Center for American Progress

Counting All the Benefits

Energy Efficiency and Systems Thinking

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Introduction

We are living in an increasingly carbon-constrained world. We need to consider the deployment of every technological and behavioral option to reduce carbon emissions if we are to avert the catastrophic consequences of climate change. Yet we do not necessarily have the luxury of tackling all options at once, particularly given the current global economic crisis. We therefore need to prioritize our low-carbon options on the basis of cost-effectiveness. Energy efficiency represents the most cost-effective, low-carbon strategy compared to other options such as renewable energy, nuclear power, and carbon capture and storage. The cheapest form of energy is, after all, the energy you do not use.

The compelling case for energy efficiency is best understood through analogy. It is undisputed in health care that prevention is better, and cheaper, than cure. The same is true in energy and climate. Smartly reducing energy consumption is a more cost-effective approach for reducing emissions than deploying relatively immature technologies such as solar photovoltaics or carbon capture and storage, or CCS, which address the symptoms of a carbon-intensive lifestyle, rather than tackling the root cause of high energy consumption in the first place.

It is obvious that we should use cost-effectiveness as a criteria to assess our priorities, but it is less clear which measure of cost-effectiveness is most appropriate. Should we use upfront cost, or lifecycle cost? Some studies have suggested that although energy efficiency is cheaper over the lifecycle, it can be significantly more expensive upfront. The problem is that such studies generally do not count all the benefits of energy efficiency. They fail to recognize energy efficiency's powerful force as a lever to address the root of our energy problem—wasteful use—and give too much credit to solutions that only patch over symptoms—the resulting carbon emissions—of our wasteful energy system.

To be clear, we do not argue that higher-cost abatement options such as renewable energy and CCS should not be pursued. If we don't address the high-carbon nature of our energy sources, even the most aggressive use of energy efficiency will not be enough to help us stabilize our greenhouse gas concentrations at a level that allows us to avoid the worst consequences of climate change. We will need to keep all technical options on the table, including CCS, especially since the political economy of energy points to the continued reliance on coal combustion as a source of electricity. The higher costs of such technologies make it all the more urgent that we dedicate resources for research and development to validate their feasibility and bring down costs in order to drive rapid deployment.

What we do argue is that, to the extent that the cost-effectiveness of current carbon abatement options shape investment and policy decisions, we need to make sure that these decisions are made with a robust framework for assessing costs. When it comes to energy efficiency, the distinction between lifecycle costs and upfront costs may not matter. When we take a fresh look at these numbers using a more holistic framework that is sometimes referred to as "systems thinking," it becomes clear that energy efficiency is actually significantly cheaper on both metrics. Energy efficiency is cheaper over the lifecycle and requires less investment upfront to reduce CO2 emissions.

Systems thinking emphasizes the importance of optimizing the whole system, rather than just a narrow focus on optimizing the parts. In the case of energy, this means optimizing the entire energy system—from generation, to distribution, to consumption—instead of focusing on optimizing each of these parts in isolation.

The only way to fully understand why a problem or element occurs and persists is to understand the part in relation to the whole. This is especially true of energy systems, where interactions and feedback loops along the system of energy supply, transmission, and demand are complex and dynamic.

Systems thinking applied

Well-applied systems thinking can make economic analyses more robust. A recent landmark report by consulting firm McKinsey & Co., "Pathways to a Low-Carbon Economy,"[1] analyzes both the lifecycle cost-effectiveness and the capital intensity of various carbon abatement options such as renewable energy, energy efficiency, and land use management. Capital intensity is a measure of how much upfront investment is needed to abate one ton of carbon dioxide equivalent, and is calculated by dividing the amount of capital needed to install an abatement technology by the lifetime savings of carbon dioxide emissions realized by that technology.

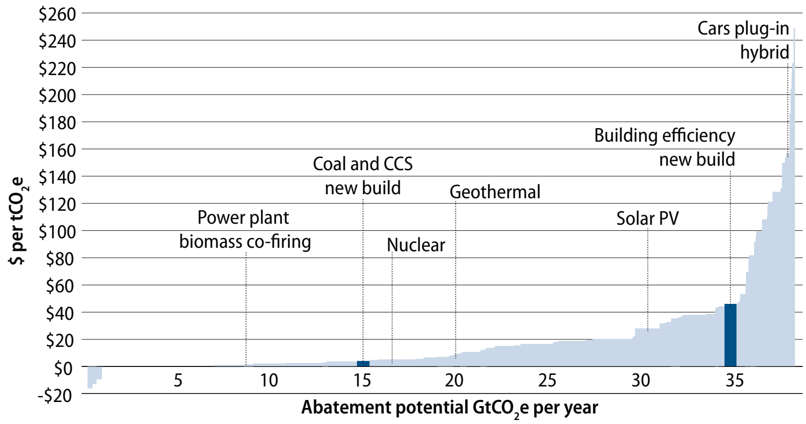
The McKinsey report finds that energy-efficiency measures in buildings will be some of the most capital-intensive sources of abatement. For example, their calculations show that new coal-fired power plants with carbon capture-and-storage technology require roughly $7 (€5) of invested capital per ton of abatement, which is less than one-sixth of the capital intensity of new energy efficient buildings, which require about $43 (€30) of invested capital per ton of abatement (See Figure 1). Capital intensity is not to be confused with lifecycle costs; the capital intensity measure focuses solely on how much upfront capital is needed to achieve one ton of CO2 abatement.

Indeed, McKinsey makes the point several times that coal CCS will not pay itself back over its lifecycle. Its upfront costs may be lower, but it does not produce cost savings over time. Building energy efficiency, on the other hand, is more capital intensive because it has higher upfront costs, but it ultimately has a "negative cost" because it creates savings over time through reduced utility bills via lower electricity use. Figure 2 shows that efficiency measures in buildings have negative abatement costs, while power sector solutions such as CCS incur a net cost over the life cycle.

It is surprising that McKinsey found that, as Figure 1 shows, the capital investment needed to invest in new green buildings is significantly higher than capital needed for coal CCS power plants. This is particularly surprising because CCS is still not a proven technology, while over 20,000 buildings have registered for LEED ratings with the U.S. Green Building Council,[2] and many, many more buildings have pursued other energy-efficiency measures. McKinsey accepts that CCS is not yet a reality and assumes that the technology will be commercialized with initially high costs that gradually reduce over time.

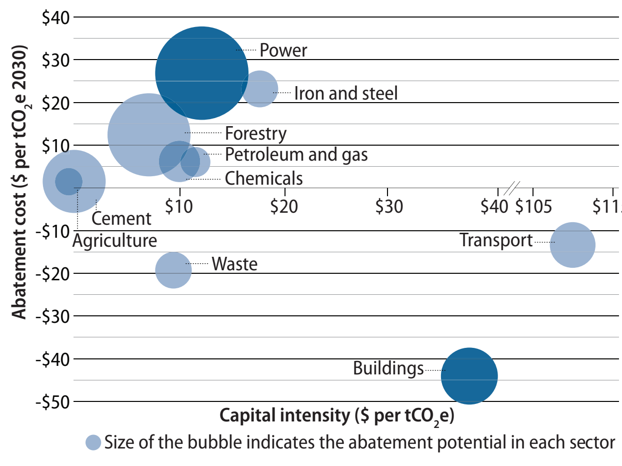
Yet the McKinsey analysis misses a critical point, even taking CCS's eventual commercialization at face value. Their conclusion does hold for one building, but it does not hold for a lot of buildings. Given the scale of emissions reductions needed to avert the worst effects of climate change, a single building simply does not matter. Analyzing the capital intensity of greening the entire building stock gives a very different result.

Figure 1: New build green buildings require significantly more capital per ton of greenhouse gas abatement than new coal power plants with carbon capture and sequestration



McKinsey & Company, "Pathways to a Low-Carbon Economy" (2009).

Figure 2: Green buildings are one of the most capital intensive sources of carbon abatement, but these investments are "negative cost," meaning that building energy efficiency investments pay for themselves over time



McKinsey & Company, "Pathways to a Low-Carbon Economy" (2009).

The logic is stunningly simple and goes like this: McKinsey's analysis is indeed correct for the first few buildings. Buildings require more invested capital for each ton of carbon emissions. Our analysis uses the fairly well established 2 percent average upfront-cost premium, and 33 percent average energy-savings data for new build green buildings, and shows that greening a single 100,000 square foot building requires approximately $25 (€18) in capital per ton of CO2e abatement (see Appendix, Table 1). Our analysis also uses cost and performance assumptions from MIT and the Department of Energy National Energy Technology Laboratory to show that a 500 MW new build coal-fired power plant with CCS requires only about $7 (€5) of capital per ton of CO2e abatement (see Appendix, Table 2). This type of analysis implies that new build coal CCS abatement technologies are 70 percent more capital efficient than new build green building abatement technologies.

Let's now imagine we keep greening building after building. Very soon, we've reduced energy use so much that we can avoid building an entire coal power plant with CCS technology. Think of the massive capital savings there. Not building the power plant means we can also avoid the capital costs of building transmission lines to connect that coal plant to the grid, which can be 50 percent of the capital cost of generation. When we credit the building with these capital savings, it turns out that energy-efficient green buildings actually require *less* capital per ton of abated carbon than coal power plants with CCS. When we include systems thinking to our analysis, reducing a ton of CO2e through a new build green building requires slightly more than $5 of capital—fully 80 percent less than what conventional analysis of greening buildings (over $25) would suggest, and also less than the capital needed for coal-fired power plants with CCS (see Appendix, Table 3).

It is also important to note that these calculations of avoided capital costs only include the capital costs associated with building a coal power plant. We're not talking about the ongoing operation and maintenance costs of the coal power plant or the costs of decommissioning the power plant at the end of its life, all of which are substantial.

A fuller analysis should also include the other avoided capital costs associated with green buildings. For example, green buildings' water conservation and waste recycling features mean fewer water treatment plants and the associated sewage infrastructure, which leads to further capital savings. If we look at green buildings as part of a larger system of neighborhood design, we see even greater savings; the mixed-use nature of smartly designed communities and the transit-oriented design principles associated with green urban development have the potential to save significant transportation-related infrastructure costs. These capital cost savings would result in even lower capital intensity for green buildings.

Moreover, the CCS capital intensity analysis does not include the additional infrastructure costs for the pipelines and storage needed for large-scale implementation of the technology, which leads to an underestimate of CCS' capital intensity. Building out a widespread CCS infrastructure would likely require significant capital; a recent MIT study estimates that the annual volume of CO2 from coal-burning power plants would be equivalent to one-third of the annual volume of natural gas transported by the U.S. gas pipeline system.[3] Needless to say, significant infrastructure build out would be required to accommodate this type of volume.

Tunneling through the cost barrier

Analysis of relative costs of climate change mitigation options, such as those conducted by McKinsey, are incredibly important in helping to drive the clean-energy policy and investment conversation. But climate change economists could provide even more useful and relevant analysis by adding systems thinking elements to their analysis.

The use of systems thinking allows for society to "tunnel through the cost barrier," as energy efficiency guru Amory Lovins likes to say. What this means is that there is a generally assumed cost-effectiveness limit for most efficiency investments. Yet systems thinking shows that sometimes moving beyond the narrow definition of cost-effectiveness for efficiency can allow us to tunnel through the initial cost barrier and unlock other savings that initially did not seem possible. What this means in concrete terms is that once we green enough buildings, we will be able to eliminate entire coal power plants, saving both energy and money, upfront and in the future. This is one of the key takeaways of systems thinking, and why it is so important to include it in a comprehensive cost analysis of clean-energy technologies.

Systems thinking is generally most effective for understanding the cost and benefits of energy efficiency because of the holistic and integrative nature of green building. One good example is in thermal regulation design in buildings, particularly as it relates to glass and heating and cooling systems. Installing high-efficiency glass means buying more expensive glass, and therefore more upfront capital investment. But when developers look at the buildings as a system, they realize that high-efficiency glass allows them to downsize their heating and cooling systems and the electrical systems that support them. Given the more capital-intensive nature of heating and cooling systems, developers can often adopt this far more energy-efficient design at a lower overall capital cost. Indeed, the latest McKinsey report on energy efficiency in the United States recognizes how such whole-building design approaches have the potential to increase the cost-effectiveness of energy efficiency.[4]

This example extends to the larger energy efficiency picture. Green buildings are to high-performance glass as coal power plants are to heating and cooling systems. Investing in what appears to be more capital-intensive energy efficiency at the building level will allow us to downsize the massive mechanical systems (coal power plants) needed to power society, as well as the electrical system (the grid) that supports the mechanical system. The result is a system that costs less both to build and to operate.

The unfortunate fact of this particular case of capital intensity economics is that the lower upfront cost applies at the level of society as a whole. There is a mismatch between who pays the increased capital costs and who reaps the savings. The building developer pays the increased capital spending, but the utility receives the concomitant benefit of reduced capital spending on coal power plants. Of course, the building developer will save money on their electricity bills and be more likely to attract environmentally conscious tenants, but in this example, unfortunately, the capital savings of avoided power plants will accrue to the utility. Federal policy must therefore play a key role in incenting developers, building owners, and utilities to focus on energy efficiency.

Properly analyzing complex systems means examining the whole system, not just separately looking at its parts. Utilities and buildings are not separate systems; in fact, utilities exist primarily to power buildings. We can avoid constructing a coal power plant by building efficient buildings, but we can never avoid constructing a building through outfitting coal power plants with CCS. This is clear from the immutable linkages between buildings and power plants. Analyzing CO2 emission reduction opportunities within this system therefore requires a look at the entire system, with a particular focus on the interactions between the different parts of the system.

It is also important to count the benefits and costs that result from the linkages between the various parts of the system. In this case, it is critical that we count all the benefits of green building, even those ones that are much harder to see, such as reduced need for transmission infrastructure. But unless we think of buildings and utilities as a system, it can be very difficult to see these capital cost savings.

Cost curves for different greenhouse gas abatement strategies will be instrumental in providing policymakers and business leaders with analysis regarding the costs of technologies and solutions needed to avert climate catastrophe. Whole-systems thinking is instrumental in ensuring that these assessments are as useful as possible. Systems thinking adds a layer of complexity to already difficult analysis, but it ultimately allows for a more holistic and accurate results.

This examination of McKinsey's capital intensity analysis suggests that their report may be overestimating the capital intensities for energy efficiency solutions, which is worrisome because such analysis may drive investment to suboptimal supply side solutions.

As McKinsey notes in their report:

> [M]any energy-efficiency opportunities that appear on the left-hand side of the cost curve [i.e. are cheaper] end up much further to the right in the capital intensity curve [i.e. are more capital intensive]. This demonstrates the different priorities that could emerge in a capital-constrained environment. Investors might choose to fund the opportunities with the lowest capital intensity rather than the ones with lowest cost over time. This would make the cost of abatement substantially higher over time.[5]

We couldn't agree more. It is therefore vitally important that we use the best possible in-depth analysis to ensure that investors in our capital-constrained world put their investment capital toward the best possible use. And the best use is generally efficiency. We are all in this together, and we have a narrow window of opportunity to get the fix right and avoid climate catastrophe. Using systems thinking will help bring forward some of the richer, and more accurate, analysis that cannot be achieved without this type of thinking.

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All USD/ EUR calculations use 1 USD : 0.7 EUR.

Endnotes

1 McKinsey & Company, "Pathways to a Low-Carbon Economy" (2009)

2 "LEED Projects Doubled in 2008" *Environmental Building News*, March 1, 2009.

3 Massachusetts Institute of Technology, "The Future of Coal" 2007.

4 McKinsey & Company, "Unlocking Energy Efficiency in the U.S. Economy" (2009) p. 32

5 McKinsey & Company, "Pathways to a Low-Carbon Economy" (2009) p. 18.

Appendix: Methodology

We began with a building size assumption of 100,000 square feet and then multiplied this by a 15.7 kWh per square foot baseline energy use intensity to arrive at a baseline building energy use. We then estimated the energy savings by multiplying this baseline building energy use by an efficiency improvement assumption of 33 percent. We multiplied these energy savings by the carbon emissions factor of 0.000606 metric tons per kWh to establish an annual CO2 emissions savings figure. We multiplied this annual CO2 emissions savings by our assumed building lifetime of 50 years to arrive at the total lifetime emissions savings. We then took our building size assumption and multiplied it by the cost per square foot number to arrive at our total cost. We multiplied total cost by the green cost premium of 2 percent to arrive at the total increase over the business-as-usual, or BAU, investment. Finally, we divided the total lifetime emissions savings by the total increase over BAU investment to arrive at the dollar capital cost per abated ton of CO2.

Table 1. Conventional analysis for a 100,000 sf building in the United States

Building size	100,000	sf
Baseline energy use intensity	15.7	kwh/ sf per year
Baseline energy use	1,570,000	kwh per year
Efficiency improvement	33%	
Energy savings	518,100	kwh per year
Carbon emissions factor	0.000606	metric tons/ kwh
Baseline CO2 emissions	951.4	metric tons per year
Annual CO2 emissions savings	314.0	metric tons per year
Building life	50	years
Lifetime emissions savings	15,698.4	metric tons
Building size	100,000	sf
Cost per sf	$200	
Total cost	$20,000,000	
Green cost premium	2%	
Total increase over BAU	$400,000	
Capital cost $ per abated ton	**$25.48**	

Source: Baseline energy intensity is based on Energy Information Administration "Commercial Buildings Energy Consumption Survey" (2003) available at http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set19/2003html/e06.html; Efficiency improvement and green cost premium are based on Good Energies, "Greening Buildings and Communities: Costs and Benefits" (2008) available at http://www.goodenergies.com/news/research-knowledge.php; Carbon emissions estimate based on U.S. DOE Energy Information Administration, "Updated State-level Greenhouse Gas Emission Coefficients for Electricity Generation, 1998-2000" (April 2002) available at http://www.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/e-supdoc.pdf

We began with a plant size assumption of 500 MW and then multiplied this by an 85 percent capacity factor and by the number of hours in a year, to arrive at total annual power output in kWh. We then estimated the emissions saved by subtracting CO2 emitted with capture—94 g/kWh per year—from CO2 emitted without capture—738 g/kWh per year. We then converted the emissions saved figure to metric tons per kWh per year by dividing the g/kWh per year figure by $1x10^6$. Next, we multiplied the emissions saved by the annual power output to establish the annual CO2 emissions savings due to CCS, and then multiplied this figure by our assumed plant life of 40 years to calculate the lifetime emissions savings. We next calculated the capital cost increase over BAU per kw by subtracting the capital cost for coal plant without CCS—$1,549 per kW—from the capital cost for coal plant with CCS—$2,895 per kW. We then multiplied this capital cost increase over BAU per kW by the plant size to get the total increase over BAU. Finally, we divided lifetime emissions savings by total increase over BAU to arrive at dollar capital cost per abated ton of CO2.

Table 2. Analysis for 500 MW sub-critical pulverized coal plant with CSS in the United States

Plant size	500	mw
Capacity factor	85%	
CO2 emitted without capture	738	g/kwh per year
CO2 emitted with capture	94	g/kwh per year
Emissions saved	644	g/kwh per year
CO2 emissions savings per KWH due to CCS	0.000644	metric ton/ kwh per year
Annual power output	3,723,000,000	kwh per year
CO2 emissions savings due to CCS	2,397,612	metric tons per year
Plant life	40	years
Lifetime emissions savings	95,904,480	metric tons
Capital cost for coal plant w/o CCS	$1,549	$ per kw
Capital cost for coal plant with CCS	$2,895	$ per kw
Increase over BAU	$1,346	$ per kw
Total capacity	$500,000	kw
Total increase over BAU	$673,000,000	
Capital cost $ per abated ton	$7.02	

Source: CO2 emitted with and without capture figures are based on Massachusetts Institute of Technology, "The Future of Coal" (2007) available at http://web.mit.edu/coal/; Capital cost figures are based on U.S. DOE National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Power Plants Study, Volume 1: Bituminous Coal and Natural Gas to Electricity" (2007) available at http://www.netl.doe.gov/energy-analyses/baseline_studies.html.

We began by following the methodology described for Table 1. However, in this case, we multiplied the energy savings by a transmission loss factor of 5.9 percent to arrive at the upstream kWh savings. We then calculated how many 100,000 sf, 33 percent more efficient buildings we would need to build to offset a coal power plant's generating capacity by dividing upstream kWh savings by total 500 MW coal plant generation of 3,723,000,000 kw per year from Table 2. We found the capital cost of a coal power plant (generation) by multiplying the capital cost for coal power plant with CCS of $2,895 per kW times the plant size of 500 MW. We then assumed that grid transmission and distribution, or T&D, costs to connect coal plant to grid were 50 percent of generating capital costs. We summed the capital cost of a coal power plant (generation) and the T&D costs to establish our total avoided capital cost. We then calculated the capital cost reduction per square foot by dividing total avoided capital cost by the number of 100,000 sf buildings needed to offset a 500 MW coal plant times 100,000 sf. We then credited the buildings with this capital cost reduction in capital cost savings from avoided coal plant, which we added to our total increase over BAU for green features from Table 1 to calculate net increase over BAU. Finally, we divided the lifetime emissions savings from Table 1 by net increase over BAU to arrive at dollar capital cost per abated ton of CO2.

Table 3. Systems thinking analysis for a 100,000 sf building in the United States

Building size	100,000	sf
Baseline energy use intensity	15.7	kwh/ sf per year
Baseline energy use	1,570,000	kwh per year
Efficiency improvement	33%	
Energy savings	518,100	kwh per year
Transmission loss factor	5.9%	
Upstream KWH savings	548,668	kwh per year
500 MW coal plant generation	3,723,000,000	kwh per year
# of 100,000 sf buildings needed to offset coal plant	6,786	buildings
Capital cost of coal plant (generation)	$1,447,500,000	
T&D costs to connect coal plant to grid	$723,750,000	
Total avoided capital cost	$2,171,250,000	
Capital cost reduction	$3.20	per square foot
New capital cost		
Building size	100,000	
Cost per sf	$200	
Total cost	$20,000,000	
Green cost premium	2%	
Total increase over BAU for green features	$400,000	
Capital cost savings from avoided coal plant	$(319,983)	
Net increase over BAU	$80,017	
Capital cost $ per abated ton	$5.10	

Source: Transmission loss factor based on Electric Power Research Institute "The Green Grid: Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid" (2008) available at http://my.epri.com/portal/server.pt.

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