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The Economics of Energy Efficiency in Buildings

Trevor Houser

Trevor Houser, visiting fellow at the Peterson Institute for International Economics, is a partner at the Rhodium Group (RHG), a New York-based research firm, and adjunct professor at the City College of New York. He is currently serving as senior adviser to the US Special Envoy on Climate Change and will resume his work at the Institute in 2010. His work focuses on energy markets, climate change, and the role emerging Asian countries play in both. His publications include A Green Global Recovery: Assessing US Economic Stimulus and the Prospects for International Coordination? *(Policy Brief 09-3, 2009)*, Leveling the Carbon Playing Field: International Competition and US Climate Policy Design *(2008), and* China Energy: A Guide for the Perplexed *(2007).* *He would like to thank Fred Bergsten, Mirka della Cava, Susanne Droege, James Fritz, Karsten Neuhoff, Mattia Romani, William Sisson, Michael Taylor, and Constant Van Aerschot for comments on this brief. The views expressed here are the author's alone and do not reflect the views of the US government. This analysis was partially supported by the World Business Council for Sustainable Development and the two firms that co-chaired its project on Energy Efficiency in Buildings, United Technologies and Lafarge.*

At the 2008 summit in Hokkaido, Japan, and again in 2009 in L'Aquila, Italy, G-8 leaders called for a 50 percent global reduction in greenhouse gas (GHG) emissions below current levels by 2050 to avoid "the most serious consequences of climate change."[1] Meeting this goal will require transforming the way energy is produced, delivered, and consumed across all sectors of the economy and regions of the world. Buildings, which account for nearly 40 percent of global energy demand today and 30 percent of projected growth in energy demand between now and 2050, will play a critical role in this process (IEA 2008b).

Improving the energy efficiency of buildings is often heralded as the cheapest way to cut emissions, with a wealth of individual investment options available at negative cost.[2] Few studies, however, have attempted to estimate the cost of completely overhauling the buildings sector to meet long-term emission-reduction goals. The World Business Council for Sustainable Development's (WBCSD) Energy Efficiency in Buildings project has developed a model, based on a rich database of building types, designs, and technologies, that makes such analysis possible (WBCSD 2009).

This policy brief utilizes the WBCSD model to assess the cost of transforming the global building stock in line with the G-8's 50 percent emission-reduction target and evaluates the policy options for achieving such a transformation. It demonstrates that while aggressive, whole-building improvements in energy efficiency are more expensive than studies of individual building components have suggested, average abatement costs in the buildings sector are still cheaper than in other sectors. Barriers to efficiency investment in the buildings sector, however, make it difficult to take advantage of these low-cost abatement opportunities, even with a relatively high carbon price. New approaches to financing are important to overcoming these investment barriers, but such tools will need to be coupled with improved standards for building construction, government spending to buy down "first costs," (the upfront investment required to increase energy efficiency) and improved awareness of potential energy savings among households and firms. Successful transformation of the buildings sector would significantly reduce the cost of addressing climate change and can help to prevent the higher energy prices that result from climate policy from raising consumers' overall energy costs.

ROLE OF BUILDINGS IN ADDRESSING GLOBAL CLIMATE CHANGE

Buildings are the largest source of energy demand globally and are central to efforts to address climate change. Heating,

1. "Environment and Climate Change," July 8, 2008, available at www.g8.utoronto.ca/summit/2008hokkaido/ (accessed on April 24, 2009) and "G8 Leaders Declaration: Responsible Leadership for a Sustainable Future." July 8, 2009, available at http://www.g8italia2009.it/ (accessed on August 3, 2009).

2. The most well-known study of abatement costs for building efficiency is McKinsey & Company (2009).

Table 1 IEA emission reductions by sector

Sector	CO_2 emission reductions: Gt CO_2 per year in 2050	CO_2 emission reductions: Percent of total
Power generation	18.2	38
Industry	9.1	19
Buildings	8.2	17
Transport	12.5	26
Total	48	100

Source: BLUE Map scenario from International Energy Agency (IEA 2008b).

Table 2 IEA emission reductions by technology

Technology	CO_2 emission reductions: Gt CO_2 per year in 2050	CO_2 emission reductions: Percent of total
CCS industry and transformation	4.3	9
CCS power generation	4.8	10
Nuclear	2.9	6
Renewables	10.1	21
Power generation efficiency and fuel switching	3.4	7
End use fuel switching	5.3	11
End use electricity efficiency	5.8	12
End use fuel efficiency	11.5	24
Total	48	100

Source: BLUE Map scenario from International Energy Agency (IEA 2008b).

cooling, and powering residential, commercial, and government buildings consumes 38 percent of all energy produced worldwide, compared with 26 percent for transportation (IEA 2008d). If the energy consumed in manufacturing the steel, cement, aluminum, and glass used in building construction is included, this number grows to more than 50 percent. With rapid urbanization and rising income levels in developing countries and suburban expansion in developed countries, energy demand in the buildings sector has grown by 2 percent per year on average for the past decade (IEA 2008c). And with only 50 percent of the world's population living in cities at present, buildings will continue to drive global energy demand for years to come (World Bank 2009).

How these new buildings are constructed, and how existing buildings are maintained or renovated, will shape the world's ability to reduce CO_2 emissions and to address global climate change. Current global emissions equal 28 billion tons of CO_2 each year. Buildings are responsible for 8.4 billion tons of this, either directly by burning coal, oil, or natural gas for heating and cooking or indirectly through the consumption of fossil fuel–generated electricity delivered through an electrical grid. The International Energy Agency (IEA) predicts that by 2050, global CO_2 emissions will grow to 62 billion tons, 20.1 billion tons of which will come from buildings, putting the world on a dangerous trajectory (IEA 2008b).

To avoid the worst effects of climate change, the Intergovernmental Panel on Climate Change (IPCC) recommended in its Fourth Assessment Report reducing greenhouse gas emissions by 50 to 85 percent below current levels to limit global temperature increases to between 2 to 2.4 degrees Celsius above preindustrial levels (IPCC 2007). The 50 percent target was endorsed by leaders of the G-8 group of industrialized countries during their 2008 summit in Hokkaido, Japan and reaffirmed during their 2009 meeting in L'Aquila, Italy. In its 2008 *Energy Technology Perspective*, the International Energy Agency (IEA 2008b) described a possible pathway for reducing global emissions along these lines, broken down by sector and technology (tables 1 and 2). The IEA's model looks for the lowest cost mix of emission abatement opportunities given currently available technology and projected future innovations (see box 1).

Reducing emissions associated with energy demand in buildings can occur in two ways:

- by reducing the amount of energy a building consumes through improved efficiency; or
- by reducing the emissions associated with that energy by switching from high-carbon sources like coal and petroleum to low-carbon sources like nuclear, hydropower, or renewable energy.

The IEA (2008b) estimates that the buildings sector alone will need to reduce annual CO_2 emissions by 8.2 billion tons below business-as-usual by 2050 through efficiency improvements, an amount equal to nearly one third of global emissions today. Another 18.2 billion tons of reductions will need to come from lowering the emissions intensity of future electricity supply, half which will be consumed in buildings. Together these building-related emission reductions account for more than one third of the total reductions the IEA sees as necessary to meet the climate challenge.

This is just one possible pathway to achieve target atmospheric concentrations of greenhouse gasses. Different assumptions about technology cost or consumer behavior would lead to a different mix of abatement opportunities. But in most analyses, emission reductions in buildings are seen as a critical component of cost-effective climate policy. This is because improving energy efficiency in buildings not only reduces

Box 1 Definitions of selected key terms

To assess the attractiveness of a prospective investment in terms of reducing GHG emissions, economists start by calculating its *net present value* (NPV). This is done by subtracting the additional upfront operation and maintenance costs required for the more-efficient investment from the expected energy cost savings over the lifetime of the more-efficient investment. The energy cost savings used to calculate the NPV of a particular investment are discounted by 6 percent annually, to reflect the greater value consumers place on current vs future income. This can be thought of as the interest rate society expects on its efficiency investments. The NPV is then divided by the cumulative change in emissions resulting from the investment over the course of its life. This is known as the *abatement cost* and is expressed in dollars per ton of carbon dioxide (CO_2). The abatement cost is the economic impact on society as a whole of policies to reduce emissions and is referred to as the *economic abatement cost* in this policy brief. This is used in climate policy cost-benefit analysis, with the economic abatement cost weighed against the economic impact of climate change (referred to as the *social cost of carbon*) in order to assess the net benefit to society as a whole of reducing emissions.

The economic abatement cost of a given investment, while expressed in dollars per ton of CO_2, is different from the carbon price required to prompt households or firms to take advantage of that abatement opportunity. The economic abatement cost is measured over the lifetime of the investment. Decision-makers often demand shorter payback periods and thus require a higher carbon price in order to make an emission-reducing investment. The carbon price required to induce households or firms to make this investment is referred to in this policy brief as the *behavior-changing carbon price*.

GHG emissions but also lowers energy bills. Theoretically, the energy savings resulting from many efficiency improvements more than offset the additional upfront-investment and ongoing operational costs. Such investments are described as having a negative abatement cost (see box 1 for definitions). Economically speaking, society as a whole is better off as a result of such investments, even before the benefits of halting climate change are taken into account.

BARRIERS TO IMPROVING BUILDING EFFICIENCY

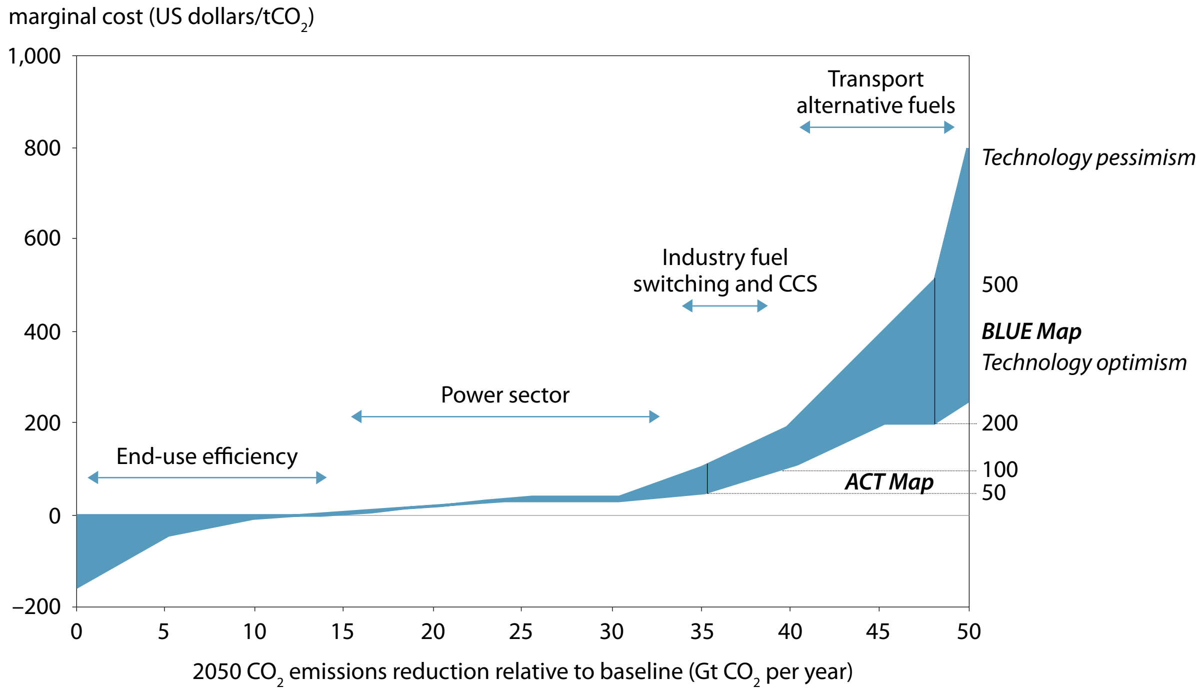
This notion of negative GHG abatement-cost opportunities has been popularized recently through work of the consultancy McKinsey & Company, which graphically displays the abatement costs of a range of technologies on what is called an emission-abatement cost curve (2009). An illustrative example of this type of analysis from the International Energy Agency can be found in figure 1. The horizontal axis indicates the GHG reduction potential of a given technology. The vertical axis indicates the net cost of that technology after energy savings are taken into account, measured in dollars per ton of CO_2 reduced. The technologies on the left-hand side of the curve have negative abatement costs because the NPV of the energy savings achieved through these investments more than offset the additional investment cost. In work by McKinsey & Company and others, this is where most building efficiency investments lie. The technologies on the right-hand side of the cost curve have the highest abatement costs.

This type of analysis shows there are ways to reduce emissions at no economic cost. Indeed, it suggests there are already abundant opportunities to turn a profit while saving the planet, even without climate policy that puts a price on carbon. The challenge is translating theory into practice. The very fact that these negative-cost abatement opportunities exist suggests that there must be barriers to implementation otherwise we would have captured these savings regardless of climate change concerns. Understanding these barriers is particularly important in the buildings sector, where many abatement opportunities are potentially negative cost, and is critical in considering the types of policies needed to achieve the efficiency improvements in the buildings sector called for by the IEA.

Market-based climate policies work by imposing a price for carbon equal to or greater than the cost of abating the required amount of CO_2, thus making it profitable to reduce emissions. This can be done through a cap-and-trade system, where a fixed number of emission allowances are issued and the market sets the allowance price, or it can be achieved through a carbon tax, where policymakers try to reduce GHG emissions by taxing polluters for every ton they emit at a fixed rate.

But the existence of negative-cost abatement opportunities shows some of the limitations of market-based climate policy. If businesses and households have not already taken advantage of profitable efficiency-investment opportunities, there is good

Figure 1 Marginal emission reduction costs for the global energy system, 2050



Source: IEA (2008b).

reason to doubt that making those opportunities a little more profitable through a carbon price will make much difference.

What accounts for the disconnect between what the cost curves suggest makes economic sense and the actual behavior of firms and individuals? Academic literature, policy experience, and business case studies cite a range of reasons. In multifamily residential and commercial buildings, the people making investment decisions are often different from those paying the energy bills (known as the "principal-agent problem"). In single-family homes, the owner sees the sticker price for more-efficient design or equipment but may lack information about the potential energy cost savings. And even when that information is available, households have limited capital and may not be willing to make the upfront investment, even if it pays off fairly quickly. Businesses with greater access to capital may still be unwilling to accept payback periods stretched out over the life of the investment (the way most cost curves are calculated), given uncertainty about future energy prices and actual energy cost savings. At the other end of the spectrum, the economic benefit of small investments, like compact florescent light bulbs or attic insulation, may not rise to the level where building owners take the time to make these improvements.

The net result is a market failure that makes it difficult to predict how market-based climate policy will change consumer behavior in the buildings sector. As part of the WBCSD's Energy Efficiency in Buildings initiative, a consortium of fourteen major global companies spent four years developing a model to simulate actual behavior in the buildings sector when it comes to improving efficiency (WBCSD 2009). The model, based on a rich database of building types, designs, and technologies, focuses on five submarkets: single-family residential buildings in France and the southeast United States, multifamily residential buildings in China, and office buildings in Japan and the northeast United States. In each submarket, the model simulates investment decision-making based on a database of thousands of potential building types and equipment configurations, each with its own cost and energy-demand profile. Passive design, energy-efficient technology, and onsite power generation are all included in the model as options to reduce building-sector emissions.

This policy brief uses the WBCSD model to assess the amount of investment required to achieve the building-sector emission reductions called for by the IEA, the resulting energy cost savings, and the abatement cost of these investments. Per square meter results from the five WBCSD submarkets were converted into global estimates using energy demand and CO_2 emission data from the IEA (2008a, 2008c), economic growth projections from the Economist Intelligence Unit (EIU 2009), and population forecasts from the United Nations Population

Table 3 The economics of global building transformation

Country/region	**Additional investment, 2005–50** (billions of US dollars per year)	**Net present value,* 2005–50** (billions of US dollars per year)	**Emission reduction relative to BAU** (million tons in 2050)	**Average abatement cost, 2005–50** (USD per metric ton)
OECD North America	244	–46	1,699	30
United States	209	–40	1,555	28
OECD Europe	170	–26	915	30
EU-27	158	–25	861	30
OECD Pacific	67	–17	353	48
Japan	37	–9	168	52
Transition economies	78	–12	548	24
Russia	51	–10	345	33
Developing Asia	188	–26	2,343	14
China	114	–15	1,427	14
India	19	–2	221	12
Latin America	31	–5	148	39
Brazil	10	–2	28	61
Middle East	80	–17	663	32
Africa	29	–3	298	10
World	1,042	–180	8,200	25

* Net present value is calculated over 20 years using constant energy prices and a 6 percent discount rate.

Source: WBCSD Energy Efficiency in Buildings Model (WBCSD 2009), International Energy Agency, United Nations Development Program, Economist Intelligence Unit.

Division (UNPD 2009).[3] Upfront investment costs (known as "first costs") and energy prices are held constant across regions, and energy savings are discounted at 6 percent annually over the average life of the investment (20 years in most cases in the WBCSD model) to assess the overall economic impact and to compare it with abatement opportunities in other sectors. I also used the WBCSD model to test the effectiveness of a range of policy scenarios in reducing building-sector emissions, including carbon pricing, efficiency investment financing mechanisms, improved consumer awareness, and more-efficient building standards and codesbuildings sector. These results are discussed later in the policy brief.

INVESTMENT REQUIREMENTS OF IMPROVED EFFICIENCY

Achieving the emission reductions called for by the IEA would require significant upfront investment in more energy-efficient design and equipment and onsite renewable power generation. Based on the technology cost estimates in the WBCSD model, cutting annual buildings sector emissions by 8.2 billion tons below business-as-usual by 2050 would require an additional $1 trillion per year in investment globally between now and 2050 without taking into account the savings from energy efficiency.[4] This accounts for roughly 1.5 percent of global GDP over the same time period and would constitute an increase in energy-related investment of 18 percent. Of this, $209 billion

3. While the analysis in this policy brief uses cost and technology-adoption assumptions from the WBCSD model, my building stock and economic growth-rate assumptions are somewhat different from those used in the analysis reported in WBCSD (2009). The two approaches produce moderately divergent investment requirements for a given level of CO_2 abatement, but are similar enough to produce the same policy conclusions. To estimate the size of the current global building stock, I divide total residential and commercial sector emissions in 2005 from the IEA (2008a) by the per-square foot energy demand assumptions from the WBCSD model multiplied by the carbon-intensity of residential and commercial energy demand in 2005 from the IEA (2008a). I use the IEA's commercial sector building stock growth estimates from the *Energy Technology Perspective* (IEA 2008b). For the residential sector, I average the GDP growth projections from the Economist Intelligence Unit (EIU 2009) with the population growth projections from the United Nations Population Division (UNPD 2009) to estimate residential building stock growth. This creates a business-as-usual emissions trajectory for the buildings sector as a whole similar to the IEA's *Energy Technology Perspectives* (2008b).

4. When evaluating the economic impact of measures to reduce emissions, it's important to keep in mind the economic cost of continuing on a business-as-usual trajectory. Economists estimate that, left unchecked, climate change could cost the global economy 5 to 20 percent of GDP (Cline 1992, 2009; Stern 2007).

per year would take place in the United States, $158 billion in the European Union, $114 billion in China, and $37 billion in Japan (table 3), assuming per-building transformation occurs equally across regions.[5]

This is significantly more than the investment cost estimates in IEA (2008b), which estimated that $1 trillion in additional investment annually would be sufficient to achieve target emission reductions in all sectors, not just in buildings. For residential and commercial buildings, IEA (2008b) estimated that only $164 billion per year in additional investment would be required to reduce emissions by 8.2 billion tons by 2050, only 16 percent of the estimates made in this policy brief using WBCSD data.

Failure to catalyze building-sector transformation will raise the cost of meeting long-term climate goals by at least $500 billion per year globally.

Much of the difference between these estimates can be explained by solar photovoltaic (PV) technology.[6] In the IEA's (2008b) model all 8.2 billion tons of emission reductions come from improvements in building efficiency. In the WBCSD model, however, the buildings sector must move beyond just energy-efficient equipment and design and install onsite renewable power generation in order to achieve 8.2 billion tons of reductions. The purchase and installation of solar PV panels to replace electricity purchased from the grid account for 53 percent of the forecasted investment cost in residential buildings and 19 percent in commercial buildings.[7] The WBCSD model assumes an installed solar PV cost of $8 per watt in 2005, declining sharply to $5.5 per watt by 2010 (a decline of 7 percent per year). This is a faster rate of decline than that observed in the US PV market over the past decade. The Lawrence Berkeley National Laboratory (LBL) estimated that between 1998 and 2007, the installed cost of PV declined from $10.50 per watt to $7.60 per watt, an annual rate of decline of 3.5 percent (Wiser, Barbose, and Peterman 2009). Beyond 2010, however, the WBCSD model predicts very modest annual declines in solar PV costs of 0.3 to 0.4 percent per year through 2050. This is based largely on an assumption that nonmodule costs, like installation, will not decline over time. Module costs are assumed to continue declining at 1.7 percent per year through 2050.

If these PV cost assumptions prove conservative, the investment required to achieve 8.2 billion tons of emission reductions from buildings would fall considerably. There are reasons to be optimistic on this front. The LBL study (Wiser, Barbose, and Peterman 2009) observed a 5 percent annual decline in nonmodule costs over the past decade, putting them below the $4 per watt assumed in the WBCSD study. If these trends continue, overall installed cost will decline substantially. During the first half of 2009, PV module costs declined by 5 percent in the US and 4 percent in Europe and thin-film solar modules are now selling below $2.00 per watt.[8]

While the investment required for building transformation is large, it is not unprecedented. In the United States, meeting emission-reduction goals in the residential sector would require an additional $139 billion in annual investment on average between now and 2050. Based on the technology cost estimates in the WBCSD model, reducing emissions from the US housing stock by 65 percent by 2050 would require a 16 percent increase in the amount of money spent on residential building construction and renovation each year.[9] This is roughly on par, in terms of scale, with the increase in spending that occurred between 2002 and 2007 as a result of low-cost capital and lax mortgage lending criteria, most prominently in the United States but also in parts of Europe and the developing world. But while residential investments over the past decade grew less sustainable over time as income lagged and mortgage payments soared, investments in efficiency get cheaper over time as lower energy bills offset upfront costs and home resale values increase. Investment in building efficiency also replaces the need for investment in new power generation capacity. In the United States, annual investment in the electricity sector tops $60 billion. Globally, the IEA (2008b) predicts that $551 billion per year in investment in power generation and transmission will be required to keep pace

5. Investment costs are calculated using the per-square foot cost of efficiency improvement from the WBCSD model for single-family residential, multi-family residential and commercial buildings. The investment cost per square foot is held constant across regions and multiplied by the building stock estimates and growth in building stock described in footnote 3.

6. Other factors contributing to higher investment costs in the WBCSD model are a) less aggressive technology learning curves for building shell design and materials (e.g. windows and insulation), b) shorter building shell lifespan assumptions, c) more aggressive improvements in efficiency between 2010 and 2030 (rather than 2030-2050) when technology costs are higher and d) a less efficient optimal building design option (IEA uses a Passivhaus standard, which is significantly more efficient than the most efficient building code level in the WBCSD model).

7. A recent report from NAIOP (2008) also found that PV panels would be required to meet aggressive per-building energy-saving goals and would raise overall investment costs significantly.

8. Retail solar module price index from www.solarbuzz.com (accessed on August 3, 2009)

9. US residential construction data are from US Census Bureau (2009).

with growing demand. Curbing some of that demand growth through efficiency improvements will free up capital that can be used in the buildings sector.

ENERGY SAVINGS AND EMISSION REDUCTIONS

The overall economic impact of investing $1 trillion per year in the buildings sector to meet global emission-reduction goals is determined in large part by the energy cost savings that investment produces. If the savings provide a rate of return on the investment that is better than other investment options, then it is a net gain for the economy as a whole. If the lifetime energy savings fail to cover first costs, or provide a lower rate of return than alternative investment opportunities, then the investment has a net economic cost. This cost, however, comes with a social benefit: reducing greenhouse gas emissions. If the net economic cost of reducing emissions through building efficiency (referred to in this policy brief as the economic abatement cost; see box 1) is less than the economic abatement cost in other sectors, it can still be the most economic means of addressing climate change.

Based on data from the WBCSD model, the majority of first costs required to reduce building-sector emissions by 8.2 billion tons by 2050 would be offset by energy savings, but the offset is less than previous studies, such as McKinsey & Company (2009), have suggested. Many individual building improvements, like insulation and heat pumps, easily pay for themselves over the life of the product. Investments necessary to achieve whole-building emission reductions of 50–75 percent, however, will not be paid back in energy savings at current energy prices, even over relatively long time horizons.[10] At the global level, 83 percent of the investment required for transformation is recovered over a 20 year period, resulting in a net cost of $180 billion per year.

Efficiency measures in residential buildings offer better cost recovery than in commercial buildings, and within the residential sector, investments in multifamily homes score better than in single-family homes. Variation in building stock between regions creates differences in the net present value (NPV) of efficiency investments. In the United States, $209 billion in annual investment to improve the efficiency of the buildings sector as a whole has a negative NPV of $40 billion per year. In Europe, the NPV is negative $25 billion per year, and in Japan it is negative $9 billion (table 3). This is the economic cost of transforming the buildings sector at current energy prices.

While significant in absolute terms, the economic cost of a 50 to 75 percent improvement in building efficiency is still cheap relative to other abatement opportunities. Cutting building emissions by 8.2 billion tons globally by 2050 has an average abatement cost of $25 per ton of CO_2. Lower carbon-intensity of energy supply makes abatement costs slightly higher in Europe ($30 per ton), while China's coal-dominated energy mix yields an average abatement cost of $14 per ton. With a higher share of investment costs recovered through energy price savings, reducing emissions in residential structures is cheaper than in other parts of the buildings sector. In the United States, the average abatement cost for households is $9 per ton, compared with a building-sector wide average of $28 per ton.

Globally, a $30 per ton carbon price yields only 0.6 billion tons of annual emission reductions by 2050, far short of the 8.2 billion tons required in the IEA analysis.

These abatement costs do not include any CO_2 emission reductions resulting from surplus onsite-generated renewable electricity sold to the grid. Solar panels installed on buildings produce more power than the building requires during the middle of the day and less than the building requires in the morning, evening, and at night. Electricity must be purchased from the grid during those times when onsite solar power is insufficient. But in places where utilities are equipped to buy electricity from rate-payers, surplus solar power generated during the day can be sold to the grid. This helps balance out the electricity purchased during solar off-hours. If utilities purchased all surplus solar power produced in buildings and used it to replace existing generation, the investments described above would yield an additional 1 billion tons of annual emission reductions. This would lower average abatement costs globally in the buildings sector from $25 to $22.50 per ton of CO_2.

Given the WBCSD model's conservative cost estimates for onsite solar generation, excluding PV altogether would reduce abatement costs even further. As mentioned in the previous section, nearly half of the investment required to achieve 8.2 billion tons of reductions in the WBCSD analysis

10. The WBCSD model uses 2005 energy prices (primarily electricity and natural gas at the equivalent of $0.08-$0.10 per kilowatt hour) held constant in real term across regions and through 2050. The International Energy Agency (2008e) expects global oil and gas prices to roughly double by 2030, and the Energy Information Administration (2009) expects US electricity prices to increase by 10% over the same period. This price increase would make efficiency investments more profitable than the WBCSD model estimates.

is attributable to solar panel purchases and installation. Yet if the ability to sell surplus generation to the grid is excluded from the model, PV accounts for only one third of the overall building-sector emission reductions. This leaves PV with an abatement cost well over $100 per ton, raising the building-sector wide average abatement cost considerably.[11] If the CO_2 emissions saved by selling surplus solar power to the grid are included in the model, the average abatement cost for PV falls to roughly $50 per ton over the 2010–50 time frame.

Getting all the way to the 8.2 billion tons of emissions reductions called for in the IEA's 2050 scenario will require new building codes and standards exclusively focused on energy efficiency.

Even with the WBCSD's cost estimates for PV (and excluding sales of surplus electricity back to the grid), reducing emission by 8.2 billion tons in the buildings sector is more affordable than IEA estimates of the cost of achieving comparable emission reductions from power generation, industry, or transportation (IEA 2008b). The average building-sector abatement cost of $25 per ton based on the WBCSD model is slightly less than the $27 per ton abatement cost for the 18.2 billion tons of reductions from the power sector described in IEA (2008b) and is significantly less than the $57 per ton abatement cost for the 9.1 billion tons of reductions from industry. Failure to catalyze building-sector transformation, however, would require reducing emission by an additional 8.2 billion tons in other sectors, requiring deeper, more costly investments in these sectors than forecast by the IEA (2008b). In power generation, the cost of these additional reductions would be $85 per ton based on IEA estimates (2008b). Reducing an additional 8.2 billion tons of emissions from industry would cost more than $210 per ton, and it would cost well over $300 per ton in the transportation sector. This makes it critical from an economic standpoint to remove barriers to improved building efficiency. Failure to catalyze building-sector transformation will raise the cost of meeting long-term climate goals by at least $500 billion per year globally.

11. Solar panel utilization rates vary by region due to differences in solar resources. For this policy brief, solar panel utilization rates are based on a sample of single-family residences in France and the US southeast, multi-family residences in China, and commercial office buildings in the US northeast and Japan.

THE POLICY CHALLENGE

Given the central importance of building-sector transformation in responding to climate change affordably, it is critical to understand what policy approach will be most effective in catalyzing that transformation. As discussed previously, the fact that many abatement opportunities in the buildings sector already have a negative cost suggests that market-based climate policies, like a carbon tax or a cap and trade system will have limited success alone. This conclusion is supported by recent analyses of proposed market-based climate legislation in the United States.

In April 2008 the Energy Information Administration (EIA) modeled the impact of the Lieberman-Warner Climate Security Act (S.2191), a cap and trade proposal that would have reduced US emissions 33 percent below 2005 levels by 2030 and 70 percent by 2050 (EIA 2008b). EIA forecasted that allowance prices would start at around $17 per ton and rise to $61 per ton by 2030. In the EIA's National Energy Modeling System (NEMS), the vast majority of emission reductions resulting from this carbon price come from fuel switching in the power-generation sector. Building efficiency improves, but only modestly. In 2005 average residential energy consumption in the United States was 58,000 BTU per square foot. In the EIA's business-as-usual scenario, residential energy use declined to 45,000 BTU per square foot by 2030 (EIA 2008a). Under the Lieberman-Warner climate policy scenario, residential energy consumption declined to 41,000 BTU per square foot, only 10 percent below business-as-usual (EIA 2008b).

The WBCSD model allows for a similar assessment of the effectiveness of carbon pricing alone in improving building efficiency and reducing building-sector emissions. In the WBCSD model, households and firms select more energy-efficient designs and equipment if the additional investment cost is recouped through energy savings in five years or less at a discount rate of 6 percent. Energy-efficient options with a first cost premium greater than 25 percent are disregarded. These assumptions are based on market research of observed investment decision-making in the buildings sector conducted by the WBCSD Energy Efficiency in Buildings project between 2005 and 2009 (WBCSD 2009).

Working with the WBCSD team, I analyzed the impact of a $30 per ton of CO_2 carbon price on investment decision-making in all five submarkets. The effect is quite modest. Globally, a $30 per ton carbon price yields only 0.6 billion tons of annual emission reductions by 2050, far short of the 8.2 billion tons required in the IEA analysis. Even though $30 per ton is higher than the $25 per ton abatement cost for the buildings sector as a whole, it fails to produce the necessary transformation. This is primarily due to the difference between the economic abatement cost and the price for carbon necessary to change investment decision-making when first costs must be recouped in five years or less rather than over the lifetime of the investment (the behavior-changing carbon price; see box 1). Consider the following examples:[12]

A household is in the market for a new central air conditioning system. The standard system costs $8,000, and the more energy-efficient system costs $9,000. The more-efficient system would save the household $32 per year and last 20 years. At a 6 percent discount rate, only $400 of the $1,000 premium would be recouped in energy cost savings over the life of the system in the absence of a carbon price. But because the more energy-efficient system would save one ton of CO_2 per year, a carbon price of $30 per ton would allow for full cost recovery over the life of the system (the economic abatement cost). Covering the first cost premium in five years, however, would require a carbon price of $163 per ton (the behavior-changing carbon price).

Transformation of the buildings sector along the lines outlined here would more than offset these cost increases, cutting overall household energy expenses from $285 billion per year in 2030 to $130 billion.

Decision-makers in other sectors, like power generation, have longer payback periods than owners of residential and commercial buildings, which narrows the gap between the behavior-changing carbon price and the economic abatement cost. Take, for example, a utility company choosing between building a coal-fired power plant and a wind farm. The wind farm would cost $100 million more than the coal-fired power plant but would save 150,000 tons of CO_2 per year. If the life of the equipment were 20 years, the economic abatement cost would be $58 per ton (using a 6 percent discount rate). If the investor in the wind farm required a 10 year payback period, the behavior-changing carbon price would be $91 per ton. Since this is less than the $163 per ton required to prompt the household to purchase a more-efficient air conditioning system, the wind farm investment would happen sooner if a market-based regime like a carbon tax or a cap and trade system were the only climate policy in place, even though the overall economic cost per ton of CO_2 reduced is greater for the wind farm investment than for the more-efficient air conditioning system. By simulating actual investment decision-making, the WBCSD model demonstrates the limitations of using market-based policies alone to spur improvements in the energy efficiency of buildings. Complementary policies are necessary.

ATTRACTING LONG-TERM INVESTMENT

As illustrated in the examples above, the economics of energy efficiency are shaped in large part by the amount of time a household or business is willing to wait to recoup its investment. Increasing public awareness of potential energy cost savings through education, labeling, and advanced metering can play an important role in extending required payback periods, but only up to a point. Ultimately, households have limited capital and must balance efficiency improvements with college tuition, medical expenses, and retirement savings.[13] Implementing the efficiency investments required to transform single-family homes in line with global emission-reduction goals will require external capital.

The deepest and most affordable pool of capital available to homeowners is the mortgage market. New mortgage origination totals in the trillions of dollars each year in the United States alone (Greenspan and Kennedy 2005). Some banks have begun experimenting with the concept of "green mortgages," where the interest rate is lowered if the buyer opts for a more energy-efficient home and the potential energy savings can be verified by the bank. The bank's willingness to lower the interest rate for the loan is based on an improvement in the perceived creditworthiness of the borrower as a result of lower monthly utility costs.

Another potential source of low-cost, long-term capital is the utility sector. Market fragmentation, obstacles to data collection, and uncertainty about future energy prices, which all make it difficult to tap the mortgage market for efficiency investments, are less of a challenge for utilities. Electrical utilities have access to low-cost capital, have an existing relationship with every home, can accurately track energy consumption, and are well positioned to forecast future energy prices. As a result policymakers are increasingly focusing on electrical utilities as a potential source of efficiency investments (Cappers et al. 2009, Brennan 2009). The theory behind this effort is that utilities would make direct investments in energy-efficiency equipment and design and share the savings from these invest-

12. The numbers used in these examples are for illustrative purposes only. The actual abatement cost of a wind farm could well be less than that of a more energy-efficient air conditioning system.

13. Retirement savings could potentially be a powerful pool of capital for efficiency investments if financial intermediaries are able to structure efficiency investments to meet the risk profile households expect when planning for retirement.

ments with households. But such policies require that regulations be changed to allow utilities to earn revenue by delivering efficiency rather than energy. In the United States a number of states have begun experimenting with "decoupling" utility revenue from electricity sales. Decoupling can be structured so that utilities are ambivalent to efficiency improvements by rate-payers—i.e., their revenue stream can be determined by the number of customers rather than by the quantity of electricity delivered—or so that utilities have incentives to administer efficiency programs and to make equipment investments themselves (Cappers et al. 2009).

For multifamily residential and commercial buildings, the challenge is a bit different. Owners of these large buildings are not under the same capital constraints as single-family homeowners, but they also do not have the same incentives to improve efficiency. In most office or apartment buildings, the owners make investment choices but the tenants pay for energy. These split incentives prevent efficiency improvements even when building owners have the means to make them. Split incentives can be overcome through financial intermediaries, such as energy service companies (ESCOs) and banks providing direct access to capital markets (WBCSD 2009), but policy will be required to address some of the credit risks specific to efficiency finance like energy price volatility and the inability to adequately collateralize efficiency equipment.

Successfully connecting households and firms with deep pools of long-term capital improves the effectiveness of market-based climate policy considerably. Using the WBCSD model to simulate investment decision-making, a $30 per ton carbon price in an environment where investors are willing to accept a 10-year payback at a 10 percent discount rate yielded 3.9 billion tons of emission reductions globally by 2050, 48 percent of the total called for by the IEA.[14]

CLOSING THE GAP WITH CODES AND STANDARDS

Getting all the way to the 8.2 billion tons of emissions reductions called for in the IEA's 2050 scenario will require new building codes and standards exclusively focused on energy efficiency. While market-based mechanisms generally achieve policy objectives at lower cost than codes and standards, where market failures exist other measures are required. In the case of climate policy, building efficiency codes and standards could significantly reduce the overall economic cost of reducing emissions. Recall the examples discussed above. The coal-fired power plant can either be replaced with one wind farm or with 150,000 more energy-efficient air conditioners. Market-based climate policy alone would give preference to the wind farm, even though the economic abatement cost of the wind farm is higher than the abatement cost of the air conditioners. Codes that required more-efficient air conditioning systems would overcome this market failure and, in these examples, save $420,000 per year. So while standards still impose an economic cost, in the case of buildings that cost is likely to be lower than the alternatives.

The costs building owners would likely face from new energy-efficiency standards are certainly not unprecedented. Even after introducing a $30 per ton of CO_2 carbon price and extending payback periods to ten years through financial intermediation in the United States, codes and standards would still be required to prompt the additional $140 billion per year in efficiency investments needed to meet 2050 emission-reduction goals. These energy-efficiency codes and standards would result in a 10 percent premium over business-as-usual building-sector investment between 2005 and 2050, all of which would be recouped through energy cost savings over the lifetime of the efficiency improvements. By comparison, meeting building fire codes in the United States requires a 5 percent investment premium, none of which is recuperated through future cost savings.[15]

Codes and standards come with administrative costs, which are not included in this analysis. Code development, management, training, and enforcement all require resources, much of which will be borne by government. Market-based climate policy requires government management as well, of course, and it is unclear which policy approach imposes greater administrative costs. But codes and standards, unlike market-based policies, require households to improve efficiency rather than merely providing an incentive for them to do so. While there is both a macroeconomic case for the use of codes and standards as a climate policy tool and a number of microeconomic benefits from these policies for individual households and firms over time, new building efficiency codes would require energy consumers to make significant upfront investments they would not otherwise have been willing to undertake. Fortunately the same market-based climate policy that is effective in reducing emissions in other sectors also generates resources that can be used to offset the costs of new energy efficiency codes for buildings. Coupling market-based climate policy with building codes and standards can also help guard against a building efficiency

14. Based on a literature review and interviews, I selected a 10-year payback window and a 10 percent discount rate as proxies for greater involvement by financial intermediaries in financing efficiency investments.

15. This calculation is based on 2005 estimates. Fire code compliance cost estimates are from Hall (2008). US property investment data are from US Census Bureau (2009).

rebound effect, where households respond to lower energy bills by consuming more energy (e.g., leaving lights on, running air conditioning longer, and plugging in more appliances).

OFFSETTING COSTS TO CONSUMERS

Market-based climate policy works by raising the price of high-carbon energy, such as coal, oil, and natural gas, relative to low-carbon energy, such as nuclear, hydroelectric power, and renewables, prompting firms and consumers to make the switch to lower-carbon energy sources. Higher energy prices can be quite regressive in their impact, depending on how revenue generated from these policies is used (Burtraw, Sweeney, and Walls 2009). Low-income consumers and rural populations spend a larger share of their disposable income on energy than do urban populations and more-affluent consumers. This creates a political mandate in most countries to develop mechanisms that make the distributional impact of climate policy more progressive.

Both cap-and-trade and carbon tax systems generate resources that can be used in this effort, the former through the auction of allowance permits and the latter through direct tax revenue. In Europe the market value of allowances issued each year under the European Union's Emissions Trading System (ETS) has ranged between 10 billion to 30 billion euros since its launch in 2005.[16] In the United States the Environmental Protection Agency (EPA) estimates that the American Clean Energy and Security Act of 2009 now working its way through Congress would produce allowances valued at between $62 and $99 billion per year between 2012 and 2050 (EPA 2009).

One strategy for containing cost increases faced by consumers is to provide emission allowances free to energy suppliers like electrical utilities and natural gas distributers. This was the strategy adopted during phases one and two of the EU Emissions Trading System and it has resulted in considerable criticism both inside and outside the European Union that the provision of free allowances results in windfall profits for utilities without preventing electricity prices from increasing. As Ellerman and Joskow demonstrated in a 2008 report for the Pew Center on Global Climate Change, the key variable in the impact of free allowances on electricity prices is the degree of regulation the utility faces. Regulated entities can be prevented from raising electricity prices while simultaneously capturing allowance value, but utilities in competitive electricity markets are less constrained. Burtraw, Sweeney, and Walls from Resources for the Future have done extensive work on the distributional impacts of climate policy in the United States, particularly in terms of how allowances are distributed. They found (Burtraw, Sweeney, and Walls 2009) that providing allowances free to emitters is regressive in its impact, while auctioning allowances and providing the revenue to households either directly through a "cap-and-dividend" policy or through expanding the Earned Income Tax Credit would be more progressive.

While distributing allowance revenue to vulnerable groups can make climate policy less regressive, improved building efficiency can do the same by ensuring that an increase in energy prices does not result in an increase in total energy costs for households. In the United States, for example, the EIA estimated that the Lieberman-Warner Climate Security Act of 2007 would have raised residential energy prices by 11 percent by 2030 (EIA 2008b). While the modest improvements in building efficiency projected by the EIA would have mitigated some of these increases, overall household expenditures in 2030 would have been $10 billion higher than in the absence of climate policy.

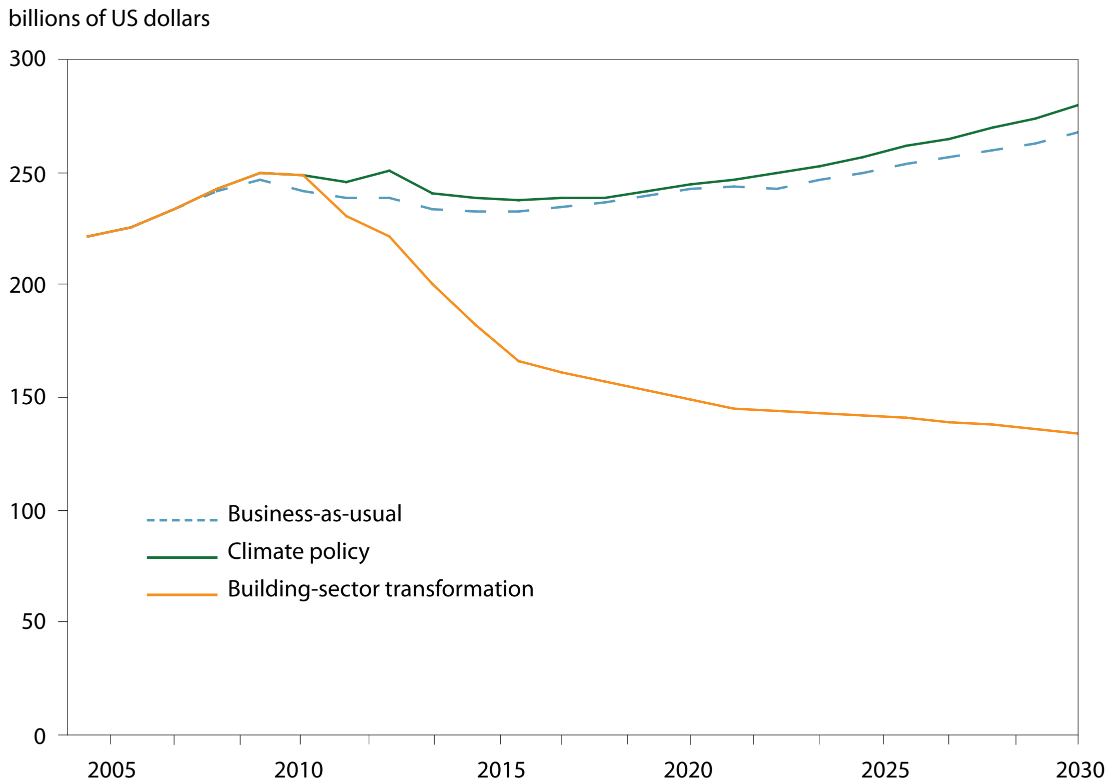
Transformation of the buildings sector along the lines outlined in this policy brief would more than offset these cost increases, cutting overall household energy expenses from $285 billion per year in 2030 to $130 billion (figure 2), given EIA's (2008b) estimates for future energy and emission allowance prices, which are different from those used in the WBCSD model.[17] A relatively small share of the government revenue raised through a carbon tax or a cap-and-trade program could offset the costs to businesses and households of complying with the more-stringent building efficiency codes that would make such a transformation possible. Burtraw, Sweeney, and Walls (2008), modeling the impact of using 25 percent of allowance revenue to invest in efficiency programs, found that these investments would reduce the cost of climate policy for the economy as a whole relative to providing free allowances to emitters and would result in a net welfare gain for low-income households.

This is particularly important in Europe, where the comparatively low carbon-intensity of energy supply means that meeting aggressive emission-reduction targets will require more-ambitious improvements in energy efficiency. The German Federal Environment Agency estimated that reducing GHG emissions by 40 percent below 1990 levels by 2020 would cost $31 billion annually, one third of which would come from spending on building and infrastructure modernization; but improving end-use energy efficiency would yield savings of $38 billion per year (Bundesumweltamt 2008).

16. Point Carbon, *Carbon Market Monitor.* January 2008: A review of 2007.

17. This does not include the decline in energy prices that would likely result from such a steep drop in demand. This price effect would extend household savings resulting from efficiency improvements.

Figure 2 US residential energy expenditures



Source: Business-as-usual projections are from EIA (2008a). The climate policy scenario is EIA's assessment of the impact of the Lieberman-Warner bill (EIA 2008b). The building transformation scenarios is Lieberman-Warner plus per-square foot efficiency improvement achieved in the WBCSD model (WBCSD 2009).

CONCLUSION

Reducing emissions in the buildings sector in line with global emission reductions of 50 percent below current levels by 2050 is possible with existing technology and without compromising living standards. In analyzing the cost of such reductions, and the mix of policies necessary to achieve it, this policy brief finds the following:

- Reducing building-sector emissions by the 8.2 billion tons outlined by the IEA would require an additional $1 trillion in annual investment based on the WBCSD's technology cost assessment. As these cost assessments are conservative, particularly for onsite solar power generation, overall investment costs could be reduced significantly by innovation and through economies of scale.
- Energy cost savings at current prices would recover most, but not all, of this investment. Reducing building-sector emissions in line with global goals would come at an average economic cost of $25 per ton.
- Given barriers to action by building owners and occupants, a carbon price of $25 per ton alone would not catalyze the necessary transformation. New approaches to efficiency financing are critical, but these must be coupled with new codes and standards.
- Failure to overcome barriers to efficiency improvements in buildings would raise the cost of meeting emission-reduction goals considerably. Making up the 8.2 billion tons in buildings sector emission reductions outlined by the IEA via emission reductions in other sectors would impose an additional economic cost of at least $500 billion per year globally.
- Successful transformation of the buildings sector, on the other hand, can offset the impact of increased electricity and fossil fuel prices resulting from climate policy on household income, ensuring that higher energy prices do not translate into higher energy costs.
- How revenue generated from market-based climate policy like a carbon tax or cap-and-trade system is used determines the distributional impact of reducing emissions. Using revenue to improve building efficiency helps make climate policy more progressive.

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