 1,000 FTE-years.
  - EPA's ENERGY STAR Industrial Partnership (through Lawrence Berkeley National Laboratory) and other organizations have created subsector- and technology-focused guidebooks that highlight operational best practices and provide tools for conducting energy-savings assessments. Wisconsin's public benefits program, Focus on Energy, serves as one example of impact: an independent evaluation revealed that their pulp and paper guidebook achieved 67 percent market awareness; 75 percent of those aware of the report consulted the guidebook and 11 percent of those aware of the report implemented identified practices.[200]

- **Monetary incentives** *(piloted/emerging)*.[201] Monetary incentives can address capital allocation and availability concerns, shorten payback times, and help overcome product availability barriers by reducing procurement challenges. There are multiple examples of innovations in this area:
  - Companies that have a strong relationship with end-users can improve the energy efficiency of related businesses by requiring greater energy efficiency from them and others in their supply chain. Wal-Mart's "supply chain of the future" initiative, for example, is targeting 20 percent energy savings in its supplier base by 2012, focusing on energy and emissions in seven product categories.[202] Wal-Mart provides suppliers incentives and support (e.g., subsidized energy audits) for

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[197] A consortium of companies and governments (including the U.S. Council for Energy Efficient Manufacturing) are currently developing ISO 50001, in order to make energy management an integral part of industrial operating practices on par with safety, quality, waste reduction and inventory management.

[198] Proven in two clusters (energy support systems and process improvement in energy-intensive industries) and piloted in one cluster (process improvements in the non-energy-intensive industries).

[199] Donald Kazama et al., "California's Industrial Energy Efficiency Best Practices Technical Outreach and Training Program," California Energy Commission, 2007. John Nicol, "Market Impact of the Pulp and Paper Best Practices Guidebook," Science Applications International Corporation, 2007; survey size: 19 customers.

[200] John Nicol, "Market Impact of the Pulp and Paper Best Practices Guidebook," Science Applications International Corporation, 2007; survey size: 19 customers.

[201] Piloted in two clusters (energy support systems and process improvement in energy-intensive industries) and proposed in one cluster (process improvements in the non-energy-intensive industries).

[202] "Supply Chain Sustainability: Wal-Mart's Commitment to the Future," SIF International Working Group, October 2008. <www.socialinvest.org/projects/iwg/documents/Anderson_Presentation_10-08_v2.pdf>.

energy-saving projects. Similarly, a few manufacturers provide energy efficient equipment at reduced upfront cost, which they finance through shared savings.

- Direct incentives from manufacturers, distributors, government, or utilities would accelerate the adoption of new technologies. Support system and process system upgrades remain rare, because of the large perceived risk of early adoption. Supporting pilots and providing incentives could help address this problem.

- **Establishing efficiency targets or equipment standards** *(piloted/emerging).*[203] Agreements tailored to a subsector can be effective in raising awareness of energy efficiency among top management. Such agreements can increase capital allocations, lengthen allowed payback times, build awareness at the line level, and increase product availability as management drives the organization to meet targets.
  - **Voluntary agreements.** A variety of commitments are possible with voluntary agreements,[204] including industry covenants, negotiated and long-term agreements, codes of conduct, benchmarking, and monitoring schemes. In return, participants may receive compensation, potential regulatory exemptions, avoidance of stricter regulations, and/or financial rewards. The flexibility, speed of implementation and ease of adjustment appeal to regulators, though concerns over recourse regarding non-compliance persist. Sweden's 2005 program launching 5-year agreements[205] and the Netherlands long-term agreements ("LTA1" and "LTA2") with the chemical industry to implement approved energy-management systems together drove 23 percent energy efficiency improvement from 1998 to 2006.
  - **Efficiency standards for support-system equipment.** Setting high efficiency standards for support-system equipment can help address technology availability by increasing demand (and therefore supply) of efficient equipment. The benefits of standards have to be balanced against implementation challenges arising from system customization, high engineering costs, limited speed of deployment, and long equipment life: for example, of 43,000 industrial, commercial and institutional boilers with heat input greater than 10 million BTUs per hour, 70 percent were more than 40 years old as of 2002,[206] limiting the impact of standards on new equipment. Standards are even more difficult, and possibly not cost-effective, to impose on specialized process equipment given the low volume and case-specific usage characteristics of such equipment.

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[203] Piloted in one cluster (process improvement in energy-intensive industries) and proposed in two clusters (energy support systems and process improvements in the non-energy-intensive industries).

[204] Though participation is usually voluntary, once industry members and regulators reach an agreement, non-compliance typically leads to penalties.

[205] Sweden requests companies to implement an accredited energy management system, carry out an energy audit and implement all identified measures with a payback period less than 3 years. In return the company receives a tax exemption on process-related electricity consumption, dependent on compliance.

[206] "Industrial Boiler MACT Analysis," EPA, 2002.

## INDUSTRIAL AND COMMERCIAL COMBINED HEAT AND POWER

Combined heat and power (CHP) systems generate electricity and thermal energy in a single, integrated system. The result is significantly higher overall energy efficiency: engine-driven CHP systems can achieve total thermal efficiencies of 70 to 80 percent. This compares favorably to a net thermal efficiency of 45 percent from the combination of a conventional power plant and an on-site boiler providing comparable benefits.[207] Eliminating transmission and distribution losses and recycling waste heat produce this efficiency improvement.

Industrial CHP typically involves the use of steam or natural gas turbines for electricity generation, with capacities as high as 100 MW or more. Commercial CHP typically uses smaller systems providing some or all on-site thermal and electricity using natural gas reciprocating engines (capacities range from 800 kW to 5 MW). The United States has approximately 75 GW of on-site industrial CHP and 10 GW of installed commercial capacity. Installations are highly concentrated geographically, with 24 GW (28 percent of U.S. capacity) along the Gulf Coast in Louisiana and Texas, 5.8 GW in New York, and 9.2 GW in California.[208] It is worth noting that both California and New York have higher than average energy prices and spark spreads, and stringent air quality requirements, demonstrating that it is possible to achieve high levels of penetration to meet economic and compliance goals.

An additional 50.4 GW of CHP are NPV-positive for deployment by 2020, involving upfront investment of $56 billion (Exhibit 35) and providing a present value savings of $77 billion and an annual savings of 100 million tons of $CO_2$e emissions. The potential varies markedly by region, system capacity, and sector:

- The South (mostly industrial) and East (mostly commercial) Census regions offer 70 percent (approximately 35 GW) of the NPV-positive potential. Further variation of the potential by region depends on local power prices, space conditioning loads, and the cost and availability of primary fuels, typically natural gas.
- Large CHP systems (greater than 50 MW) represent some 70 percent of the NPV-positive potential in the industrial sector.
- Sectors like chemicals and iron and steel, which together consume 20% of the total industrial end-use energy represent a disproportionate share of the opportunity with 47% of the total industrial CHP potential, owing to their large steam energy requirements.
- Opportunities in the commercial sector represent 24 GW of NPV-positive potential distributed among small-scale installations in thousands of buildings across the country. Large office buildings (14 GW), healthcare facilities (6 GW), and universities (4 GW) comprise the largest opportunities.

Although some additional attractive opportunities may exist in residential or other commercial settings, substantial cost reductions would be necessary to create a broader market for CHP in these applications.

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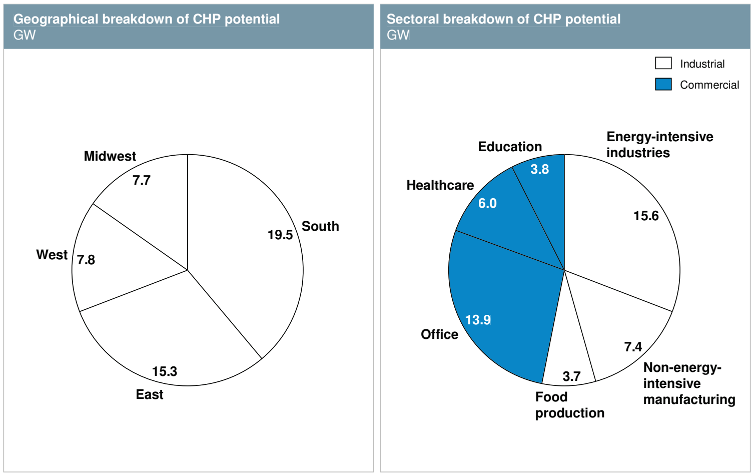
[207] Lauren R. Mattison, “Technical Analysis of the Potential for Combined Heat and Power in Massachusetts,” University of Massachusetts, Amherst, May 2006.

[208] “CHP Installation Database,” ICF International/EEA, accessed June 2009. < www.eea-inc.com/chpdata/index.html >.

Exhibit 35: Potential for combined heat and power (CHP) – 2020



Source: EIA AEO 2008; McKinsey analysis

The chart on left side of the exhibit shows the total amount of CHP potential (both industrial and commercial) divided among the four Census regions. The chart on the right splits out the potential by the different industries in the commercial and industrial sectors.

## Barriers to greater energy efficiency

Over the past two decades, a number of technical and regulatory barriers to wider adoption of CHP have been removed; however, cost, information, and regulatory barriers impede the full capture of CHP potential in the industrial and commercial sectors.

- **Capital constraints.** Installing a CHP system requires significant upfront investment and ongoing operating expense that are recovered through lower energy costs over the life of the equipment.[209] Installation of a typical 10-MW gas turbine system can cost $10 million to $13 million, with annual non-fuel operating and maintenance costs ranging from $200,000 to $700,000.[210] Many industrials do not have the discretionary capital or are hesitant to use it on such a long-term investment.
- **Risk and uncertainty.** Beyond installation costs, developing a CHP system incurs a range of additional project and operational risks that the host company would not bear if it were to rely on a central utility for its power needs. These risks include installation overruns, system integration issues, permitting challenges, lost margin due to system shutdowns, volatility in gas prices, power price uncertainty, and environmental emissions exposure, among others. Additionally, moving to a single source of power exposes companies to higher commodity and disruption risk related to the chosen commodity.
- **Lack of awareness and limited management support.** CHP systems are often seen as fixed cost-centers that require non-core expertise to manage and operate.
- **Pricing distortions.** If rules governing grid connections are not supportive, they can be a significant obstacle to adoption. Operators of CHP systems must pay various tariffs that, while potentially justifiable from a grid operator's point of view, can diminish the attractiveness of CHP:
  - — **Interconnection requirements.** Economic use of CHP for most customers requires integration with the utility grid for back-up and supplemental power needs, and, in some cases, sale of excess power. CHP systems must be able to safely, reliably and economically interconnect with the existing utility grid system. To

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[209] "CHP Project Development Handbook," EPA, 2008.

[210] "Catalogue of CHP Technologies," EPA, December 2008. Assumes 6000 annual hours of operation.

ensure safety and reliability of self-generators, grid operators typically need to grant approval for new generation systems prior to interconnection. The current lack of uniformity in interconnection standards makes it difficult for equipment manufacturers to design and produce modular packages;[211] gaining approval can, therefore, be complicated, time consuming, and costly.

- **Standby rates and exit fees.** Facilities with CHP systems usually require standby or back-up service from the utility to provide power when the CHP system is down for routine maintenance or unplanned outages. The utility must therefore bear a maintenance cost associated with the generation, transmission and distribution capacity (depending on the structure of the utility) required to supply backup power when requested (sometimes on short notice). The level of these charges is often a point of contention between the utility and the consumer, and can, without proper oversight, create unintended and important barriers to CHP. Furthermore, customers that leave the grid may be charged an exit fee to allow a utility to recover future costs already allocated to the support of that customer. In some cases, the charges are prohibitively high, undermining the case for CHP installation.
- **Site permitting and environmental regulations.** Input-based emissions standards penalize CHP systems that increase on-site emissions while decreasing overall grid emissions. Twelve states have adopted output-based environmental regulations. Output-based regulations are expressed as emissions per unit of useful energy output (e.g., pounds per megawatt-hour [lb/MWh]), and promote clean energy by accounting for the benefits of reduced air pollution effects from energy efficiency in the compliance computation.[212] CHP in ozone non-attainment areas in the 38 states where these regulations have not been enacted may require additional pollution-control equipment and emissions-offset purchases that can affect project economics.

### Solution strategies to unlock potential

Overcoming the barriers to CHP deployment would likely require a mix of awareness campaigns, regulatory support (including provisions to align utility and ESCO incentives), and financing support (Exhibit 36).

- **Create CHP-supportive regulations** *(proven).* The United States has used regulations effectively to encourage CHP installation. Installed CHP capacity has increased from about 12 GW in 1980 to more than 52 GW in 1999. The lessons learned from previous legislation can inform development of a new model with similar aims, such as:
  - Target high-efficiency CHP systems that are designed to meet the thermal needs of the site. If this approach to a thermal base-loaded project produces excess electricity, it is important to then ensure means for a reasonable return on this excess electricity
  - Focus on balancing transaction and regulatory barriers, including standby charges, and interconnection requirements, with the need for overall efficiency, reliability, long term planning, and customer costs
  - Assure grid reliability for utilities and market clarity for would-be CHP installers
  - Consider output-based emissions standards and simplified environmental permitting procedures.

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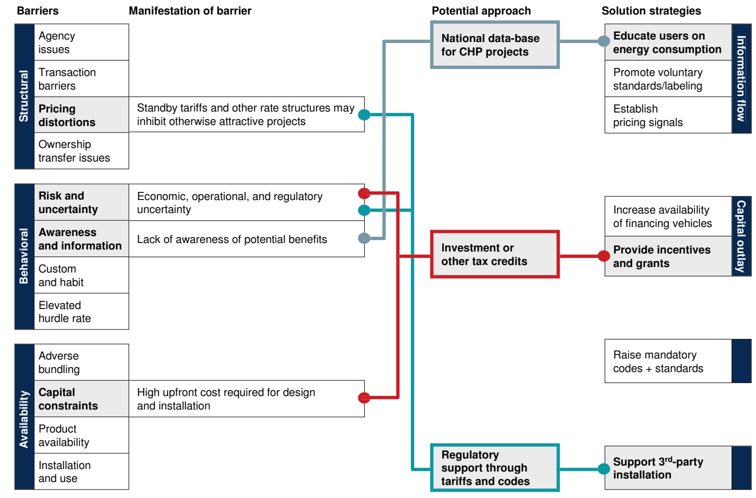
[211] "CHP Effective Energy Solutions for a Sustainable Future," DOE, December 2008.

[212] "Output-based Environmental Regulations Fact Sheet," EPA, 2007.

- **Provide financial incentives** *(proven).* Financial incentives to make CHP economics favorable for third-parties, utilities, and industrials could target upfront capital costs of the system or system installation costs. Tax rebates and direct incentives would help address upfront costs. Although tax rebates are widely recognized as an enabler for CHP systems, they may not be as effective in the commercial sector where some non-profit organizations (e.g., universities) would not be able to take advantage of them. In this case, direct incentives (e.g., grants) may prove to be more effective. Alternatively, an assisted-installation incentive, in which a qualified installer receives an incentive payment once a system is installed successfully and functioning,[213] could help address capital constraints while mitigating project risk and uncertainty.
- **Build awareness** *(proven).* A nation wide survey of industrial and commercial facilities that would be possible candidates for CHP could raise awareness of CHP's potential. A publicly available database of such facilities would decrease risks, uncertainties, and transaction costs for developers willing to support CHP installations and financiers willing to provide upfront financing.

Exhibit 36: Addressing barriers in combined heat and power (CHP)



Source: McKinsey analysis

The left side shows categories of opportunity-specific barriers that can impede capture of energy efficiency potential, with a description of the specific manner in which the barrier is often manifested in the cluster extending toward the right. The far right side of the exhibit lists general solution strategies for pursuing efficiency potential, with the near right column describing how this might be combined into specific approaches to overcome barriers in the cluster. The colored lines map specific solutions to specific barriers.

Additional policy options could support further deployment of CHP. Simplifying interconnection of CHP systems by standardizing grid interconnection guidelines and "fast tracking" approval processes would minimize several development risks and enable manufacturer cost reduction through scale. Implementing output- rather than input-based emission standards would allow CHP to gain full credit for the efficiencies embedded in its integrated design. Finally, aligning utility incentives by including CHP as an eligible resource for Renewable Portfolio Standards (RPS) and/or Energy Efficiency Resource Standards (EERS) could enlist utilities constructively in the development of this resource, an approach used in 13 states today.

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[213] NYSERDA and ConEdison offer $0.10 per kWh plus $750 per kW to a maximum of $2 million, while the federal government offered limited-term investment tax credits of 10 percent when launching PURPA in 1978.

# 5. Developing a holistic implementation strategy

Although the U.S. economy has improved energy productivity in important ways over the past three decades, significant opportunities remain. The intent of this research effort is to help inform discussion about ways to unlock opportunities for greater energy efficiency, as the nation considers how to ensure energy affordability, promote energy security, and address the issue of climate change. This report does not advocate a specific strategy or set of policies for capturing additional energy efficiency potential, rather it attempts to delineate issues and choices the nation will face. We hope that this report may provide business leaders, policymakers, and other interested parties with a solid fact base and some perspectives on possible approaches for economically sensible strategies for pursuing greater energy efficiency in the U.S. economy.

**The central conclusion of our work:** *Energy efficiency offers a vast, low-cost energy resource for the U.S. economy – but only if the nation can craft a comprehensive and innovative approach to unlock it. Significant and persistent barriers will need to be addressed at multiple levels to stimulate demand for energy efficiency and manage its delivery across more than 100 million buildings and literally billions of devices. If executed at scale, a holistic approach would yield gross energy savings worth more than $1.2 trillion, well above the $520 billion needed through 2020 for upfront investment in efficiency measures (not including program costs). Such a program is estimated to reduce end-use energy consumption in 2020 by 9.1 quadrillion BTUs, roughly 23 percent of projected demand, potentially abating up to 1.1 gigatons of greenhouse gases annually.*

In 2008 the nation spent an estimated $10 billion to $12 billion on efficiency-related investments;[214] capturing the full efficiency potential identified in this report would require an additional investment of roughly $50 billion per year (in present value terms, four- to five-times this value, sustained over a decade. Even the fastest-moving technologies of the past century that achieved widespread adoption, such as cellular telephones, microwaves, or radio, took 10 to 15 years to achieve similar rates of scale-up. Without an increase in national commitment it will remain challenging to unlock the full potential of energy efficiency.

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[214] Spending on energy efficiency in 2008 included $2.5 billion in utility-sponsored programs, $3.5 billion on energy efficiency in the $5-billion ESCO market, and $4 billion to $6 billion for incremental investment in insulation and efficiency devices. We excluded approximately $8 billion in spend on insulation because it represents standard building practice rather than incremental spend targeted solely at improved energy efficiency.

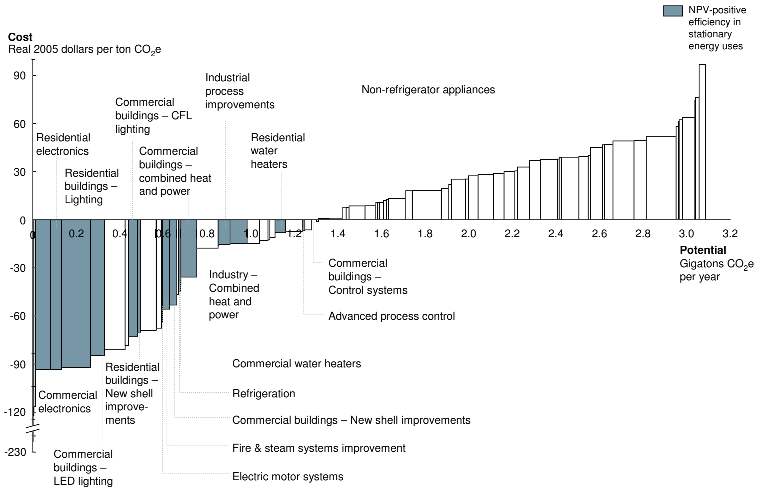
Accomplishing such an increase in scale will require a comprehensive strategy for pursuing opportunities and a coherent approach to system-level issues. Our research suggests five important observations are critical to consider when developing such a comprehensive strategy. Both national and regional strategies will need to:

1. Recognize energy efficiency as an important energy resource that can help meet future energy needs, while the nation concurrently develops new no- and low-carbon energy sources
2. Formulate and launch at both national and regional levels an integrated portfolio of proven, piloted, and emerging approaches to unlock the full potential of energy efficiency
3. Identify methods to provide the significant upfront funding required by any plan to capture energy efficiency
4. Forge greater alignment between utilities, regulators, government agencies, manufacturers, and energy consumers
5. Foster innovation in the development and deployment of next-generation energy efficiency technologies to ensure ongoing productivity gains.

## 1. RECOGNIZE ENERGY EFFICIENCY AS AN IMPORTANT ENERGY RESOURCE THAT CAN HELP MEET FUTURE ENERGY NEEDS, WHILE THE NATION CONCURRENTLY DEVELOPS NEW NO- AND LOW-CARBON ENERGY SOURCES

Energy efficiency is an important resource that is critical in the overall portfolio of energy solutions. Likewise, as indicated in our prior greenhouse gas abatement work, new sources of no- and low-carbon generation are also important components of the portfolio. While it may seem counterintuitive initially given the magnitude of the energy efficiency potential available over the next decade, there are important reasons for continuing to develop new no- and low-carbon options for energy supply. First, as described in our original report on U.S. greenhouse gas (GHG) abatement (Exhibit 37), energy efficiency in stationary uses of energy represents less than half of the potential abatement available to meet any future reduction targets. Additionally, some areas of the country will continue to experience growth and some may need to retire and replace aging existing assets. The uncertain growth of electric vehicles could further these requirements. Finally, pursuing energy efficiency at this scale will present a set of risks related to the timing and magnitude of potential capture. As such there remains a strong rationale to diversify risk across supply and demand resources.

Exhibit 37: U.S. mid-range greenhouse gas abatement curve – 2030



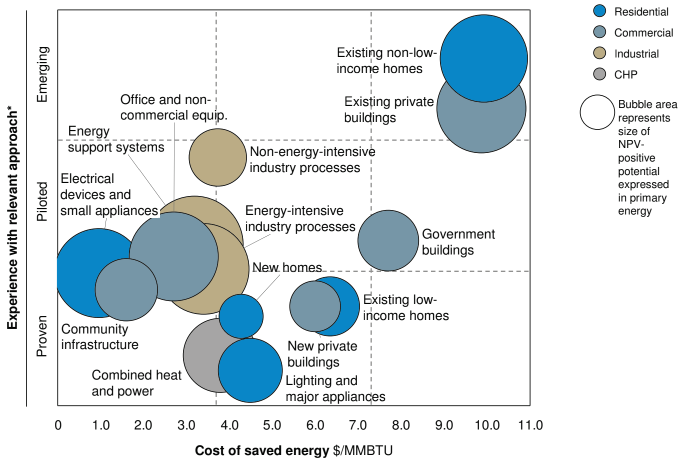
This exhibit shows the mid-range greenhouse gas abatement potential as depicted in McKinsey's greenhouse gas report, with the energy efficiency opportunities from stationary sources highlighted. The height of each bar is the cost in dollars to abate a ton of carbon; the width is the gigatons of carbon emissions equivalent abated per year.

## 2. FORMULATE AND LAUNCH AT BOTH NATIONAL AND REGIONAL LEVELS AN INTEGRATED PORTFOLIO OF PROVEN, PILOTED, AND EMERGING APPROACHES TO UNLOCK THE FULL POTENTIAL OF ENERGY EFFICIENCY

A range of tools can stimulate demand for energy efficiency, from those with a heavy reliance on market forces (e.g., education and awareness building, greater information transparency, price signals, energy efficiency markets) to those with a more interventionist approach (e.g., mandates, codes, standards, and efficiency performance targets). To capture the magnitude of potential identified in our research within the timeframe it uses, the U.S. will need to establish energy efficiency as a national priority and assemble a portfolio of strong, coordinated policies and market mechanisms drawing from the proven, piloted, and emerging solution strategies discussed in Chapters 2 through 4. Exhibit 38 arrays the clusters of potential (scaled to size of the opportunity) by the required upfront investment (dollars per MMBTU of efficiency gain) along the horizontal axis and the experience with a given solution strategy used to capture that cluster's potential (proven, piloted, or emerging) along the vertical axis. This tool facilitates evaluation of a portfolio against the relevant parameters of cost, risk (i.e., experience), and return (i.e., size of potential). The portfolio depicted focuses on the most proven solution strategies deployed to date. The portfolio focuses on codes and standards for electrical devices and small appliances, lighting and major appliances, office and non-commercial equipment, and new buildings. It looks to government intervention to address existing low-income homes (i.e., WAP). Finally, it employs a blend of voluntary agreements, mandates, and incentives for industrial clusters, government building, community infrastructure, and CHP and a mix of audits, labeling, and incentives for existing private commercial buildings and non-low-income homes.

Exhibit 38: Portfolio representing cost, experience, and potential of clusters possible with specified solution strategies

The bubbles depict the NPV-positive efficiency potential in each cluster, measured in primary energy, with the area of the circle proportional to the potential. The position of the bubble's center on the horizontal axis indicates the cost of capturing this potential with the measures modeled in this report (excluding program costs) in dollars per million BTUs per year. The center's position on the vertical axis represents the weighted average of the national experience with the approaches outlined for the cluster.



* Drawing an analogy to our work with business transformation; piloted solutions represent those tried on the scale of a state or major city (i.e., over 1 million points of consumption), emerging are untested at that level, and proven have broad success at a national scale

Source: McKinsey analysis

In addition to seeking the impact of national efforts this portfolio should effectively and fairly reflect regional differences in energy efficiency potential. Any approach would need to make the following three determinations:

- The extent to which government should mandate energy efficiency through the expansion and enforcement of codes and standards
- Beyond codes and standards, the extent to which government (or other publicly funded third parties) should directly deploy energy efficiency
- The best methods by which to further stimulate demand and enable capture of the remaining energy efficiency potential.

### Use of codes and standards

Codes and standards have proven effective at capturing potential at national and state levels. Codes and standards have advantages over other solution strategies in that they match the incremental investment directly to those users who enjoy the reduced consumption benefits; they offer a high level of certainty about execution; and their cost of execution, at $0.15 to $0.30 per MMBTU,[215] is typically lower than other approaches. There would be some disadvantages to codes and standards: these would include costs for effective enforcement; the difficulty of gaining agreement on the level and design of the code, which could slow implementation and reduce impact; and, if not well designed, a forcing of uneconomic measures in some regions or specific situations, even if measures were economic on average. Additionally, some observers have reservations about government intervention, and the corresponding sacrifice of personal liberty, leading them to favor more market- or voluntary-based approaches.

To the extent that legislators pursue codes and standards to capture the full potential in areas where codes and standards currently apply (new buildings, lighting and major appliances, electric devices and small appliances, and office and non-commercial equipment), they would address 2,090 trillion end-use BTUs (23 percent) of the potential energy savings. The required upfront incremental investment associated with deployment

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[215] *Scenarios for a Clean Energy Future*, Interlaboratory Working Group, ORNL/CON-476 and LBNL-44029, November 2000.

of efficiency measures prompted by these codes and standards would total $53 billion and produce approximately $240 billion of present value in energy savings.

There are, however, additional areas where codes and standards could apply. For example, if a broader approach were taken to place codes and standards on government buildings and energy-intensive industries where such measures have been piloted, these figures would grow by an incremental $77 billion in upfront investment, which would yield an additional 1,910 trillion end-use BTUs (21 percent of total potential) in energy savings and offer $231 billion of present-value benefits. An even more expansive application of codes and standards would apply them to existing commercial enterprises and residential buildings. This would offer 2,110 trillion end-use BTUs (23 percent of total potential) of energy savings, requiring an incremental upfront investment of $226 billion and providing an associated $271 billion in present-value savings. This approach would be analogous to requiring emissions inspections on existing vehicles and requiring owners to pay for bringing vehicles up to standard if they fail the emissions test; however, these energy efficiency upgrades would be NPV-positive, returning the owners more savings than the upfront cost.

The design of building codes would need to balance the benefits of uniformity with those of regionality. Uniform codes enable manufacturers to capture economies of scale, reducing the total cost of implementation to society. Regionality allows customization to account for such factors as climate or local energy prices. In addition, administration and enforcement at the state, regional, and federal levels each have advantages and challenges. Codes and standards set at a national or regional level would establish the "floor" for efficiency going forward. Once the strategy for codes has been developed, other aspects of a comprehensive strategy could be layered into place.

### Role for government (or other publicly funded third parties)

Select clusters, including low-income existing homes, government buildings, and community infrastructure, may warrant government (or other publicly funded third party) intervention. These clusters present a social imperative or represent a shared resource potentially justifying public intervention.

The DOE's Weatherization Assistance Program (WAP) has been effective with existing low-income homes. Over the past 32 years WAP has retrofitted 6 million of the existing 45 million low-income homes, with an average pace in recent years of approximately 100,000 homes per year. With recent economic stimulus funding of approximately $5 billion, the program is projected to address some 1 million homes per year for the next 3 years, a 10-fold increase in pace. Capturing the full efficiency potential of 610 trillion end-use BTUs available in 2020, however, would require a further eight fold increase in spending to fund the unaddressed approximately $40 billion of upfront investment in this cluster. Government intervention could be expanded in clusters where it is appropriate but less proven, namely government buildings, and community infrastructure. Addressing the entire potential in these clusters, as well as non-low-income homes, offers 1,260 trillion end-use BTUs (14 percent of total potential) with an upfront cost of $76 billion and present value savings of $174 billion. Alternatively, limiting this approach to homes while deepening it to address all households with annual incomes under $50,000 would address 1,090 trillion end-use BTUs (12 percent of total potential) and require $94 billion in upfront investment.

### Other means to stimulate demand

Any portfolio of solutions will require approaches for stimulating demand for greater efficiency beyond codes and standards and government intervention. Exhibit 39 outlines six commonly discussed tools for stimulating demand and comments on their relative merits against five criteria. Either market participants or policymakers could use these tools. Manufacturers or distributors, for example, often launch an awareness campaign when marketing products; load-serving entities could approach regulators about adjusting recovery mechanisms to provide more accurate price signals to power customers. A balanced portfolio would seek to capitalize on the strengths of all market participants in the context of activities by other participants. Though these additional approaches may be helpful in pursuing efficiency potential in clusters where codes, standards, and third-party deployment are used (as described above), these additional approaches may be especially useful in the remaining clusters. These otherwise underserved clusters include existing non-low-income homes, existing commercial enterprises, energy support systems, non-energy-intensive industry processes, and combined heat and power which together represent 4,200 trillion end-use BTUs (46 percent of total potential) and have an associated $344 billion in upfront investment providing present value savings of $608 billion.

Exhibit 39: A wide portfolio of approaches will be necessary to capture the full efficiency potential

A portfolio of strategies will be necessary for the full energy efficiency potential to be realized. Each of the strategies is described across a range of factors.

| Strategy | Experience to date | Speed of deployment | Complexity of implementation | Source of investment | Administration & other costs |
|---|---|---|---|---|---|
| **Education and awareness** | Varies, depends on message design | Slow, as it requires behavior change | Simple in concept; requires careful message design | End user | Typically 15 percent or less |
| **Transparency of consumption information** | Low – only piloted; unclear durability as may rely on conservation | Slow, as it requires behavior change and infrastructure | Challenging, requires incorporation into many devices and simple home display | End user | Unclear, depends on device, with prices ranging from pennies to hundreds of dollars |
| **Price signals** | Impact on efficiency not directly evaluated | Fast to implement, time to capture savings will vary | Dependent on rate structure proposed | End user | Limited incremental costs |
| **Energy efficiency resource standards** | Unclear | Fast to implement, time to capture savings will vary | Simple to design, can have complicated EM&V | Public | Limited incremental cost; total cost dependent on programs deployed |
| **Energy efficiency credits** | Unclear | Fast to implement, time to capture savings will vary | Complex to design, requires complicated EM&V | Public | Unclear |
| **Financial incentives** | Moderate to high given success of utility scale programs | Slow, as it requires behavior change | Straight forward | Public | Varies between 10-50% by program type, effectiveness & scale |

Source: McKinsey analysis

- **Education and awareness.** Options for improving awareness include expanded labeling of devices and buildings; benchmarking; building audits and disclosures; annual reporting requirements (e.g., an annual energy "10K" from businesses); and education campaigns. Increased education and awareness is widely viewed as a necessary-but-not-sufficient component of a holistic approach, because it relies on end-user activity and provides savings of unclear durability. However, it can be highly cost effective, even at low capture ratios, if well designed.
- **Transparency of consumption information.** A variety of tools would improve transparency of consumption information and relative energy performance, including in-home displays of energy use, similar to a "miles-per-gallon" display in cars; availability of consumption on-line, similar to usage counters for mobile phones; and building control systems that allow for real-time tracking of consumption for major pieces of equipment. Studies in multiple countries have shown that transparency into real-time consumption (e.g., through in-home displays) can result in long-term 4- to 15-percent reductions in demand, while delayed feedback provides lower savings.[216] It seems important to include the context of any numbers provided such as relative performance compared to similar buildings or efficient products currently available commercially. This approach suffers from limitations similar to education and awareness, but represents a policy of limited market intervention.

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[216] Sarah Darby, "The Effectiveness of Feedback on Energy Consumption," Environmental Change Institute, University of Oxford, April 2006.

- **Price signals.** There are several options for price signals, including tiered pricing (e.g., higher rates for higher levels of consumption), general rate increases, and rate adders, such as a cost for carbon. These could increase the price of energy and enhance the financial attractiveness of energy efficiency. While there is undoubtedly some price level that would drive wide-spread adoption of efficiency measures, the challenge will be the political acceptability of achieving – and sustaining – a high enough price to induce significant adoption. Based on EIA estimates of price elasticity, energy prices would need to increase by approximately 20 percent for industrial customers and approximately 50 percent for residential and commercial customers for consumption to decline by the amount identified as NPV-positive potential in this report.[217] There is, however, no guarantee that customers will seek efficiency solutions to reduce demand.
- **Energy Efficiency Resource Standards (EERS) and targets.** Business leaders and policymakers could stimulate demand more directly by establishing energy efficiency targets at the national, state, or local levels. Targets should be set against a forecast consumption that includes growing and emerging applications (plug-load devices, data centers, and electric vehicles, for example) and is regularly re-evaluated to assure accuracy. Targets could also apply to specific segments; for example, new federal government buildings must reduce energy consumption by 30 percent, as mandated by the Energy Independence and Security Act of 2007. Targets should incorporate an assessment of the efficiency potential within a region, with careful attention to differences in climate, energy cost, and prior efficiency measures. California, for example, has made measured progress at capturing energy efficiency for decades and benefits from a mild climate. As such, it may require a different target than regions with less well-established efficiency efforts and different consumption profiles. Some approaches to capturing energy efficiency may result in funds collected in one customer class to be invested for the benefit of another. Regulators may want to make provisions to align funds and investments within a customer-class. EERS offers the advantage of clearly articulating an expected pace and magnitude of efficiency improvements, while leaving the choice of specific actions open. Furthermore, the managers of targets remain responsible for developing a portfolio of solutions to capture the potential.
- **Energy efficiency credits (EEC) and markets.** A market for efficiency could take several forms, though the central objective would be to enable market participants to compete for savings to meet an energy efficiency target. To some extent, this approach operates today in two forward-capacity markets (New England and Pennsylvania-New Jersey-Maryland power markets). Energy efficiency bids captured 26 percent of the 2,550 MW of new and existing demand resource capacity in the ISO New England's February 2008 auction. Ideally, such markets would attempt to deliver the most cost-effective efficiency to meet targets. These markets, however, are relatively untested, potentially complex and expensive at scale, and require well-developed evaluation, measurement and verification (EM&V) systems. Creating an efficiency market at scale would require development of rules to define tradable credits and could be challenging to administer. If pursued such a market would need to be tested thoroughly to understand all implications before being deployed at a national level. Finally, an EEC market requires a target (e.g., EERS) and faces the challenges discussed under that mechanism (above).
- **Financial incentives.** Utilities and governments offer diverse financial incentives in the form of rebates, price subsidies, and tax incentives to participants in the industrial, commercial, and residential sectors. Though a proven method, incentives do rely on end-user participation and are limited to addressing capital barriers,

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[217] AEO 2003 price elasticity study incorporated into the National Energy Modeling System (NEMS) suggests residential price elasticities of -0.41 to -0.60 and commercial elasticities of -0.39 to -0.45 for different fuels; industrial of -1.0. Energy Information Administration: price responsiveness in the AEO 2003 NEMS residential and commercial building sector models.

including elevated discount rates and access to capital. Further, administrative costs (see below) vary with approach, program maturity, and administrative effectiveness. A scaled-up program should identify the most cost effective channel and administrative structure to drive impact.

The magnitude of the effort implied by pursuing such an extensive integrated portfolio should not be underestimated. The pace of deployment will be a significant consideration, given challenges with the legislative process, manufacturing constraints, and human resources.

- **Legislative process.** Crafting legislation, understanding its impact on stakeholders, and moving through the public process to law and rule-making can consume significant time and often require substantial compromise. Codes typically take 3 years to institute, while new legislation takes an unknowable but considerable amount of time and resources (for example, carbon pricing legislation was first introduced in the U.S. Congress in 1998 and is still under consideration in 2009). Creating the necessary administrative structures will also require considerable time.
- **Manufacturing constraints.** Producing hundreds of billions of dollars of merchandise needed for deployment will be challenging. Nonetheless, some manufacturers have indicated that – if demand signals are clear – they can produce the required products within a few years. For example, SEER-13 air conditioners grew from 5 percent of sales to 90 percent in only 3 years with the introduction of a new standard.[218] Others remain concerned about having capacity to increase output to required levels if the nation were to pursue the full savings identified in this report.
- **Human capital requirements.** Limitations in the available workforce and skill base will likely present a significant challenge. Despite a national appetite for new jobs – especially green jobs – identifying, training, and deploying contractors, inspectors, manufacturers, managers, and administrators within the timeframe envisioned in this report represents a considerable effort. Capturing the full potential could require a workforce of roughly 600,000 or more active over the next decade to develop, produce, deploy, administer, and verify efficiency measures.

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[218] Expert interviews.

## JOB CREATION

Energy efficiency has been much discussed for its potential to create jobs, particularly in an economic downturn. A full economic analysis of energy efficiency (i.e., general equilibrium analysis) is beyond the scope of this work; however, research suggests that the employment benefits of increased national energy efficiency could be significant. The number of jobs created by unlocking the full efficiency potential identified in this report is difficult to forecast, but research suggests that on a national level jobs created through labor intensive retrofits could total 600,000 to 900,000 on-going jobs that persist through the decade covered by this report. This total includes jobs created though two major initiatives:

- **Labor intensive retrofits.** Assuming roughly $290 billion is invested in deployment of labor-intensive efficiency measures in the residential and commercial sectors between 2009 and 2020, energy efficiency retrofits could generate between 500,000 and 750,000 direct, indirect, and induced jobs through 2020:
  - **Direct jobs.** Physical deployment of efficiency measures would involve construction workers (≈60 percent), trade professionals (≈25 percent), and their managers (≈15 percent), with an average salary of $36,000 to $41,000. In weatherization programs direct jobs represent 30 to 40 percent of the jobs created.[1]
  - **Indirect jobs.** Suppliers of materials used in energy efficiency measures, such as insulation or appliance manufacturers, in the United States and overseas, would see 25 to 40 percent of the jobs created, depending on the measures deployed and country where the jobs are located,[2] with an average salary of $26,000.
  - **Induced jobs.** Local jobs generated by a larger workforce (i.e., where direct workers spend their paychecks, such as grocery stores) represent the remaining 25 to 40 percent of jobs created.[3]
- **Energy efficiency programs and codes and standards.** Other energy efficiency programs could create a range of jobs as well. Improved building codes and equipment standards, plus various other efficiency programs, such as rebate or awareness initiatives, would likely create a range of jobs in manufacturing, engineering, program management, and government roles.[4] Increasing enforcement of building codes nationwide – currently at about 50 percent compliance – would also likely require adding building officials in municipalities across the country. In total these jobs are likely to exceed 100,000.

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[1] Economic Opportunity Studies, "How Many Workers Does the Weatherization Assistance Program Employ Now? What Jobs Will the Recovery Act Offer?", 2009.

[2] Indirect jobs include jobs created in other countries at manufacturers, which research suggests may be even larger than the domestic job creation; Robert Atkinson, "The Digital Road to Recovery: A Stimulus Plan to Create Jobs, Boost Productivity and Revitalize America," Information Technology and Innovation Foundation, January 2009. David Swenson and Liesl Eathington , "Determining the Regional Economic Values of Ethanol Production in Iowa Considering Different Levels of Local Investment," Iowa State University, July 2006; Josh Bivens, "Updated Employment Multipliers for the U.S. Economy," Economic Policy Institute, August 2003.

[3] Economic Opportunity Studies; Robert Atkinson; David Swenson and Liesl Eathington; Josh Bivens.

[4] Natalie Hildt, "Appliance and Equipment Efficiency Standards: New Opportunities for States," Appliance Standards Awareness Project, December 2001; David Roland-Holst, "Energy Efficiency, Innovation and Job Creation in California," Center for Energy, Resources and Economic Sustainability, October 2008.

## 3. IDENTIFY METHODS TO PROVIDE THE SIGNIFICANT UPFRONT FUNDING REQUIRED BY ANY PLAN TO CAPTURE ENERGY EFFICIENCY

Defining a portfolio of policies and mechanisms will require trade-offs among the five characteristics defined in Exhibit 39 – experience to date, speed of deployment, complexity of implementation, source of investment, and administration and other costs. Identifying appropriate and sufficient funding for the upfront investment will be a particular challenge, for which there are two broad approaches. "End-user funding" refers to occasions when end-users pay for energy efficiency investments directly (upfront or over time), even when driven by a building code or appliance standard. "Public funding" refers to monies that are provided through any third-party channel (e.g., state, federal, or local tax revenues, $CO_2e$ allowance receipts, utility rates, or system-benefit charges).

- **End-user funding methods.** End-user funding by consumers has proved difficult for capital-intensive measures, due to the multitude of barriers described in Chapters 2 through 4. Partial monetary incentives and supportive codes and standards increase direct funding by end-users by encouraging participation: the former by reducing initial outlays and raising awareness, the latter by essentially requiring participation.[219] Performance contracting represents another method, one that has begun to find acceptance in commercial and industrial markets. ESCOs fund the upfront investment for efficiency improvements or connect customers with a financier, in order to share in the energy and maintenance savings generated by the investments, while the resulting cash flows remain positive for the end-user at all times. The risk of business failure among ESCO clients, as well as ordinary business churn, and the corresponding repayment exposure presents a significant challenge to ESCOs and has limited their effectiveness to date. With a blend of public and end-user funding mechanisms, a loan guarantee program could help overcome this issue; loan guarantees potentially requiring 3 to 6 percent of the invested amount, could help enable the upfront investment needed.[220]
- **Public funding sources.** Load-serving or government entities typically raise funding for energy-supply requirements, such as new power generation, new power and gas delivery infrastructure, or other public goods, by spreading the costs across all consumers. When pursuing energy efficiency utility or third-party programs typically "stimulate" demand through incentives for only a portion of the investment, because much of the benefit flows to participating end-users through lower bills. As an alternative, programs such as the WAP fully fund and execute efficiency improvements with public funds. Utilities or third parties typically gather program funds through system-benefit charges, though less conventional means, such as proceeds from a carbon price, have been discussed. Funding the entire deployment cost of $520 billion would require a system-benefit charge of $0.0059 per kWh across 4,250 TWh of electricity and $1.12 per MMBTU across 24.5 quadrillion end-user BTUs of other fuel for a period of 10 years, the anticipated implementation period. Alternatively, 10 years of a carbon price of $12.50 per ton on 4.2 gigatons of $CO_2e$ emissions could fund the upfront investment as well. These costs would add approximately $120 to the average annual homeowner's energy bill as well as $2,400 and $75,000 to the average commercial and industrial building annual energy bill. However, as mentioned below, average energy bill reductions would more than offset these investment costs. Savings of 24 percent in average customer energy bill from the efficiency savings would more than offset the 8-percent increase in bills to fund the upfront investment.[220]

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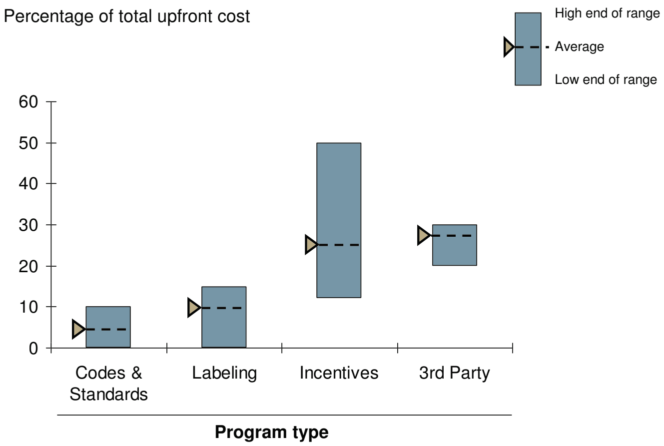
[219] It is worth noting that appliance standards and building codes may reduce the premium required for efficiency measures as manufacturers drive down cost through increased scale; this effect is not incorporated in our analysis.

[220] The student loan model represents the basis of this approach. The insuring agent charges 1 to 2 percent of the credit issuer to guarantee the loan amount and bears the default risk, typically 5 to 6 percent. Applying this model to performance contracting yields a net cost of 3 to 6 percent of the loan amount.

Portfolio designers would also need to consider the efficiency of spending within each solution strategy. Program spending will depend heavily on how programs are designed, the effectiveness of the program and management teams, and many other factors. Nonetheless, different program types do appear to involve different levels of spending. Exhibit 40 shows the average program cost, as well as high and low ranges of typical programs, expressed as a percentage of the upfront investment needed. It is worth noting that codes, standards, and awareness building (i.e., labeling) require the least overhead of the four broad strategies identified. With the scale advantage brought by a national effort, however, program costs for other approaches, namely third-party implementation and provision of incentives, could decrease substantially.

Exhibit 40: Program cost ranges by program type



Source: Scenarios for a Clean Energy Future, Interlaboratory Working Group, 2000; McKinsey analysis, EIA, ACEEE, From 861 filings

The height of the columns on the chart represent the range of administrative costs of different program types, as a percentage of the total upfront costs.

## 4. FORGE GREATER ALIGNMENT BETWEEN UTILITIES, REGULATORS, GOVERNMENT AGENCIES, MANUFACTURERS, AND ENERGY CONSUMERS

Designing and executing a coordinated initiative across more than 100 million residential, commercial, and industrial sites will be a major challenge. If such an initiative is to realize a substantial portion of the efficiency potential available, then many parties will participate, including government agencies, utility regulators, manufacturers, utility companies, interested community support organizations, building owners, and end-users. Forging this alignment should address four concerns:

- Overcoming regulatory barriers in utility ratemaking
- Understanding the relationship between bills and rates
- Establishing responsibility in currently unaddressed areas
- Achieving appropriate evaluation, measurement, and verification.

### Overcoming regulatory barriers in utility ratemaking

The task of aligning a utility organization with the goal of achieving greater energy efficiency and ensuring its objectivity would have two parts: a financial challenge and a cultural challenge.

**Financial challenge.** The financial challenge stems from legacy regulatory practices in rate-making, which base utility revenues on the number of units of energy sold. The price of each unit of energy typically covers the variable costs as well as a significant portion of the fixed costs of generating or producing and delivering the unit of energy, on the basis of projected sales volume. If more units are sold than projected, earnings will be higher as the utility over-recovers its investment; if fewer units are sold, earnings will be lower and the utility will not be compensated for its investment. Rates are periodically "trued up," that is, adjusted to more accurately provide for recovery of and return on investments, but in the time between these "rate cases" utilities face both positive and negative exposure to sales volume fluctuations. Variations in volume can result from many factors, including changes in weather, economic activity, increased penetration of devices, and reductions associated with more efficient devices. Under traditional rate mechanisms, utilities typically under-recover on their investments and see a decrease in earnings when electricity load declines due to energy efficiency initiatives. This erosion in finances becomes an even greater concern if utilities are expected to concurrently provide power purchase agreements (PPAs) to developers for renewable energy or undertake significant construction of renewable assets themselves, because constructing new assets, for example, requires balance-sheet strength and the ability to raise capital. Several options can help overcome this potential disincentive to pursue energy efficiency and address the financial risk associated with other energy goals:

- **Decoupling revenues from units sold.** Decoupling is a system of periodic true-ups in base rates that separates the recovery of authorized fixed-cost revenue from sales volume. While units of energy are still priced above their variable cost, decoupling both restores to the utility costs that are under-recovered, and returns to customers costs that were over-recovered. This is because the revenue collected from unit sales is reconciled to an alternative method for determining target revenue. While addressing the concern energy efficiency raises regarding recovery of existing investments, decoupling raises several concerns for utilities, customers, and regulators. First, utilities may be concerned that decoupling carries unknown regulatory exposure. Furthermore, customers may be concerned that decoupling shifts normal business risks such as weather or slumps in economic activity to ratepayers, rather than leaving them with utilities. However, some regulatory mechanisms exist to shift these risks, especially weather, back to the utility. Finally, regulators may be concerned that decoupling does not provide incentive for a utility to actively pursue energy efficiency; at best, it removes a portion of the disincentive associated with lower sales. In high-growth markets, there is also resistance to decoupling, because it could work against the benefit to utilities of regulatory lag; whereas in declining markets, decoupling works against the benefit to customers of regulatory lag. Thus, while decoupling offers some benefits in mitigating the volume exposure faced by utilities, it may not be the best approach in all areas, and may be insufficient on its own to drive energy efficiency.
- **Migrate to true fixed/variable rate structures.** An alternative approach would involve reducing the per-unit cost of energy to the true variable cost and assessing a flat fixed-cost charge to each customer. Incremental sales up or down would not impact utility profits. Some raise a concern that very low unit prices may work against consumers' desire to reduce consumption. However, prices could be set to accurately reflect the intermediate- or long-term costs of investing in fixed infrastructure and potential climate impact. Such a price signal could reduce consumption to levels appropriate to the "real" cost of energy. There is a practical challenge with this mechanism: migrating from the prevailing approach to a true fixed-variable structure could benefit heavy electricity users relative to others within a rate category (and, for example, might increase the burden on low-income and fixed-income populations). Again, this approach does not in itself create an incentive for utilities to pursue energy efficiency.

- **Modifications to traditional regulation.** Modifications to the traditional volumetric approach to revenue offer an additional set of options. These modifications could include ROE caps or sharing mechanisms to distribute "excess" profits back to customers, more frequent rate true-ups, test cases incorporating projected energy efficiency impact, and/or special trackers to capture costs and lost revenues due to energy efficiency. These modifications can reduce – but will likely not fully remove – the alignment challenge associated with volumetric recovery, though they can overcome some of the other disadvantages cited above.

These mechanisms and others might reduce the disincentive for utilities, but they do not create a positive incentive to pursue energy efficiency at scale. There remains a risk that utilities might choose to remain neutral toward energy efficiency, rather than commit and aggressively pursue the full potential. Regulators will likely need to assure utilities of timely cost recovery of program expenses. Additionally, a number of incentives and modifications to existing recovery mechanisms could motivate utilities to promote energy efficiency. Regulators and legislators have proposed or implemented a number of these mechanisms already:

- **Shared savings.** Similar to the ESCO model for the end-user market, this approach allows for the stream of energy savings to be shared with the utility. Generally, the amount expended on energy efficiency is recovered in the same year, minimizing the utility's risk of recovery. This incentive structure links utility compensation to the savings provided for the customer, and requires a clearly defined methodology for calculating the savings.
- **Performance incentive.** This mechanism is typically linked to program spending or the allocated budget, providing a payment based on performance against energy efficiency spending targets. With this approach as well, utilities recover the costs of energy efficiency programs within the year. This incentive structure links utility compensation to the scale of programs undertaken.
- **Capitalization.** This method links energy efficiency with traditional utility earnings-growth mechanisms by allowing capitalization of actual upfront investments for energy efficiency, which are then recovered over future years on a set depreciation schedule. Some markets provide a higher return on equity – a "bonus ROE" – for energy efficiency-related capital to promote the allocation of capital to energy efficiency projects. Capitalization approaches allow for a customer-owned asset to appear on the utility's books. A key risk of the capitalization model, is the ability of a regulator to eliminate one of these "virtual" (regulatory) assets from the utility's balance sheet, destroying cost recovery in the process.
- **Virtual power plant.** This approach links energy efficiency with traditional utility investment mechanisms by allowing the utility to substitute energy efficiency investments for avoided power plant investments. The utility has responsibility for producing an equivalent level of "capacity" from energy efficiency at a reduced cost relative to construction of new supply, plus an incentive to most effectively deploy that capital. The virtual power plant model faces the same risk of regulatory elimination though as the capitalization model.

These incentive mechanisms can provide a wide range of compensation, depending on the specific values chosen and the level of energy efficiency targeted. It is important to note that the incentives are "exchangeable" in value: for any set of incentives, there are values that will make them equivalent in payout for a specific utility. The primary differences relate to both the nature and degree of the risks borne by utilities and ratepayers. The design and selection of the appropriate incentives and regulatory mechanisms should be based on careful analysis of the unique situation in each regulatory jurisdiction.

In summary, various mechanisms could improve the alignment between the utilities' financial incentives and the challenge of aggressively pursuing energy efficiency. There is not one best answer that will work for all utilities, given the differences in markets, regulatory practices, customer preferences, and utility risk profiles. However, in general we find across rate-making mechanisms and the wide range of potential incentives, that:

- To fully align load-serving entities and local distribution companies or utilities with the goals of energy efficiency, they must recover the revenue associated with their lost load, receive timely recovery of program costs, and earn incentives on energy efficiency to assure their financial health.
- Single solutions are generally not enough to make an energy provider financially whole in the face of energy efficiency. Most shareholder-incentive programs do not fully compensate investor-owned utilities. Neither decoupling nor true fixed/variable structures, though they can reverse the effect of energy efficiency on short-term returns, can by themselves compensate an energy provider for long-term growth in many scenarios.
- A combination of shareholder incentives and fixed-cost recovery mechanisms can make energy providers financially whole in most market structures. The appropriate level of incentive and choice of fixed-cost recovery mechanism will vary based on the market structure, growth environment, initial market position, and mix of chosen mechanisms.

**Cultural challenges.** Beyond the financial challenge of achieving full alignment with greater energy efficiency, many consumers and energy providers will also need to overcome cultural inertia brought on by years of promoting consumption of energy. This mindset is a natural byproduct of the customary business practices, and for many years the growth of energy consumption has brought substantial comfort and benefits to customers. The fundamental challenge will be to change the mindsets and behaviors of employees throughout the energy providers' organizations. The U.S. economy, however, offers many stories of comparable transformations in other industries, be it around such topics as quality control, lean production, innovation, or customer-service mindsets.

### Understanding the relationship between bills and rates

One of the most perplexing challenges associated with energy efficiency in the electricity sector is that although it clearly will drive down average energy bills, the integrated effect on rates (i.e., the cost per unit of electricity) can vary across the U.S., based on how various elements in the rate-setting process are treated. It is certain that rates will increase from where they are today as energy efficiency is incorporated into legacy ratemaking structures. It is also possible that under some circumstances these rate increases will outpace rate increases expected in the business-as-usual scenario even though in the energy efficiency case the overall bills paid by ratepayers would decrease. The relative importance of six effects will drive this uncertainty and will cause rates in some areas of the country to increase compared to business-as-usual while other areas experience a decrease:

- **Reallocation of fixed costs.** Reallocation of existing fixed costs across fewer units of consumed energy puts upward pressure on rates. This effect will depend on the market mechanism that determines how those costs are recovered.[221] This effect occurs, however, regardless of who drives energy efficiency programs or funds the costs, and regardless of any utility incentive payments. Fixed-cost reallocation is an effect of legacy systems of rate-making that charge fixed costs on a variable basis; decoupling and proposed rate designs other than true fixed/variable will not address this issue, as discussed above.

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[221] Fixed costs include generation, transmission, distribution and other non-variable support costs. In regulated markets, prudent fixed costs would be reallocated over remaining sales though there could be a timing lag. In restructured markets, generation costs are recovered through market prices and would likely not be recovered resulting in effectively a transfer of value from merchant generators to rate payers.

- **Avoided new generation and load-serving infrastructure.** Reducing or avoiding investments in additional generation and distribution capacity would place downward pressures on future rates relative to the increases that would have occurred, because energy efficiency is a lower-cost alternative to building new assets. The relative importance of this effect compared to the reallocation effect depends on the size of the existing rate base and the scale of planned new investments.
- **Improvements in the marginal dispatch cost of generation.** Though much more complex, this factor is likely to put downward pressure on rates, particularly in restructured markets. Two effects drive the downward pressure: first is the potential to reduce output from marginally less-efficient generation units (i.e., improve system heat rates); and second is the change in the marginal fuel being burned (e.g., less gas-fired generation and more coal-fired generation as the price-setting mechanism). Though coal-fired generation would set the price more often, carbon output would not increase (as coal generally runs already when gas is setting the price). Carbon prices would dampen this second benefit, because they tend to bring the generation costs of coal closer to generation costs of gas. Potential upward price impacts that could partially offset the downward pressure on rates would include any loss to efficiency of baseload assets with increased cycling, as well as in the near-term, the delayed construction of more efficient assets that could displace older, less-efficient ones.
- **Commodity fuel prices.** Fuel prices could decline due to reduced overall demand (e.g., reduced natural gas or coal consumption). We estimate, however, that the overall impact on rates is likely negligible relative to the range of other factors beyond energy efficiency that impact commodity prices.
- **Carbon prices.** Similarly, if legislators put a price on carbon emissions, deploying energy efficiency could place downward pressure on that cost. This effect will depend on many unknown factors including the price setting mechanism, targets, and allowances.
- **Upfront energy efficiency investments and program costs.** If these outlays are recovered through a public-benefit charge or other rate-based mechanism, they will likewise put upward pressure on rates. Incentive payments to load-serving entities or special-purpose energy efficiency entities would also be included, though they are typically a fraction of the program cost.

Assessing the net impact of these factors requires detailed modeling of load characteristics, economics, and regulatory treatments region by region. In addition, numerous other market effects would occur simultaneously, such as responses to renewable portfolio standards or other environmental requirements, which in combination could lead to very different results. In general, our models suggest that regions with higher levels of purchased and passed-through generation would tend to see decreases in rates, because value would transfer from generators to ratepayers. Regions with higher levels of full-cost recovery on generation assets, and with little or no projected need for capital investment in generation, would see an increase in rates relative to the business-as-usual approach.

### Establishing responsibility in currently unaddressed areas

Certain elements of a program will have natural owners, such as government entities for designing and legislating codes and standards. A key issue, however, will be deciding who should have responsibility (i.e., the authority and accountability) for deploying energy efficiency measures with less clear ownership. The right choice will likely be a topic of debate within each state, involving trade-offs of strengths and weaknesses of different entities against a number of attributes, as illustrated in Exhibit 41. Expertise in the economics of energy consumption, for example, would be important so that the design of a program accounts for such factors as regional climate, rates, existing building stock, prior programs, and the cumulative effect of initiatives. Local energy brand recognition and trust would foster acceptance of programs. An integrated view and responsibility for supply and demand would help ensure coordinated planning and accountability for overall reliability of the energy system. This responsible party would also need a proven ability to organize and manage large-scale programs. Ideally they could be held financially accountable for the delivery of results on time and on budget.

For each type of entity that might lead comprehensive energy efficiency programs, the coloration of the circles represents an estimated starting position relative to various attributes. More color indicates a relatively higher starting position.

Exhibit 41: Overview of entities managing comprehensive energy efficiency programs

● High starting position
○ Low starting position

| Attributes | Load-serving entities | Special-purpose entities* | Govern-ment entities | Energy service companies | Product manufac-turers |
|---|---|---|---|---|---|
| • Expertise in energy consumption and efficiency | ● | ◑ | ◑ | ● | ● |
| • Local energy brand recognition | ● | ◑ | ◑ | ◑ | ◑ |
| • Integrated supply and demand accountability | ● | ○ | ○ | ○ | ○ |
| • Integration with pricing /and metering technologies | ● | ○ | ○ | ◑ | ○ |
| • Financial accountability /for program management | ● | ◑ | ◑ | ● | ● |
| • Integration across fuel opportunities | ◑ | ● | ● | ● | ● |
| • Procurement and hiring capabilities | ◑ | ● | ○ | ● | ● |
| • Objectivity and alignment toward energy efficiency | ○ | ● | ● | ◑ | ○ |

* Similar to NYSERDA, Efficiency Vermont; dedicated entities for energy efficiency program management

Source: McKinsey analysis

Based on these attributes, three likely candidates emerge: utilities, special-purpose entities, such as Efficiency Vermont and Oregon's Energy Trust, and government entities, such as NYSERDA and those used in other countries. For completeness, we also profiled ESCOs and product manufacturers against these criteria, though their likely roles will be to support implementation of energy-service programs that they initiate directly with end-users or as part of a larger program coordinated and to some extent funded through the party with overall responsibility. Utilities emerge with the strongest starting position because they have the natural information-gathering, management, and delivery systems in place through metering and billing functions. Furthermore, their extensive experience managing energy delivery provides skills that will facilitate management of programs and integrated resource planning. They do, however, face several challenges: principally, there are substantial concerns that most current regulatory structures encourage utilities to increase electricity sales and build new assets rather than aggressively pursue a strategy of reducing consumption as discussed above. Additionally, in many service territories, homes with multiple fuels are served by different utilities, complicating delivery of energy efficiency measures.

By contrast, it would be straightforward to align special-purpose and government entities against the goal of driving efficiency and enable them to address all fuels and energy users in a region. Creating special-purpose entities, however, would separate the responsibility for demand- and supply-side planning and accountability. Load-serving entities would retain responsibility for system reliability and likely be reluctant to trust aggressive promises of demand reduction asserted by another organization. Also, this split responsibility would likely adversely impact coordination of energy-pricing and metering technologies needed to reinforce behaviors and monitor consumption.

If governments choose to designate special-purpose or government entities as responsible parties, they should take care to properly design incentives, regulations, and management structures to foster efficient and effective operation. Doing so would be a reasonably straightforward procedure, because it could be a clean-sheet exercise and well worth the time invested to address these issues.

### Achieving appropriate evaluation, measurement, and verification

The difficulty of measuring energy efficiency requires effective evaluation, measurement and verification (EM&V) to provide assurance to stakeholders that programs and projects are achieving the savings claimed for them. EM&V can also provide feedback for program and project design, and assist in attributing savings to participants. If significant levels of energy efficiency are to be pursued and supported by significant levels of public funding, the need for a clear, consistent, and widely accepted EM&V system will be even more important than it is today.

Energy efficiency is hard to measure because it focuses on avoiding consumption rather than on actively producing something; verifying savings is an intrinsically difficult task. Actual consumption may be affected by weather, customer growth, usage differences, device penetration, and economic growth; all of these issues must be considered in determining actual savings impact.

Measuring these attributes exactly and providing a "perfect" EM&V system is not possible; instead, a "sufficient" EM&V system should reflect three key qualities:

- **Consistency.** If investments are to be made with the expectation of future returns that are contingent on the EM&V system, it will be critical that the rules for EM&V-associated rewards and penalties are internally consistent and remain fairly stable over time. This consistency is important for all parties, if they are to plan investments in energy efficiency.
- **Simple in design.** While a more complex EM&V system might permit more precise and accurate measurements and approximations of energy savings, as well as more detailed ways to attribute the drivers of those energy savings, the value of such a system must be considered in the context of the complexity and cost it will drive.
- **Address both inputs and impact.** Measurement methods should incorporate the activities undertaken by the responsible party, to ensure that activities are undertaken in an appropriate manner, and the measurement of energy consumption to determine the impact of those activities.

As California's efforts to improve energy efficiency have shown, even in a state that has taken a relatively aggressive approach to capturing energy efficiency, the issues surrounding attribution can be complex. Detailed EM&V programs that cause a slowdown in the pursuit of energy efficiency are unlikely to merit their expense. For example, in some California programs, discussions of attribution sought to resolve differences of $70 million in incentives, of a total program spend of $2.1 billion – with benefits that exceed $4 billion. A detailed EM&V program that risks disrupting the pursuit of energy efficiency is unlikely to deliver savings equal to the opportunity cost. For example, slowing the capture of the $4 billion in benefits by four months decreases their present value by $70 million.

The International Performance Measurement and Verification Protocol (IPMVP) provides a basis for analyzing project-level savings from energy efficiency measures. Though the IPMVP primarily addresses project savings in commercial and industrial sectors, it could provide the basis for broader measurement of energy efficiency programs. Development of this protocol has been supported by the Department of Energy and provides the basis for measurement in federal Energy Services Performance Contracts. A shared foundation for EM&V of this sort might provide the consistent methodology upon which energy efficiency program managers can build.

## ELECTRIC VEHICLES

Electric vehicles (EVs) hold the potential to offer U.S. consumers a practical alternative to gasoline-powered vehicles by 2020. A variety of electric vehicles, including electric-only vehicles (or battery electric vehicles, BEVs), as well as plug-in hybrid electric vehicles (PHEVs), due to reach the market in the next several years could offer a battery-only driving range sufficient for many urban and suburban commutes.

Vehicle electrification impact[3]

| Electrical vehicle penetration Percent of fleet | Load increase TWh |
|---|---|
| 1% | 8 |
| 5% | 41 |
| 10% | 84 |
| 15% | 126 |
| 20% | 168 |
| 100% | 840 |

If electric vehicles reach significant penetration levels, electric load levels could increase substantially. The table at right shows the impact that various levels of electric vehicle penetration could have on the total load levels in the economy.

### Challenges

Even at relatively low levels of market penetration, electric vehicles will pose a challenge to the electricity grid. Highly localized energy assessments will be needed to ensure that peak and non-peak generation capacity and the transmission and distribution system can meet expected load requirements of PHEVs and BEVs. Although generation capacity available during non-peak hours could accommodate electrification of up 73 percent of the current vehicle population,[1] vehicle charging would have to be timed to avoid peak usage; otherwise, additional generation capacity will be needed. If EV charging were not timed around the peak in California, for example, peak load could increase by 10 percent (3,700 MW).[2] Requirements for charging points, such as the build out of infrastructure and the actual power demand of each charging point (220-volt/60-amp versus 120-volt/15-amp), could strain local power grids and require changes to distribution capacity. This requirement could limit the creation of “rapid charging” stations and restrict the number of cars that can be charged at any one time.

Beyond the challenges posed to utilities and the electricity infrastructure, end-users will need to learn new behaviors, such as remembering to plug in their car for charging, limiting use of other vehicle options (e.g., the air conditioner or radio) to optimize range, and perhaps learning a different way of interacting with their cars (e.g., swapping batteries). Consumers will also need to be aware of the availability of charge points during daily trips, with competition for these charge points arising if demand outstrips supply.

### Approaches

Emerging smart grid technologies are expected to increase the connectivity, coordination, and automation of the electricity grid, addressing some of the energy usage and capacity concerns, though new capacity for generation, transmission, and distribution will eventually be required. Smart grid applications could allow utilities to increase the price of electricity at peak hours, for example, encouraging off-peak charging. A smart grid may eventually have the ability to precisely reduce load, notifying a customer that charging will not occur or will take longer, perhaps allowing the customer to opt-in or opt-out, depending on the price they are willing to pay. Local dynamics in power markets will affect the degree to which new generation comes from renewable sources and what T&D investments are needed (especially relevant for isolated parts of the electricity grid).

In addition to changes in the energy infrastructure, building out the charging infrastructure and ensuring consumer acceptance will need attention. Possible solutions could include municipality-built public charging stations, addition of battery-swap stations to gasoline stations, and marketing campaigns by public and private entities to educate the public and promote EVs to potential customers.

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[1] Pacific NorthWest National Lab/U.S. DOE; Wirtschaftswoche.

[2] Cal ISO website, McKinsey.

[3] Estimated impact to load based on 12,000 annual miles per vehicle, 280 million vehicles in the U.S. passenger and light truck fleet by 2020, and 4 miles traveled per kWh.

### 5. FOSTER INNOVATION IN THE DEVELOPMENT AND DEPLOYMENT OF NEXT-GENERATION ENERGY EFFICIENCY TECHNOLOGIES TO ENSURE ONGOING PRODUCTIVITY GAINS

Technology development plays a small role in the potential identified in the near term targets of this report. However, we expect that innovative and cost-effective energy-saving technology will continue to emerge. It will likely be cost effective to fund its research and development in order to accelerate its path to market.

The Inventions and Innovation (I&I) Program run by EERE demonstrates that fostering innovation can be cost effective and have substantial impact. I&I was established in 1976 as the Energy-Related Inventions Program (ERIP); through 2000, it received cumulative funding of $117 million. More than 25 percent of I&I grantees successfully entered the marketplace, delivering a cumulative 973 trillion end-use BTUs of energy savings since I&I's inception. The $117 million investment has saved $4.92 billion in cumulative energy costs to date. As of 1995, administrative costs represented $2.20 per MMBTU of end-use energy savings and grants represented $1.40 per MMBTU.[222] A challenge in evaluating impact arises from the inability to know how such technology would have emerged without assistance. Nonetheless, the attractive leverage and cost structure of this program suggests that fostering innovation warrants ongoing investment.

□ □ □

In the nation's pursuit of energy affordability, climate change mitigation, and energy security, energy efficiency stands out as perhaps the single most promising resource. In the course of this work, we have highlighted the significant barriers that exist and must be overcome, and we have provided evidence that none are insurmountable. We hope the information provided in this report further enriches the national debate and gives policymakers and business executives the added confidence and courage needed to take bold steps to formulate constructive ways to unlock the full potential of energy efficiency.

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[222] *Scenarios for a Clean Energy Future*, Interlaboratory Working Group, ORNL/CON-476 and LBNL-44029, November 2000.

# Appendices

## A. Glossary

**Abatement.** The purposeful reduction of greenhouse gas emissions or their rate of growth.

**Accelerated deployment.** The deployment of new technologies before the end-of-life of the existing stock. Accelerated deployment is NPV-positive when the lifetime cost savings of the more efficient technology more than exceed the present value of the total (rather than incremental) upfront investment. See also "Stock and flow methodology."

**ASHRAE.** The American Society of Heating, Refrigerating and Air Conditioning Engineers, which publishes a series of standards for heating, cooling, and ventilation systems in commercial buildings that often serve as the basis for commercial building codes.

**BTU.** British Thermal Unit, the quantity of heat energy required to raise the temperature of one pound of water from 60° to 61° Fahrenheit at a constant pressure of one atmosphere. BTUs are used throughout this report as a standardized measure of energy output and consumption.

**Building shell.** The exterior structure of a building that protects the interior space, facilitating control of the interior climate. The shell consists of the roof, exterior walls, exterior windows and doors, the foundation, and the basement slab or lowest level floor.

**BAU baseline.** The reference-case forecast for U.S. energy consumption in 2020, used in this report as a standard against which incremental energy efficiency potential is calculated. The business-as-usual forecast derives from the U.S. Energy Information Administration's Annual Energy Outlook 2008 and other public sources. Although the AEO baseline contains some energy efficiency improvement, the baseline projects energy consumption in future years without a concerted, economy-wide effort to improve energy efficiency.

**CHP.** Combined heat and power, also known as "co-generation," is the use of a heat engine or a power station to generate electricity and useful heat energy from a single fuel at a facility near the consumer.

**$CO_2e$.** Carbon-dioxide equivalent, a standardized measure of greenhouse gas emissions developed to account accurately for the differing global warming potentials of various gases. Emissions are measured in metric tons of $CO_2e$ per year, usually in millions of tons (megatons) or billions of tons (gigatons).

**Consumer utility.** Functionality, such as a level of comfort, garnered from a specific energy end-use. Adjusting a thermostat or reducing the number of hours an electronic device is used in a day represent changes in utility. In a strict economic sense, maintaining consumer utility assumes a constant economic surplus for the consumer while delivering against a common benefit. Modeling of efficiency potential and energy use in this report assumed no change in consumer utility.

**Community infrastructure.** Energy-consuming devices not directly associated with a specific building. These end-uses would include municipal infrastructure (e.g., water treatment and distribution systems) and telecommunications infrastructure.

**EISA.** Energy Independence and Security Act (2007), passed by Congress to move the United States toward greater energy independence principally through greater energy efficiency and increased use of renewable fuels. It also directs the federal government to be a model in its own energy usage.

**Energy intensity.** The number of BTUs of energy consumed for each dollar of economic value created.

**EM&V.** Steps to evaluate, measure, and verify that implementation of an energy efficiency measure has produced the expected energy savings. It may include ensuring those savings are properly attributed.

**ESCO.** An energy services company is a for-profit or not-for-profit entity dedicated to providing energy solutions to business and/or residential customers, including such services as energy efficiency audits, implementation of efficiency measures, evaluation of the performance of measures, or leading energy conservation efforts.

**Existing stock.** Technologies in use in the business-as-usual baseline at the beginning of 2009, which serves as a starting point for all modeling. See also "Stock and flow methodology."

**Gt.** Gigaton, a unit of weight equivalent to 1 billion metric tons or 2.2 trillion pounds.

**GW.** Gigawatt, a unit of electrical power equivalent to 1 billion watts.

**GWh.** Gigawatt hour, a unit of electrical energy equivalent to the work done by 1 billion watts acting for 1 hour.

**Heat rate.** Efficiency of a power plant, measured by calculating the number of BTUs of energy input per kilowatt-hour of power output.

**HERS.** Home Energy Rating System, measurement of a home's energy efficiency that provides a score of 0 (net zero energy building) through 100 (based on the 2006 IECC) and higher. A 1-point decrease in score represents a 1 percent decrease in energy consumption.

**HVAC.** Heating, ventilation, and air conditioning, also known as space conditioning; end-uses of energy to heat, cool, and circulate the air of the interior of a building. This report uses the term "HVAC" generically to refer to space conditioning systems, whether a building has a heating system, a cooling system, an air exchanger or one, two or three of those systems.

**KWh.** Kilowatt hour, a unit of electrical energy equivalent to the work done by 1 thousand watts acting for 1 hour. Standard unit of residential electricity pricing; for example, a 100-watt light bulb burning for 10 hours would consume 1 kilowatt hour.

**Load-serving entity.** Load serving entities provide electricity to end users, and include investor-owned utilities, municipal utilities, cooperatives, among other entities.

**LEED.** Leadership in Energy and Environmental Design, a widely recognized certification given to buildings for excellence in sustainable building design. Based on a whole-building approach, different tiers of LEED certification are granted by the U.S. Green Building Council, based on the performance of the building in various areas of human and environmental health, with energy efficiency an important criterion.

**Life-cycle benefits.** The energy savings of an energy efficient device that accrue over the useful life of the device. This does not include energy to create the device.

**MUSH.** Municipal, university, school, and hospital; these public-sector buildings are typically able to realize the potential of attractive energy efficiency measures, because they do not change ownership at the rate of private enterprises and thus do not need accelerated payback of the capital invested in energy efficiency measures.

**MMBTU.** 1 million BTUs.

**MWh.** 1 megawatt hour, a unit of electrical energy equivalent to the work done by 1 million watts acting for 1 hour.

**NPV-positive.** Net-present-value-positive, in which the discounted future cash flows from future energy savings outweigh the initial upfront capital investment needed to implement the measure.

**PAYS.** Pay-as-you-save, a loan made or administered by an energy provider to cover an upfront investment in energy efficiency measures. The end-user repays via the utility bill with money saved through reduced energy usage such that no initial investment is required of the end user.

**Performance contracting.** An agreement between an energy services company (ESCO) and another entity in which the ESCO assumes responsibility for reducing energy consumption on the premises in specified ways for the period of the contract. The ESCO installs agreed-on energy efficiency measures and recoups its investment through contracted payments, which represent a portion of the energy savings that the entity receives from the efficiency measures.

**Plug load.** Energy consumed by electrical devices that plug into the wall, typically various electronics products and small appliances. Examples include TVs, PCs, hairdryers, coffee machines, and thousands of other similar products. Consumption in this category is highly fragmented across an average of 20 devices per household.

**PBC.** Public benefit charge, a fee added to energy bills to pay for public goods.

**RPS.** Renewable Portfolio Standards, a government mandate requiring that a certain amount of energy generated or sold in a given area, or a certain amount of energy capacity in a given area, derive from renewable energy sources, such as geothermal, wind, biomass, or solar.

**Retro-commissioning.** Process by which HVAC and other building systems are tested and adjusted to ensure proper configuration and operation for optimal efficiency. This may involve installing correctly sized motors, sealing ducts, repairing leaks in and recharging the refrigeration system, among a wide variety of measures.

**Retrofit.** Changes made after initial construction and before the expected end-of-life of the asset, typically the building shell.

**Space conditioning.** Energy consumed in the heating, cooling and ventilation of interior spaces in buildings.

**Standby losses.** Energy consumed by electrical devices while plugged in to a socket but not in active use.

**Stationary use of energy.** Energy consumed by the U.S. economy in a year, except for that used in transportation (i.e., the movement of vehicles, including transportation in mining, construction, and agriculture) and in the production of asphalt or chemical feedstock. This report analyzed approximately 81 percent of the stationary energy consumed in the U.S.

**Stock-and-flow model.** This methodology calculates energy savings potential relative to the business-as-usual (BAU) case. The model projects BAU energy consumption for future years by replacing equipment stock according to current customer preferences. In calculating the efficient scenario it substitutes energy efficiency measures for those technologies when it is NPV-positive to do so. These substitutions include upgrades in new buildings, as well as replacement of technologies contained in existing buildings.

- Accelerated deployment. The deployment of new technologies before the end-of-life of existing stock. Accelerated deployment is NPV-positive when the lifetime cost savings of the more efficient technology more than exceed the present value of the total (rather than incremental) upfront investment.
- NPV-positive choice. Technology in a specific building-Census division category that has the lowest annualized cost, taking into account such factors as energy cost, annualized capital cost (over the lifetime of the technology), and other operating expenses.
- Existing stock. Technologies used in the BAU case at the beginning of 2009, which serves as a starting point for efficiency modeling.

**TBTU.** Trillion BTUs.

**TW.** Terawatt, a unit of electrical power equivalent to 1 trillion watts.

**TWh.** Terrawatt-hour, a unit of electrical energy equivalent to the work done by 1 trillion watts acting for 1 hour.

**Waste heat recovery.** Capturing and using heat for productive work that is a byproduct of energy-intensive processes or steam systems that would otherwise be ejected into the environment.

**Weatherization.** Modifying a building to increase its energy efficiency, usually through measures to decrease infiltration of outside air and minimize the loss of heated or cooled interior air.

# B. Methodology

The purpose of our research has been to evaluate the barriers that impede capture of energy efficiency today and to provide perspectives on how potential solutions map to individual and broader system-level barriers to unlocking the potential available in the U.S. economy. We have analyzed a multitude of energy efficiency opportunities to determine how much of the potential is NPV-positive, thereby providing a fact base for our assessment of barriers and potential solutions.

This research differs from other reports on energy efficiency in a number of important ways. Specifically, we would like to note four points about our scope:

- We did not attempt to conduct a technical analysis on future energy efficiency technologies.
- We do not predict how much energy efficiency potential can or will be achieved.
- We attempted to be comprehensive – but not necessarily exhaustive – of all barriers and solutions.
- We did not assess second-order effects (e.g., impact on natural gas prices) or broader GDP impacts.

As noted previously, we focused on stationary uses of energy. We, therefore, excluded energy used in all modes of transportation, such as motor vehicles, trains, ships, and aircraft; with this focus, we also excluded energy used in agriculture, construction, and mining operations.

This appendix covers three aspects of our methodology:

1. Assumptions and methodology for calculating NPV-positive energy efficiency potential, including the micro-segmentation process and subsequent re-aggregation of micro-segments into addressable clusters of potential
2. Our approach to structuring the barriers and attributing them to clusters
3. Means of mapping solutions to address the major barriers in these clusters.

## 1. CALCULATING NPV-POSITIVE POTENTIAL

Data sources for the National Energy Modeling System (NEMS) served as the foundation of our residential and commercial potential analysis. The *Annual Energy Outlook 2008*, Table 2, supplemental tables 24-34, and unpublished AEO data serve as the foundation for the industrial potential analysis. Where insufficient data were available, we drew on public or private sources to supplement the NEMS database and provide the necessary resolution for our analysis.[1] In aggregate, this analysis addresses 36.9 quadrillion of the 45.5 quadrillion BTUs (81 percent) of end-use energy in 2008.

There are six essential components to our analysis of NPV-positive potential:

- Baseline consumption
- Stock and flow methodology
- NPV-positive selection criteria
- Technology characteristics
- Bursting of data into micro-segments
- Re-aggregation of data into addressable clusters.

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[1] In the commercial sector, 2.1 quadrillion BTUs of consumption rely on other public sources; in the industrial sector, 15.3 quadrillion BTUs of consumption rely on public sources and 4.0 quadrillion BTUs rely on private sources.

### Baseline consumption

Our baseline consumption matches the *Annual Energy Outlook 2008* for 2008 and 2020 to within 1.2 percent. Furthermore, these data match the *AEO 2008* when cut by fuel or Census division (Census region, in the case of industrial, represents the finest degree of geographic resolution). Note that this baseline incorporates no price for carbon and includes only legislation that has passed into law (i.e., the Energy Independence and Security Act of 2007, but not the American Recovery and Relief Act of 2009).

### Stock and flow methodology

We used slightly different methodologies across the sectors, depending on the availability of data and the nature of the opportunities.

**Residential and commercial sectors.** Our residential and commercial modeling considered almost 500 technologies deployed against 24 end-uses. Each technology is characterized by a working life time, upfront capital spend, annual maintenance spend, and energy efficiency impact. Current energy consumption by end-use is provided by NEMS through the Renewable Energy Consumption Survey (RECS) and Commercial Building Energy Consumption Survey (CBECS). We further characterized this consumption by the ratio of technologies deployed in the existing equipment stock.

We modeled the deployment of newer, more energy efficiency technologies in two ways: at end of life and on an accelerated basis.

- **End-of-life replacement.** As each technology reaches the end of its useful life, our model calculates the total levelized cost of all equivalent technologies that could replace it. The "NPV-positive," potential is calculated based on deployment of the technology with the lowest levelized cost.
- **Accelerated replacement.** To more accurately calculate the opportunity in retrofitting buildings, we also considered accelerated deployment. If the total levelized cost of a new technology is less than the levelized energy cost of an existing technology in the current stock, then the model replaces the current stock with the new technology immediately. This occurs in two ways: when technological advances reduce the levelized cost of a technology (as is the case with general-use LED lighting in 2017) or in the first year of the calculation (as is the case with a number of technologies that could be retrofit into buildings remain undeployed today).

**Industrial sector.** Such detailed data is unavailable for the industrial sector. Instead our model evaluates opportunities using an internal rate-of-return (IRR) calculation for potential measures available in a given year, adjusted to avoid double counting opportunities incorporated in the baseline assumptions through 2020. We separated out the five largest energy-intensive industries – those with 10 or more BTUs of energy input per dollar of output (pulp and paper, cement, refining, chemicals, and iron and steel) – and, using expert interviews and more than 15 secondary industry resources, analyzed in detail the efficiency potential in these industries. To accurately assess the efficiency potential in their manufacturing processes, we calculated the NPV-postitive efficiency potential for more than 150 measures across these five industries. The savings percentage for each industry was calculated against its consumption, and these percentages were averaged (11 percent across the five industries). We used the resulting savings percentage as a baseline to identify the energy efficiency potential for process energy in non-energy-intensive industries. Interviews with industry experts revealed that on a percentage basis, the opportunity to improve efficiency was greater in these industries, varying by business size (large businesses, 13 percent; medium-sized businesses, 14 percent; small businesses, 15 percent), because less attention has been paid to energy efficiency in these businesses.

We calculated most of the potential in energy support systems (i.e., waste heat recovery, steam systems, electric motors) for each energy-intensive industry using more than 50 measures that the team had identified through expert interviews and industry reports. We determined the savings potential, as well as capital costs, identifying the NPV-positive potential for these meausres. Waste heat recovery measures, which do not consume energy but decrease the energy required system-wide by helping to pre-heat fuel, provide incremental energy for other processes or supply energy to support systems. The team calculated the average energy efficiency savings potential across the energy-intensive industries and used this to calculate the efficiency potential for non-energy-intensive industries by multiplying it by the energy consumed in these industries for energy support systems. For building systems, the team used the more detailed commercial model and the savings rate calculated across appropriate commercial building types to find the efficiency potential across all industrial building systems (those pertaining to the building itself, rather than its industrial functions), both for energy- and non-energy-intensive industries.

**Combined heat and power.** We modeled industrial and commercial combined heat and power (CHP) applications separately, primarily because a CHP system increases on-site fuel consumption while increasing the efficiency of system-wide heat and electricity production (including off-site generation).

- **Industrial applications.** We estimated the potential for industrial CHP based on the EIA's projected steam demand supplied by "non-CHP" sources, by region and industry. We grouped this potential into five sizes of CHP systems (from less than 1 MW to greater than 50 MW) based on plant sizes and steam demand, across six industry groups and the four Census regions of the country. Each of the modeled CHP systems were sized to the thermal load and matched to the power-to-steam ratio of the specific industry. We cross-checked these results against estimates for generation potential from Oak Ridge National Laboratory and the Department of Energy. By comparing the economics of a CHP system to the installed traditional system using AEO 2008 supplemental data, we calculated the total potential for CHP for each region and industry subgroup.
- **Commercial.** There has been limited use of CHP in the commercial sector to date, with roughly 10 GW of generation capacity installed. Our model, therefore, looked at the full potential of expanding CHP in this sector. We analyzed each building type for CHP suitability (based on expert interviews, case studies, and cost analysis) across three sized-based building groups: 1,000-10,000 sq feet, 10,000-100,000 sq feet, and more than 100,000 sq ft. If a building type was suitable for CHP, we calculated opportunities for retrofit CHP systems against the full replacement cost of central energy plants, taking into consideration thermal heating, water heating, cooling and electrical capacity and demand. For new buildings, we compared these costs to the incremental cost of installing a CHP system in place of a standard boiler. Drawing on information from NEMS for capacity factors (the ratio of annual equipment output to output of the equipment at 100 percent utilization) for each building system (e.g., water heating, HVAC, miscellaneous electricity demand) in each type of building, we calculated the full economic potential for energy generation for each building type sub-group by Census division.

### NPV-positive selection criteria

We used three criteria to define the "NPV-positive" energy efficiency potential of each efficiency measure:

- **Technology costs.** These include incremental capital (or in the case of accelerated depreciation, total capital cost), installation, and additional operation and maintenance cost. This report uses the DOE's Technology Report as used by NEMS. It specifies for each end-use a set of available technology-vintage combinations that define these parameters (discussed in greater detail below).

- **Value of energy saved.** The value of energy saved is more challenging to quantify. A full treatment of avoided energy costs would require detailed consideration of primary energy savings and lies beyond the scope of this report. There is, however, a range of energy values to draw on. Each unit of energy saved will draw from this range as specified by end-use, supply assets for the selected geography, the regulatory environment, timing, and business-as-usual forecasts. This report values energy saved at Census-division industrial retail rates from AEO 2008, because it serves as a central value that is publically available and well understood. The full range of avoided costs, from lowest to highest, includes:
    - **Cost of generation.** This cost attempts to identify the variable component of generation cost through fuel and operations of impacted plants and early plant retirements (with or without regulated asset recovery). It does not capture impact of energy efficiency on capacity, transmission, or distribution.
    - **Wholesale price.** The wholesale price represents the average generation price, including utility cost recovery, of existing assets. It serves as a useful proxy for the average value of existing energy, but it does not capture the impact of energy efficiency on capacity, transmission, or distribution.
    - **Industrial retail rate.** The industrial retail rate includes the benefits of the wholesale price approach while also attributing system value of avoided capacity, transmission, and distribution. It is worth noting the industrial load factor underestimates the system load factor.
    - **Customer-specific retail rates.** These rates serve as the best tool for applying a participant "lens" to the efficiency potential, when attempting to understand when a retail customer should act to reduce their energy bills. These rates may overvalue the savings from transmission and distribution, because many fixed costs are embedded in customer-specific retail rates.
    - **Least-cost avoided new build.** This value presents an attractive option, because unlocking energy efficiency is likely to defer or eliminate construction of some new assets. Given the uncertainties in the business-as-usual forecast and the amount of efficiency unlocked, however, calculating scenarios accurately is a significant challenge, which could call into question the accuracy of results relying on the necessary assumptions.
    - **Avoided carbon-free build.** This option resembles least-cost avoided new build, except that it focuses on carbon-free sources of energy. It suffers from similar modeling challenges.
- **Discount factor.** The discount factor (or rate) represents the relative value of savings over time. Similar to discounted cash flow analysis, future energy savings in a given year, "Y," are discounted to present-day values by the amount $(1+\text{DF})^{-y}$ where DF is the discount factor in percent.

By selecting a cost of avoided power and a discount factor from among the available options, it possible to construct a cost test to determine whether – and for whom – energy efficiency potential is NPV-positive. Specifying industrial retail rates and a 7-percent discount factor creates a total-resource cost test (provided all deployment and program costs are included, regardless of funding source). Alternatively, combining customer-specific retail rates and a customer's discount factor (which many argue can be as high as 20 percent) create a participant-focused cost test.

## Technology characteristics

The technology characteristics derive from the DOE's Technology Reports, as used by NEMS. This set of characteristics includes limited innovation, an issue that could become a concern when attempting to model efficiency potential over longer timeframes. The characteristics do include expected technology improvements and cost compression in existing technologies. We further tested the sensitivity of our results to these assumptions by considering the more aggressive scenario in the Technology Report.

Characteristics of building shell technologies came from other sources. Lawrence Berkeley National Laboratory's Home Energy Saver provides publicly available energy-consumption modeling for homes, with recommended cost-effective upgrades. This report categorizes all 4,822 residential homes in the RECS survey by their energy use per square foot into five or six classes for each of five climate zones, depending on the climate zone, in order to understand likely characteristics of existing stock and identify cost-effective upgrades. It includes such relevant variables as square footage, resident income, and year of construction, to further identify these opportunities. We also drew upon work by the National Renewable Energy Laboratory (NREL) on zero-net-energy building potential and retro-commissioning to understand commercial existing and new build opportunities.[2]

## Bursting of data into micro-segments

Bursting of data into micro-segments to identify and address barriers drew upon the EIA's energy consumption surveys, Census data, and other sources to generate tens of thousands of consumption segments across the three sectors. While not statistically significant at this level of resolution, the data allowed us to identify relevant characteristics to multiple levels of depth that, when combined, produced samples that drove key findings in this report and could be used for further research. Our modeling accomplishes this by "bursting" the demographic characteristics into the lower resolution data (similar to an outer product of two vectors). This does represent an approximation of energy consumption within such a "micro-segment" of the population, provided that data remain aggregated at a high enough level of depth to remain statistically significant as discussed above.

Exhibit B-1 shows characteristics that we used to burst the residential, commercial, and industrial sectors into micro-segments. The result was 75,000 micro-segment and end-use combinations in the residential sector, which allowed us to see the important differences across regions, and across different building types, as well as understand the potential agency barriers, and conduct other important analyses. We burst the commercial sector into 39,000 micro-segment and end-use combinations, which enabled comparisons between public and government micro-segments and the split across the multiple types of buildings, each with very different energy needs. Our micro-segmentation in the industrial sector was less detailed, due to limited availability of data; the industry and geographic splits proved to be the important factors for identifying efficiency potential in the sector.

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[2] B. Griffith et al., "Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector", NREL, December 2007. Evan Mills et al., "The Cost-Effectiveness of Commercial-Buildings Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States," LBNL, Portland Energy Conservation Inc, Texas A&M University, December 2004.

Exhibit B-1: Segmentation of energy use

| | Category | No. of segments | Segments |
|---|---|---|---|
| Residential | Census division | 9 | New England, Mid-Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific |
| | Building type | 3 | Single-family, multi-family, manufactured home |
| | Age group | 3 | Young (<30), middle-age (30-55), senior (55+) |
| | Income group | 4 | Low-income (<$30K), middle-income ($30-$50K), upper-middle-income ($50-$100K), high-income (>$100K) |
| | Age of residence | 4 | Pre-1940, 1940-1969, 1970-1990, post-1990 |
| | Neighborhood | 3 | Urban, suburban, rural |
| | Occupant/bill-payer | 3 | Owner-occupied, tenant-occupied/owner pays utility bill, tenant-occupied/tenant pays bill |
| | Energy end-use | 14 | Building shell, cooling, heating, cooking, clothes washer, dishwasher, dryer, freezer, refrigerator, water heater, plug-load devices, regular lighting, torchiere lighting, linear fluorescent lighting |
| | Fuel type | 5 | Electricity, natural gas, liquid petroleum gas, distillate oil |
| Commercial | Census division | 9 | New England, Mid-Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific |
| | Building type | 11 | Assembly, education, food sales, food service, health care, lodging, office – large, office – small, merchandise/service, warehouse, other |
| | Owner category | 2 | Private, government |
| | Year of construction | 3 | Pre-1970, 1970-1989, post-1989 |
| | Occupant | 2 | Owner, tenant |
| | Number of businesses | 2 | Single, multi-business |
| | Size of business | 2 | Small (<100 FTE), large (>100 FTE) |
| | Energy end-use | 12 | Cooking, cooling, distributed services, heating, insulation, lighting, miscellaneous electrical, non-PC plug load, PCs, refrigeration, ventilation, water heating |
| | Fuel type | 3 | Electricity, natural gas, distillate oil |
| Industrial | Census region | 4 | Northeast, Midwest, South, West |
| | Industry | 5 | Cement, chemicals, iron & steel, pulp & paper, refining, 14 non-energy-intensive industries |
| | Size of company | 3 | Small (<100 FTE), medium (100-250 FTE), large (>250 FTE) |
| | Energy end-use | 6 | Electric motors, process energy, steam systems, waste heat recovery from processes, waste heat recovery from steam systems, building potential |
| | Fuel type | 4 | Electricity, natural gas, petroleum, other |

### Re-aggregation of data into addressable clusters

In re-aggregating data into addressable clusters of efficiency potential, we used available consumption characteristics and/or demographics to organize the micro-segments into clusters that solutions could address. Fourteen clusters of consumption emerged as relevant, as described in the body of this report. The most significant traits used to define these clusters represent an amalgamation of criteria that reflect the existence of similar barriers, responsiveness to particular solutions, and/or common traits relevant for consumption or efficiency potential. The most relevant characteristics that define these clusters include home owner income, building age (i.e., new versus retrofit buildings), specific end-uses or opportunities (e.g., electrical devices, community infrastructure, waste heat recovery), private versus government ownership structure, and energy intensity.

## 2. BARRIER STRUCTURE AND ATTRIBUTION

Though it is tempting to address the barriers to energy efficiency improvements using a customer purchasing funnel, such an approach would provide too limited a view of the barriers. Specifically, it would omit barriers outside the end-user's control, such as pricing distortions, adverse bundling, and technology availability. Our approach to these opportunity-specific barriers instead captures dozens of barriers identified in a large body of research dating back decades[3] and structures them into twelve barriers, which align with three discrete gates through which efficiency measures must pass to deliver energy savings:

- **Structural.** Is the opportunity available to the end-user, or are there structural limitations to the end-user's ability to capture the benefits?
- **Behavioral.** Will the end-user choose to behave in a manner consistent with pursuing the savings?
- **Availability.** Are the savings available to an end-user who can structurally capture them and who chooses to pursue them?

Some of these barriers are quantifiable; for example, it is possible to assert that agency barriers arise if and only if the building or appliance owner and the payor of energy costs are different economic agents (e.g., a tenant and a landlord). Our demographic data indicates that, for example, agency issues inhibit the capture of 8 percent of the retrofit potential in the residential sector and 5-25 percent of private building retrofit potential dependent on building type in the commercial sector. Other barriers are less quantifiable. Exhibit B-2 arrays the 12 barriers and describes the means used to attribute and, where possible, quantify their impact against the clusters.

Exhibit B-2: Quantification of opportunity-specific barriers

▨ Quantified in report
☐ Not directly quantified

| | | |
|---|---|---|
| Structural | ▨ | **Agency:** Building shell improvements, HVAC and major appliances: rented buildings in which the renter pays the utility bill. Office equipment and plug load: rented buildings in which the owner pays the utility bill. |
| | ▨ | **Ownership transfer issue:** Measures with a longer payback than the expected length of ownership of a building (e.g., 6-12 years for residential depending on building type) |
| | ☐ | **Transaction barriers:** Incidental costs incurred in deployment, including shopping time, research time, disruption of lifestyle or business activity during an upgrade, commercial and industrial procurement time and system issues, industrial space constraints |
| | ☐ | **Pricing distortions:** Varies largely by geography and rate structure and depends largely on price elasticity of customers |
| Behavioral | ☐ | **Risk and uncertainty:** Largest impact on measures with lowest level of awareness and information, including building shell and HVAC upgrades |
| | ☐ | **Awareness and information:** Surveys of awareness of efficient technologies, e.g., ENERGY STAR products, reveal relative levels of awareness for different measures. Additionally, levels of energy audits gives insight into the percent of residents and businesses that have actively sought customized energy information for their buildings |
| | ☐ | **Custom and habit:** Measures with high level of purchasing habit that is difficult to break, e.g., procurement processes or a customer replacing an appliance with exact model |
| | ▨ | **Elevated hurdle rate:** Measures with longer paybacks than purchasers are willing to wait for (i.e. purchasers have high discount rates), two years or less for residential customers and three to four years for commercial |
| Availability | ☐ | **Adverse bundling:** Measures or buildings in which high efficiency is paired with other costly features |
| | ▨ | **Capital constraints:** Measures with high up front capital relative to financing available to customers, notably low income segment in residential, commercial community infrastructure and commercial and industrial CHP |
| | ☐ | **Product availability:** Measures where efficiency upgrades are not widely available (e.g., holistic contractors for building shell and HVAC upgrades, residential water heaters, efficient new homes, and select industrial equipment) |
| | ▨ | **Installation and use:** Measures that depend greatly on proper installation, particularly building shell and HVAC in both new and existing buildings in all sectors |

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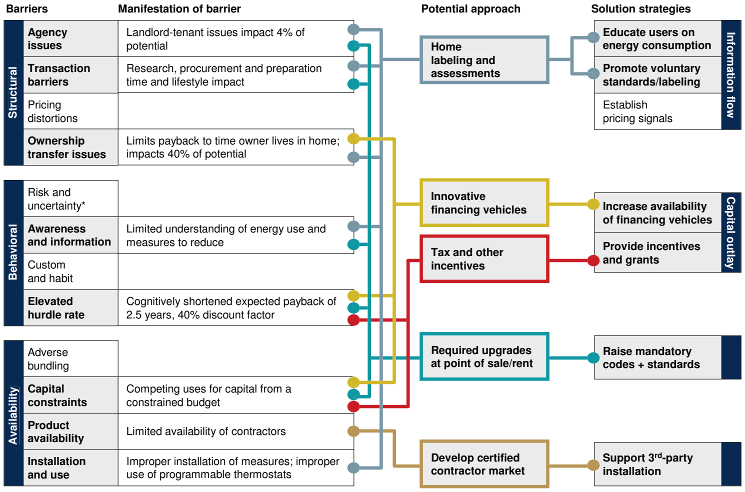
[3] William Golove and Joseph Eto, "Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency", LBNL, March 1996. C. Blumstein, "Overcoming Social and Institutional Barriers to Energy Efficiency," 1980. S. DeCanio, "Barriers Within Firms to Energy Efficient Investments," *Energy Policy*, 1993. Amory Lovins, *Energy Efficient Buildings: Institutional Barriers and Opportunities*, E Source Inc, 1992.

## 3. MAPPING OF SOLUTIONS TO CLUSTERS AND BARRIERS

We conducted an extensive survey of measures that would unlock energy efficiency in the residential, commercial, and industrial sectors. These solution measures broadly fall into three categories: those that have proven successful on a national scale, those piloted and promising but not yet proven at national scale, and those emerging but not yet thoroughly tested. We used available empirical evidence or descriptions to understand which solutions could address which barriers. For example, on-bill financing can address ownership-transfer issues, inconsistent discount rates, and capital constraints by transferring unpaid investment and benefits to future owners while providing necessary capital at a discount rate consistent with other options for energy consumption. Though the barriers addressed by each measure can vary among clusters, Exhibit B-3 provides an example of how we mapped measures to barriers in one cluster in the residential sector, in this case the existing non-low-income homes cluster.

Exhibit B-3: Addressing barriers in existing non-low-income homes



* Represents a minor barrier
Source: McKinsey analysis

Given the limited quantitative data on the barriers and the impact of solutions, this approach faces some limitations: it cannot quantitatively map solutions to every barrier, and it cannot evaluate the relative strength of different solutions. Furthermore, we did not attempt to ascertain what fraction of the potential is achievable with a given measure. However, the approach can highlight what portion of the potential is addressable with a given measure. Our research suggests that a measure or combination of measures will be needed to address all major barriers affecting a cluster, if the efficiency potential is to be captured fully. For example, the limited penetration of on-bill financing in the residential retrofit cluster is likely because this approach fails to address transaction barriers, lack of awareness, contractor availability, and installation concerns. A combination of on-bill financing with a home labeling or awareness campaign, plus direct referrals to qualified contractors could address all barriers and unlock the potential of this cluster.

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# Acknowledgments

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- City of Berkeley, Office of Energy & Sustainable Development
- City of Chicago
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- Earth Advantage Institute
- EcoBroker International
- eMeter
- Energetics Incorporated
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- Green Star Energy Solutions
- The Goldman Sachs Group, Inc.
- Hannon Armstrong
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- Intel Corporation, Global Director, Environment and Energy Policy
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- KB Home
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- National Association of Energy Service Companies (NAESCO)
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# NOTES