McKinsey Global Institute

The carbon productivity challenge:
Curbing climate change and sustaining economic growth

June 2008

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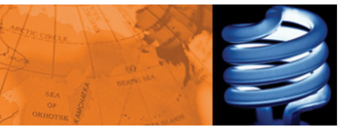

McKinsey Global Institute

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McKinsey Climate Change Special Initiative

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Preface

Two years ago, the McKinsey Global Institute (MGI) and McKinsey's energy and materials practice began a project to understand the microeconomic underpinnings of global energy demand. The overarching conclusion of this work was that a worldwide effort to boost energy productivity—the level of output we achieve from the energy we consume—is the most cost-effective way to reduce accelerating global energy demand growth. Increasing energy productivity would also make deep cuts in emissions of greenhouse gases.

In parallel, McKinsey's Climate Change Special Initiative has worked closely with policy and business leaders to develop insights into how the world can transition to a low-carbon economy as effectively and cost-efficiently as possible. To that end, in 2006 McKinsey began a collaboration with The Vattenfall Institute of Economic Research to develop a bottom-up cost curve of global greenhouse gas abatement opportunities. Subsequently, McKinsey has worked with various other partners to develop detailed cost curves for specific countries and industries.

This paper synthesizes these two strands of research, along with work by various external experts, within a concept of "carbon productivity"—the amount of GDP produced per unit of carbon equivalents ("CO_2e") emitted. Increasing carbon productivity is the key to tackling the twin challenges of mitigating climate change and maintaining economic growth.

Eric Beinhocker, a senior fellow with MGI in London, and Jeremy Oppenheim, a director in McKinsey's London office and the worldwide leader of McKinsey's Climate Change Special Initiative, jointly led the preparation of this report.

Ben Irons, a consultant in London, managed the project, working closely with Makreeta Lahti, an MGI fellow also in London. As noted, the report builds on previous research by MGI and McKinsey. MGI's work on energy productivity has been led by MGI's director Diana Farrell, Scott Nyquist, a director in MGI's Houston office, and Jaana Remes, an MGI senior fellow in San Francisco. Tomas Nauclér, a director in McKinsey's Stockholm office, and Per-Anders Enkvist, a principal, also in Stockholm, led McKinsey's work on the carbon cost curve.

We are also grateful to Janet Bush, MGI senior editor, Rebeca Robboy, MGI's external relations manager, and Ed Petter, external relations for McKinsey's Climate Change Special Initiative, for their support.

An earlier version of this paper was prepared as a briefing document to support a joint meeting between GLOBE International, an organization of legislators from governments around the world working on environmental issues, and a group of leading company chief executives held in March 2008. We are particularly grateful to Tony Hayward, the group chief executive of BP, who hosted the meeting, Chris Mottershead of BP, and Lord Michael Jay, Adam Matthews, and Terry Townshend of GLOBE International for their contributions. We would also like to thank the 15 legislators and CEOs who generously gave us their time to be interviewed in preparation for this report. Their insights were essential in helping frame the issues discussed in the paper. We should note that we have updated some of the numbers that appeared in the original briefing paper in this published version. While the overall messages of the report remain the same, we describe these updates in a note at the end of the report.

McKinsey & Company takes sole responsibility for the content of this report. The views expressed in it do not necessarily reflect the views of BP, GLOBE International, Vattenfall, or the CEOs or legislators who participated in the GLOBE meeting. This report was prepared independently and on a *pro bono* basis by MGI and McKinsey's Climate Change Special Initiative as a part of our ongoing efforts to support a fact-based dialogue between business and government leaders on the critical issue of climate change.

Diana Farrell
Director, McKinsey Global Institute

Jeremy Oppenheim
Director, Climate Change Special Initiative, McKinsey & Company

The carbon productivity challenge: Curbing climate change and sustaining economic growth

The debate on climate change has shifted dramatically over the past five years. The strong evidence presented by the scientific community through the Intergovernmental Panel on Climate Change (IPCC) process has largely settled the discussion about whether the world needs to respond. The question now is what shape such a response should take.

There is agreement approaching consensus that any successful program of action on climate change must support two objectives—stabilizing atmospheric greenhouse gases (GHGs) *and* maintaining economic growth. Research by the McKinsey Global Institute (MGI) and McKinsey & Company's Climate Change Special Initiative finds that reconciling these two objectives means that "carbon productivity," the amount of GDP produced per unit of carbon equivalents (CO_2e) emitted, must increase dramatically.[1]

We estimate that to meet commonly discussed abatement paths, carbon productivity must increase from approximately $740 GDP per ton of CO_2e today to $7,300 GDP per ton of CO_2e by 2050—a tenfold increase. This is comparable in magnitude to the labor productivity increases of the Industrial Revolution.

1 Carbon productivity is the inverse of the carbon intensity of GDP and can be derived from the Kaya identity as 1/(e*f). See Yoichi Kaya and Keiichi Yokobori, eds., *Environment, Energy and Economy*, Bookwell Publications, 1993. In a future world in which carbon is priced and the flow of emissions is restricted, we can view CO_2e emissions as an input into total factor productivity and thus consider its impact on growth along with other input factors such as labor and capital. CO_2e is "carbon dioxide equivalent," a standardized measure of GHGs that accounts for the differing warming potentials of other GHGs such as methane. Emissions are measured in metric tons of CO_2e per year, i.e., millions of tons (megatons) or billions of tons (gigatons).

However, while the extent of economic transformation implied is similar to the Industrial Revolution, the "carbon revolution" must be achieved in one-third of the time if we are to maintain current growth levels while keeping CO_2e levels below 500 parts per million by volume (ppmv), a level that many experts believe is the maximum that can be allowed without significant risks to the climate.

The macroeconomic costs of this carbon revolution are likely to be manageable, being in the order of 0.6–1.4 percent of global GDP by 2030. Borrowing could potentially finance many of the costs, thereby effectively limiting the impact on near-term GDP growth. In fact, depending on how new low-carbon infrastructure is financed, the transition to a low-carbon economy may increase annual GDP growth in many countries.

Essential to driving increases in carbon productivity will be identifying and capturing the least-cost abatement opportunities in the economy. The "global carbon cost curve" developed jointly by McKinsey and The Vattenfall Institute of Economic Research provides a map of the world's abatement opportunities ranked from least-cost to highest-cost options. The cost curve identifies 27 gigatons per annum of potential CO_2e abatement that is consistent with a stabilization target of 450 to 500 ppmv.[2] Our research finds that we can achieve an abatement of this order of magnitude by 2030 for under €40 per ton, using technologies that are either available or visible today. Our analysis also shows that 7 gigatons, or approximately one-quarter of the potential abatement, has positive economic returns due to energy efficiency and other savings.

Analysis of the cost curve identifies five areas on which we should focus if we are to drive the necessary microeconomic changes:

1. Capturing available opportunities to increase energy efficiency in a cost-effective way
2. Decarbonizing energy sources, in particular in the electric power and oil and gas sectors
3. Accelerating the development and deployment of new low-carbon technologies
4. Changing the behaviors of businesses and consumers
5. Preserving and expanding the world's carbon sinks, most notably its forests.

2 This is the range that experts suggest will be necessary to prevent the global mean temperature from increasing by more than 2.5 degrees Celsius above pre-industrial levels.

In this paper, we will discuss the opportunities to increase carbon productivity in each of these five areas, the hurdles that need to be overcome, and the questions that need to be addressed in order to achieve the goals of reduced emissions while continuing economic growth.

The microeconomic changes needed to increase carbon productivity at the levels required will not occur without the active leadership and collaboration of governments and businesses on a global basis. We need new policies, regulatory frameworks, and institutions that focus on four areas:

- Creating market-based incentives to innovate and raise carbon productivity
- Addressing market failures that prevent abatement opportunities from being captured profitably
- Resolving issues of allocation and fairness, in particular between the developed and developing worlds and between industry sectors
- Accelerating progress to avoid missing critical emissions targets and putting the climate at increased risk.

We will discuss these in more depth in the last section of this paper.

Meeting the twin objectives of carbon abatement and economic growth over the next five decades will be challenging but possible. The histories of the industrial and information-technology revolutions show that with the right incentives and institutional structures, dramatic levels of change and innovation in the economy can occur, driving growth, raising living standards, and creating opportunities. Our research shows that most of the technologies required for a carbon revolution already exist. But creating the necessary incentives and structures on a global scale will be one of the most significant political challenges of our age. It is a challenge that we must meet.

TWO IMPERATIVES: STABILIZING CARBON AND MAINTAINING GROWTH

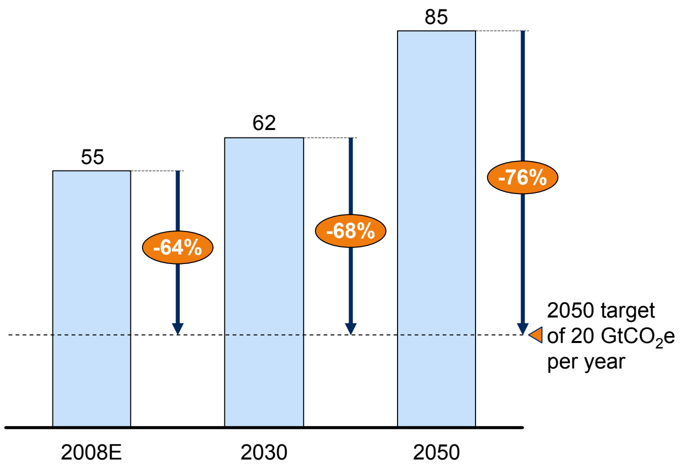
There is growing consensus on what the broad outlines of the world's response to climate change should be—a path of emissions cuts that stabilizes atmospheric carbon and other GHG concentrations in a way that minimizes the risks of damage from rising temperatures. We are now entering what will be the most challenging phase of the debate—answering the specific questions of how to achieve this end. Any successful program of action would need to meet two conditions.

First, such a program would have to be effective in stabilizing the levels of CO_2e in the atmosphere at a level and within a timeframe that minimizes likely temperature rises and thus the negative consequences of climate change to some acceptable level. Defining this acceptable level is still the subject of debate, but the European Union (EU) has committed to a target of a mean temperature increase of 2 degrees Celsius above preindustrial levels, and the G8 Summit in Heiligendamm in 2007 proposed a 50 percent reduction in global emissions by 2050. These targets are consistent with IPCC emissions scenarios of stabilizing CO_2e concentrations at 445–535 ppmv and cutting annual emissions by 30 to 85 percent versus year 2000 emissions by 2050.[3] The Stern Review proposes a 2050 target of 20 gigatons of CO_2e to achieve 500 ppmv concentration with no overshoot.[4] This is the target we adopt for the analysis that follows, although it is important to note that the emissions target required to mitigate damaging climate change is the subject of continuing scientific research. The 20 gigaton target implies a reduction in annual global emissions versus "business as usual" of 76 percent by 2050 (Exhibit 1).

Exhibit 1

SCIENCE SUGGESTS WE NEED TO REDUCE EMISSIONS BY APPROXIMATELY 76 PERCENT BY 2050 TO STABILIZE THE CLIMATE

Global "business as usual" GHG emissions, $GtCO_2e$*



* Gigatons of carbon equivalents.

Source: McKinsey analysis; IPCC; Stern Review (2006)

3 *Summary for Policy Makers*, 4th Assessment Report IPCC Working Group III, April 30–May 2007.

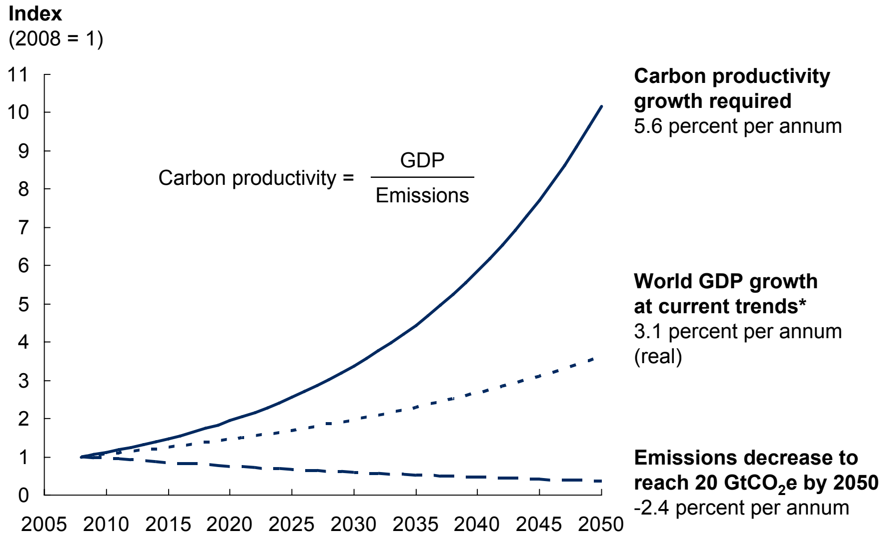
4 Nicholas Stern, *The Economics of Climate Change – The Stern Review,* 2006, and *Key Elements of a Global Deal on Climate Change*, 2008.

Second, any solution must recognize that the world has both a right to, and a need for, continued economic growth. Over the two centuries since the Industrial Revolution began, economic growth has enabled approximately one-third of the world's population, largely concentrated in Europe and North America, to escape a life of hunger, hardship, and disease. Over the past two decades, another third of the world's population, mostly in Asia, has begun this journey too. It is hoped that over the coming decades, the final third will make their escape. The need for economic growth is a moral imperative and deeply ingrained in the human spirit—in both the developed and developing worlds.

If we accept these two imperatives—carbon stabilization and continuing economic growth—we have only one choice. We must dramatically increase the level of "carbon productivity" in the economy. By carbon productivity we mean the level of gross domestic product (GDP) output per unit of CO_2e emitted. One can think of carbon productivity in the same way one thinks about labor productivity (GDP output per hour worked) or capital productivity (GDP output per unit of capital). The current level of global carbon productivity is approximately $740 per ton of CO_2e. To meet the twin goals of growth continuing at its current trajectory of 3.1 percent per year and reducing emissions to 20 gigatons per year, carbon productivity must increase by ten times, to $7,300 per ton of CO_2e, by 2050 (Exhibit 2).

Exhibit 2

REDUCING EMISSIONS AND MAINTAINING GROWTH IMPLIES CARBON PRODUCTIVITY MUST INCREASE BY TEN TIMES



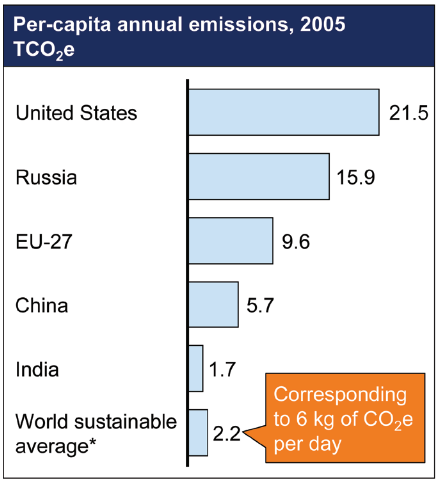
* Global Insight GDP forecast to 2037, extrapolated to 2050.

Source: McKinsey analysis

If we do not reach such a level of carbon productivity, the consequences will be stark. Meeting the 20 gigatons per year target implies a per-person carbon budget of 6 kg of CO_2e per day. If one had to live on such a carbon budget with today's low levels of carbon productivity, one would be forced to choose between a 40 kilometer car ride, a day of air conditioning, buying two new T-shirts (without driving to the shop), or eating two meals (Exhibit 3). In short, without a major boost in carbon productivity, stabilizing GHG emissions would require a major drop in lifestyle for developed countries and the loss of hope in developing economies for greater prosperity through economic growth.

Exhibit 3

THERE IS NOT MUCH WE COULD "AFFORD" IF WE HAD TO LIVE AT 20 GIGATONS CO_2E PER YEAR TODAY



"Emission budget" for a day (alternatives)	
Travel	20–40 km car ride
Stay home	10–20 hours air conditioning
Shop	2 new T-shirts (6 kg of CO_2, so don't drive to the shop)
Eat	2 meals a day (6 kg CO_2) of 300 g meat, 200 g fries, tap water

* Based on 20 Gt/year sustainable emissions and future population of 9 billion people.
Source: McKinsey analysis

Achieving a tenfold increase in carbon productivity will require radical changes in the world economy. But it is a level of change the world has seen before. During the Industrial Revolution, the United States achieved an increase in labor productivity of ten times between 1830 and 1955.[5] The key difference is the timeframe. The tenfold increase in labor productivity was achieved over 125 years; the carbon revolution needs to be achieved in only 42 (Exhibit 4).

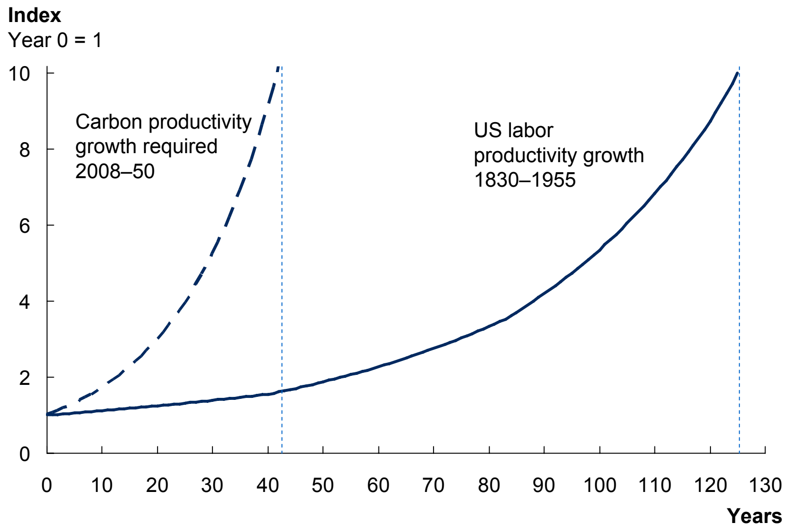
Productivity growth, such as occurred during the Industrial Revolution, is largely a microeconomic phenomenon. New technologies are developed and deployed,

5 Angus Maddison, *Contours of the World Economy 1-2030 AD*, Oxford University Press, 2007.

new investments made, new infrastructure put in place, and changes occur in the decisions, practices, and behaviors of millions of business managers, workers, and consumers.

Exhibit 4

A "CARBON REVOLUTION" NEEDS TO BE THREE TIMES FASTER THAN THE INDUSTRIAL REVOLUTION RISE IN LABOR PRODUCTIVITY



Source: *Contours of the World Economy 1 – 2030 A.D.*, Maddison, 2007; McKinsey analysis

Technological innovation often plays a critical role in productivity growth, but just as important are changes in the wider political, institutional, and cultural environment that enable technologies to be exploited and provide incentives for their deployment. For example, the productivity increases of the Industrial Revolution were partly the result of technological innovations such as the spinning jenny and the steam engine. But just as important were innovations in the way people organized and managed their businesses, such as Richard Arkwright's creation of the first large-scale factories, Henry Ford's invention of the production line, or Alfred Sloan's development of the divisionalized corporation. These technological and organizational innovations were in turn encouraged and enabled by a series of changes in government policy, institutional structures, and the regulatory environment. For example, governments created a legal framework for public companies, enabling large amounts of capital to be pooled for the first time. They also strengthened property rights, enabling businesses to make long-term investments. And they passed consumer protection laws, enabling customers to trust the products and services they were buying, thus spurring demand.

Similarly, achieving a tenfold increase in carbon productivity over the next four to five decades will require widespread microeconomic changes that are encouraged and enabled by changes in the policy, regulatory, and institutional framework of the global economy. In approaching the carbon productivity challenge we need to answer three questions:

1. Which areas offer the greatest potential for carbon abatement at the least cost and impact on growth?
2. What actions are needed to capture those abatement opportunities?
3. What policies, regulatory approaches, and new institutions would enable and encourage these actions?

MAXIMIZING CARBON ABATEMENT AT MINIMUM COST

To achieve a dramatic increase in carbon productivity, actions by governments and businesses will need to focus on opportunities to abate the maximum amount of carbon for the minimum cost. Without such a focused approach, the costs of abatement will be significantly higher and the world will be forced into difficult tradeoffs between abatement and growth. This section of the paper discusses a carbon abatement "cost curve" that identifies which actions should be prioritized, and how those actions would likely impact overall GDP growth.

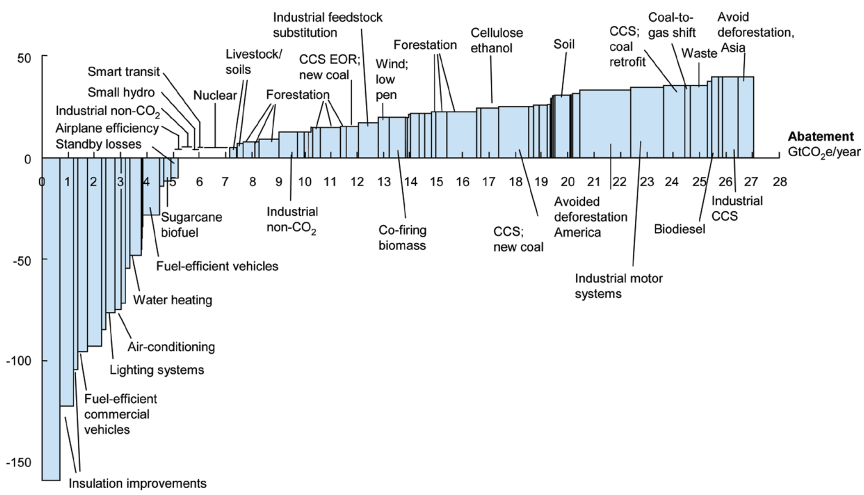
In 2006–07, McKinsey and The Vattenfall Institute of Economic Research worked together to create a comprehensive global map of the microeconomic changes required to abate GHGs. The resulting CO_2e "cost curve" shows the full range of actions that are possible with technologies that either are available today or offer a high degree of certainty about their near-term potential (Exhibit 5). The width of the bars indicates the amount of CO_2e that potentially could be abated, and the height shows the marginal cost per ton abated.[6] The graph is ordered left to right from the lowest-cost abatement opportunities to the highest-cost. The cost curve is built on a number of assumptions consistent with a scenario in which 27 gigatons of abatement versus business as usual is delivered by 2030—a quantity that could lead to CO_2e peaking at 500 ppmv. This cost curve does not aim to forecast a particular reduction scenario or a carbon price, but rather to show which levers yield the greatest potential abatement for the lowest cost under a plausible set of assumptions.

6 "A cost curve for greenhouse gas reduction," *The McKinsey Quarterly*, 2007/1 (www.mckinseyquarterly.com).

Exhibit 5

THE COST CURVE PROVIDES A "MAP" OF ABATEMENT OPPORTUNITIES

Cost of abatement, 2030, €/tCO_2e*



* Tons of carbon equivalents.
Source: McKinsey and Vattenfall analysis

The first conclusion that stands out is that a significant portion of the abatement potential, approximately 7 gigatons of annual emissions on the left side of the curve, would be at a negative cost to society. In other words, these actions would earn a positive economic return derived largely from savings in energy costs through, for example, more energy-efficient lighting or more fuel-efficient vehicles.

The second key point is that under the cost curve's assumptions, the world can achieve the 27 gigatons per year of abatement required in 2030 to stay below 500 ppmv for a marginal cost of under €40 per ton. Finally, the cost curve counters a number of myths about carbon abatement—for example, that there are only limited low-cost abatement opportunities in the developed world or that we can only achieve abatement with new technologies (Exhibit 6).

If the world were to take these abatement actions, the annual total cost to society would be €500 billion–€1,100 billion in 2030 or 0.6–1.4 percent of that year's projected global GDP, assuming growth continues on its long-term trend. This cost estimate is roughly in the middle of the range of 0.2–3.0 percent of

GDP for targets from 445–590 ppmv found in a survey by the IPCC.[7] If one were to view this spending as a form of insurance against potential damage due to climate change, it might be relevant to compare these figures to global spending on insurance (excluding life insurance), which was 3.3 percent of GDP in 2005.

Exhibit 6

THE COST CURVE COUNTERS MYTHS ABOUT GHG ABATEMENT

Myths	Realities
• Abatement opportunities are concentrated in the industry and power sectors	• Industry and power represent less than half of the total 2030 abatement potential*
• Limited amount of low-cost opportunities in industrialized countries	• Negative cost abatement potential represents 35–45 percent of the total in industrialized countries
• Abatement opportunities are concentrated in industrialized countries and China	• Developing world excluding China represents >40 percent of the total 2030 abatement potential*
• We can only achieve the required abatement through new technology	• 70 percent of the total 2030 abatement potential* not dependent on new technology
• Addressing GHG emissions will severely strain the global economy	• Reaching 450 ppmv could cost as little as 0.6 percent of GDP if all low-cost opportunities efficiently addressed

* Below €40/tCO_2e.
Source: McKinsey analysis

How abatement costs would likely impact GDP growth

It is important to note that these cost estimates (and most of the cost estimates provided by other researchers) represent a "welfare" cost versus the amount that society would be spending under the business-as-usual scenario.[8] This is not the same as the headline GDP figures one is accustomed to seeing reported for countries. Thus the above should not be interpreted as meaning that world GDP will drop by 0.2 to 3.0 percent by 2030. In fact, many of the actions required to abate emissions would increase headline GDP growth for many countries. For example, a transition to lower-emissions vehicles would raise GDP if this resulted in a faster-than-normal replacement of the vehicle stock. Likewise, major deployments of renewable energy or carbon capture and

7 *Summary for Policy Makers*, 4th Assessment Report IPCC Working Group III, April 30–May 2007.

8 Nicholas Stern, *The Economics of Climate Change – The Stern Review*, 2006; William Nordhaus, *The Challenge of Global Warming: Economic Models and Environmental Policy*, September 2007; *Fighting Climate Change: Human Solidarity in a Divided World*, United Nations Human Development Report, 2007/2008.

storage (CCS) would require substantial infrastructure investments that would raise headline GDP.

A critical question is how much of the money for these investments would be taken from current consumption, thus lowering GDP in other parts of the economy (e.g., consumers pay for their efficient cars or green energy by spending less on something else), versus simply substituting for business-as-usual investment in capital stock (e.g., investment in clean-coal capital substituting for investment in traditional-coal capital). Our research suggests that the bulk of the investment required would come from substituting low-emissions capital for traditional capital. But as carbon productivity is currently low, there would nonetheless be an incremental cost (e.g., a clean-coal megawatt will cost more than a traditional-coal megawatt). In a detailed study of the US carbon cost curve, McKinsey estimated that the cumulative net new investment associated with capturing 3 gigatons per year of abatement through to 2030 would be $1.1 trillion. While this is a large amount, it is important to note that it represents only 1.5 percent of the $77 trillion in projected real investment in the US economy over this same period.[9] Thus most of the investment required for carbon abatement will come from investments that would otherwise have been made in traditional capital.

How can we finance the necessary investment in carbon abatement?

The next question is how we can finance the required incremental capital. Some economists argue that it would make more sense for us to borrow this capital since the investments would benefit future generations.[10] If we rely on financing the incremental capital by reducing current consumption, then such investments would slightly lower GDP growth; if they are financed through an expansion in borrowing, they would not.

The United States, for example, would have no difficulty financing the $50 billion per year in incremental investment required through its $56 trillion capital market, and could do so with no drop in consumption by adding just over 5 percent to its current account deficit.[11]

9 "Reducing US greenhouse gas emissions: How much at what cost?" McKinsey & Company, November 2007 (www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf).

10 Duncan K. Foley, "The Economic Fundamentals of Global Warming," Santa Fe Institute Working Paper 2007-12-044.

11 By increasing its current account deficit, the United States would be borrowing from countries with net savings to finance its transition to a low-carbon economy. In essence dollar flows to countries such as China or oil-exporting nations would be recycled back to finance investments in low-emissions capital (although the net savings positions of these countries would likely decline over time as they invested in their own abatement actions and oil demand peaks).

The EU and other parts of the developed world would also likely find it possible to finance their incremental investment through borrowing. In essence, such borrowing would be the equivalent of a significant fiscal stimulus on the economy, boosting GDP growth, but potentially without increasing inflationary pressures as the expansion in credit to pay for the investments would go toward replacing traditional capital stock with low-emissions capital stock rather than increasing consumption.[12] There is also precedent for this kind of borrowing. The United States and other developed countries have historically borrowed significant amounts to finance major infrastructure expansion such as electrification, road-, and railroad-building efforts in the early 20th century.

However, many developing nations would find it harder to finance the incremental investments required and face more difficult tradeoffs between sacrificing current consumption for future abatement benefits. It is possible that the international community could finance such incremental investments, just as organizations such as the World Bank fund investments in traditional capital stock. It should be noted, however, that countries with strong net savings positions, such as China and the oil-producing Gulf states, would be in a different position to other developing countries. Like the developed world, these countries would have the ability to finance their incremental abatement investments without sacrificing near-term consumption and growth (in fact they would also likely be lending funds for such purposes to the United States and other developed countries). Their challenge would rather be to create the price signals, incentives, and reforms to their capital markets for this to happen.[13]

Thus at a global, macroeconomic level, the costs of transitioning to a low-carbon economy are not, in an economic "welfare" sense, all that daunting—even with currently known technologies. Financing much of the incremental investment costs through the global capital markets should be possible, and we could probably accomplish the shift to a low-emissions capital stock without significant sacrifices in current consumption, overall employment, or headline GDP growth.

Finally, we should also note that given the multi-decade timeframes involved,

12 This result is not surprising. Increases in productivity raise the noninflationary growth path of an economy. If CO_2e was in some way to be priced it would become a "factor" in total factor productivity. If total factor productivity, including CO_2e, increases, the noninflationary growth path should increase as well.

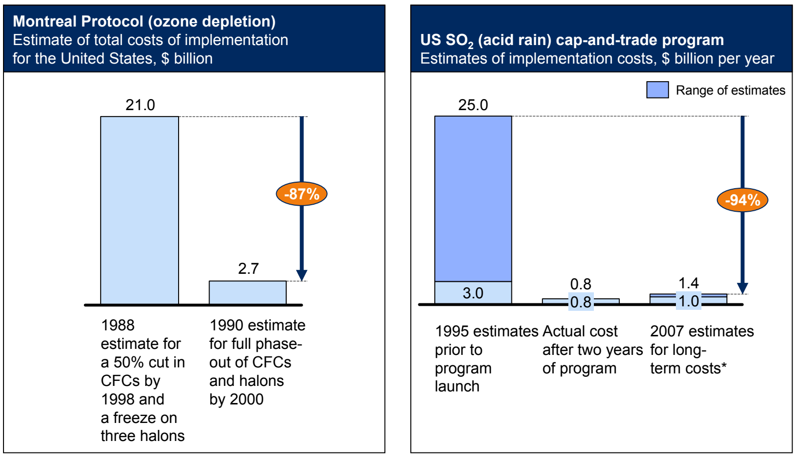
13 *Putting China's capital to work: The value of financial system reform*, McKinsey Global Institute, May 2006 (www.mckinsey.com/mgi).

costs estimated today may turn out to be higher than the costs actually incurred. The reason is that it is very difficult to predict the response to changed incentives and the impact of future (and today unknown) innovations in technology and how businesses are organized and managed.

There are two recent case examples that illustrate this point. In 1988 estimates put the cost to the United States of a 50 percent cut in chlorofluorocarbons (CFCs) by 1998 at $21 billion (Exhibit 7). The next year, the Montreal Protocol went into force and industry responded with product substitutions, technological innovations, and changed business practices. By 1990, within two years, the estimated cost for a full phase-out of CFCs had dropped to $2.7 billion—87 percent less than the original estimate. Likewise, the original estimates for the annual costs of reducing acid rain through the US SO_2 cap-and-trade program prior to launch in 1995 ranged from $3 billion to $25 billion. As of 2007, estimates for the actual long-term costs range from $1 billion to $1.4 billion—between 53 percent and 94 percent less than the original projection. CFC and US SO_2 abatement were far simpler and smaller-scale problems than global carbon abatement, but the basic principle—that many of the factors that will reduce future costs are unforeseeable—likely still holds true.

Exhibit 7

THE MONTREAL PROTOCOL AND THE US SO_2 CAP-AND-TRADE SCHEME REDUCED EMISSIONS AT LOWER-THAN-EXPECTED COST



* Long-term costs are higher than short-term costs because in Phase I (1995–99) the program covered only the most SO_2 emission-intensive power-generating units, whereas in Phase II (2000 and continuing) the program was broadened to cover almost all units.

Source: S. Barrett, *Environment and Statecraft: The Strategy of Environmental Treaty-Making*, 2003; Environmental Defense; D. Burtraw et al, *Economics of Pollution Trading for SO2 and NOx*, 2005

FIVE ISSUES TO BE ADDRESSED TO MEET THE CARBON PRODUCTIVITY CHALLENGE

McKinsey's work on the cost curve and MGI's research on energy demand and productivity show that macroeconomic cost is not the greatest barrier to raising carbon productivity. Rather, the issues and barriers lie in the realm of microeconomics. The cost curve shows that the abatement opportunities that the world must capture are scattered across scores of industry sectors and geographies. The largest single abatement lever—forestation and avoided deforestation—still accounts for only 25 percent of the total abatement opportunity, and the power sector only 22 percent. Another 42 percent of the total is strewn across dozens of developing countries.

Addressing each of the major abatement levers will inevitably create winners and losers as economic surplus shifts across companies, sectors, and countries. The challenge, therefore, is to drive abatement and carbon productivity increases across all sectors and geographies effectively, efficiently, and fairly. We now turn to the five specific issues that need to be addressed if we are to meet this challenge: 1. Capturing the energy-efficiency opportunity; 2. Decarbonizing energy sources; 3. Accelerating the development and deployment of new technologies; 4. Changing the attitudes and behaviors of managers and consumers; and 5. Preserving and expanding the world's carbon sinks. We will briefly consider the changes needed in each area and the policy and regulatory interventions required to enable and encourage those shifts, as well as the barriers that stand in the way.

1. Capturing the energy-efficiency opportunity

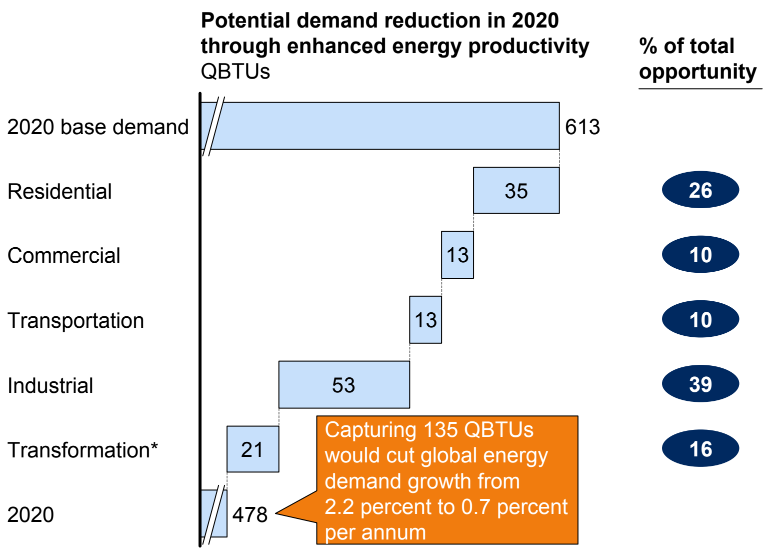
MGI's detailed research into the opportunities available to boost energy productivity—the level of output we achieve for the energy we consume—estimates that there is potential to reduce global energy demand by 125 quadrillion British thermal units (QBTUs) to 145 QBTUs, the equivalent of 20 to 24 percent of projected end-use energy demand in 2020.[14] These opportunities are available across energy end-use sectors and would yield approximately 4.7 gigatons of abatement. Each ton of CO_2e abated saves money through either reduced energy use or other efficiencies. The opportunities break down into five categories of end-use sectors (Exhibit 8):

14 *Curbing global energy demand growth: The energy productivity opportunity*, McKinsey Global Institute, May 2007, and *The case for investing in energy productivity*, McKinsey Global Institute, February 2008 (www.mckinsey.com/mgi).

- Residential (26 percent of the opportunity)—examples include high-insulation building shells, compact fluorescent lighting, efficient water heating, and reduced standby power
- Commercial (10 percent)—significant opportunities in commercial real estate, largely in heating, cooling, and lighting
- Industrial (39 percent)—this is the largest area of opportunity with a broad array of fragmented opportunities in steel, chemicals, aluminum, food processing, textiles, electronics and many other industries
- Transformation (16 percent)—energy is lost when the power generation and refining sectors transform energy from one form to another; investing in efficient technologies with 10 percent Internal Rate of Return (IRR) or better could boost BTU conversion efficiencies to 55 percent
- Transport (10 percent)—vehicle manufacturers, consumers, and commercial users have not fully captured positive economic returns from vehicle fuel efficiency.

Exhibit 8

LARGE OPPORTUNITIES FOR IMPROVING ENERGY PRODUCTIVITY ARE AVAILABLE ACROSS SECTORS



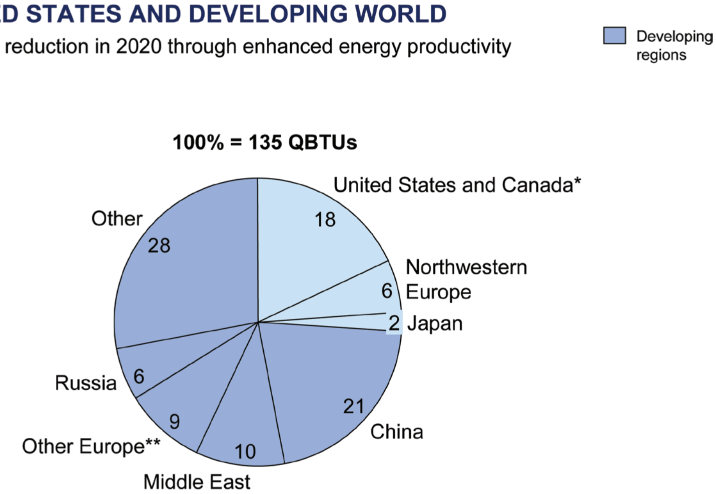
* 20 QBTU power sector opportunity not included in capital analysis.
Source: McKinsey Global Institute analysis

The opportunities are also widespread geographically (Exhibit 9). China and North America are the two largest markets in terms of their potential to abate energy demand, representing 21 and 18 percent of the total respectively. The Middle East, at 10 percent, represents another large region of opportunity due to its fast-rising status as a user of energy and the low level of its energy efficiency encouraged by high energy subsidies.

Exhibit 9

THE VAST MAJORITY OF ENERGY-EFFICIENCY OPPORTUNITIES ARE IN UNITED STATES AND DEVELOPING WORLD

Potential demand reduction in 2020 through enhanced energy productivity



* Canada presents a 2.4 QBTU opportunity.
** Includes Baltic/Eastern and Mediterranean Europe and North Africa.
Source: McKinsey Global Institute analysis

Capturing these opportunities would require a significant replacement of low-efficiency capital stock in the economy for higher-efficiency buildings, factories, and vehicles. MGI estimates that the incremental cost of replacing this capital stock would require additional annual investments of $170 billion between now and 2020, equivalent to 1.6 percent of global fixed-capital investment today. The returns would be attractive. These investments would yield $900 billion in annual energy savings by 2020 (assuming an average oil price during the period of $50 per barrel—higher oil prices would mean higher returns) and generate an average IRR of 17 percent.

Given the high returns and relatively low risk of these investments, it is natural to ask why these opportunities have not been realized despite significant increases in energy prices in recent years. There are a variety of market failures at work including:

- "Principal-agent" problems—neither builders, owners, nor tenants of commercial real estate have incentives to make efficiency investments as builders would pay the capital costs but not see the returns, owners do not pay the utility bills, and most tenants are on leases that are too short for them to capture the gains

- Lack of information—many decisions are made by parties ranging from consumers to industrial managers who have little information on efficiency alternatives and potential savings

- High consumer discount rates—surveys show that only 27 percent of consumers are willing to consider energy-efficiency investments with payback periods greater than two years

- Too small to be a priority—many individual opportunities are too small to be a priority for business managers or consumers, even though they are large in aggregate

- Access to capital—capital is often not available to businesses, individuals, and the public sector for smaller investments in efficiency with longer payback periods; developing countries also often lack capital for these investments

- Subsidies and other distortions—many governments subsidize energy consumption or create other distortions. Examples include fuel subsidies in oil-exporting countries, lack of gas metering in Russia, widespread energy subsidies to state-owned enterprises, and 30-year depreciation schedules for energy-efficiency investments in the United States.

Addressing these market failures and distortions will require action across a number of fronts, including government intervention to set minimum energy and fuel-efficiency standards. Key questions to be addressed include:

- How can government and business work together on regulatory efforts to boost energy efficiency? What types of standards would businesses be willing to sign up to? What standards are best set at the national, regional, or sectoral level?

- Action is necessary to provide incentives for energy-efficiency investments. In broad terms, what would it take for businesses to see energy efficiency as a serious profit opportunity, and what can governments do to encourage this?

- How can capital be mobilized to capture positive-return opportunities that are available today and what new market mechanisms and intermediaries need to emerge?

Increased access to energy-efficient capital and technologies in the developing world will be vital; so too will be the unwinding of distorting subsidies and policies. Governments also need to take steps to improve their own energy efficiency, making this a factor in government purchases and thereby boosting demand for energy-efficient products and services.

2. Decarbonizing energy sources

The world is dependent on carbon-emitting fossil fuels for 81 percent of its total energy needs. While supply from low-emission sources has been growing (e.g., renewables at the rate of 12 percent per year from 2000 to 2005; biofuels recently at between 15 and 20 percent per year), low carbon-emitting sources still only make up 19 percent of total energy provision. Given our assumption of continued economic growth, the world will see end-use energy demand rise from 422 QBTUs in 2003 to 613 QBTUs in 2020, a 45 percent increase under business as usual. To reduce emissions by one-fifth of current levels by 2020 even while energy demand is growing strongly, the carbon productivity of energy sources (including energy efficiency) must increase by two-thirds by 2020.

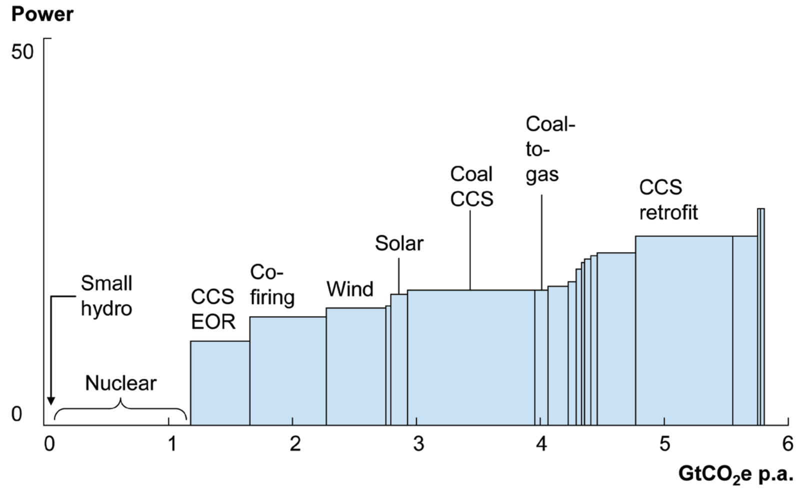
The two major sectors that are creating, transforming, and distributing those BTUs are electric power, and oil and gas. To meet abatement targets, both these sectors will need to undergo significant restructuring. The power sector will need to abate 6 gigatons of CO_2e by 2030, significantly changing its energy-source mix, with wide variations by country. Under virtually all realistic scenarios, CCS will need to play a major role, with open questions on the future of nuclear, and significant bets on emerging renewable technologies. Oil and gas abatement savings will come largely from demand reduction through fuel-efficient vehicles and increasing use of alternative fuels with potential to reduce crude oil demand by 29 percent versus today's level or about half of business-as-usual forecasts.

The global cost curve for power generation makes it clear that no single action in this sector will deliver the full potential for reducing emissions (Exhibit 10). To reach a target of 6 gigatons of annual CO_2e abated by 2030 and to keep the costs below €40 per ton, the sector will need to pull all possible levers. Due to the large installed base of coal-fired generation, and the likely continued dependence on coal, the largest potential—3 gigatons or 11 percent of total abatement—lies in various forms of CCS. Nuclear power could also provide significant abatement potential—1.1 gigatons or 4 percent of the total. A mixture of renewables (in particular wind) would make up 1.5 gigatons or 6 percent.

Exhibit 10

NO SINGLE ACTION IN THE POWER SECTOR WILL DELIVER THE FULL EMISSIONS ABATEMENT POTENTIAL

€/tCO_2e



Source: McKinsey and Vattenfall analysis

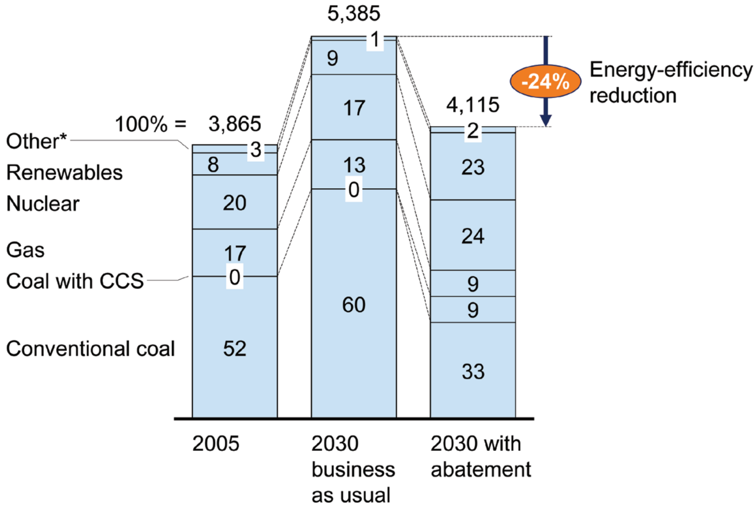
Power sector abatement strategies will vary significantly by country, depending on their starting position, level of dependence on coal, suitability for renewables, and whether they have existing nuclear-power generation. In the United States, for example, our base-case projections show power demand increasing from 3,865 terawatt hours today to 5,385 terawatt hours by 2030 (Exhibit 11).[15] As outlined in the previous section, energy-efficiency savings could reduce that by 24 percent—and thus constitute the most important lever for reducing power-sector emissions. Capturing abatement opportunities at under $50 per CO_2e ton would dramatically change the US generation mix. Renewables would expand from 8 percent of supply today to 23 percent by 2030, nuclear would expand slightly from 20 to 24 percent, and coal with CCS would grow to account for 9 percent. It is important to note that, even with these changes, conventional (non-CCS) coal would still account for a third of the overall mix, although in absolute terms this energy source would decline from approximately 2,010 terawatt hours to 1,350 terawatt hours.

15 “Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?” McKinsey & Company and The Conference Board, December 2007 (http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf).

Exhibit 11

THE COMPOSITION OF US POWER GENERATION WOULD CHANGE SIGNIFICANTLY WITH ABATEMENT

Terawatt hours, %



* Includes oil, geothermal, municipal solid waste, and pumped storage.
Source: *Reference case, US EIA Annual Energy Outlook* 2007; McKinsey analysis

China presents a particularly difficult case. The International Energy Agency (IEA) projects that China's energy demand will grow by 3.9 percent per year through to 2030.[16] The vast majority of this demand will be met by coal, although coal's share will fall slightly from 89 to 84 percent (Exhibit 12). China's power sector is expected to continue to experience efficiency gains of 15 percent by 2030, but the emissions implications of its growth in coal-fired power are nonetheless enormous. Annual emissions from this source alone are expected to grow from 4.2 billion to 8.9 billion tons from 2005 to 2030. By necessity, demand reduction from energy-efficiency improvements and significant investments in CCS will need to be a major part of any emissions-reduction plan for China.

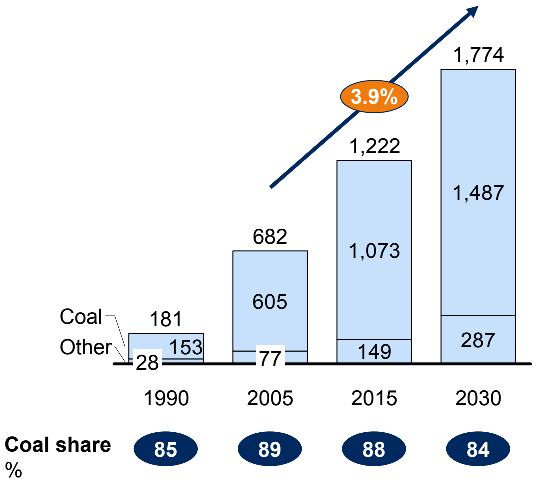
We have been fairly conservative in our assumptions about technological progress in these projections. Faster development and deployment of CCS (which we assume is not commercially deployed until 2020), the availability of lower-cost standardized nuclear designs, breakthroughs in solar or other renewable technologies, and investments in grid technologies that improve efficiency and lower the cost of integrating distributed renewable sources, all have the potential to change the shape of the sector's cost curve.

16 *World Energy Outlook*, IEA, 2007.

Exhibit 12

COAL WILL FUEL MOST OF THE RAPID GROWTH IN CHINA'S POWER SECTOR

Energy demand in power sector, millions of tons of oil equivalent per year



Source: IEA *World Energy Outlook* 2007; McKinsey analysis

A number of questions arise:

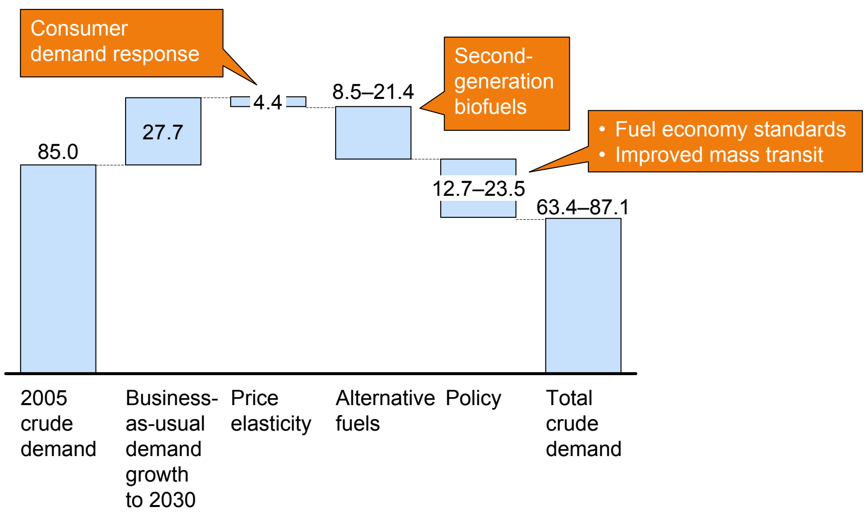
- Given the importance of CCS under virtually all scenarios, what can be done both at the national and international level to speed its development and global deployment?
- What is the most effective way of financing the significant costs of CCS development and deployment? How can fairness issues facing coal-dependent regions with significant transition costs be resolved?
- Is nuclear energy an essential element in abating carbon, or do its issues make it unviable? Do we need to foster international cooperation to help address concerns about safety, proliferation, and spent-fuel? For countries where nuclear power is part of their strategy, what can they do to accelerate the development and deployment of next-generation technology? Again, would international cooperation help? For those countries de-emphasizing or phasing out nuclear power, what is the low-emissions replacement strategy?

- What specific actions should be taken to encourage the power sector to reduce end-use demand through energy-efficiency gains (i.e., to view energy efficiency as the "fifth fuel")? Is a separate regulatory framework necessary to increase incentives for the power sector on this issue?

Turning to the oil and gas sector, the abatement potential here arises from three levers: reducing end-user demand, fuel substitution, and reducing the industry's own emissions. Of these, the first two are by far the largest. MGI's work on future energy demand shows a wide range of potential scenarios for oil demand depending on how aggressively the world moves toward higher-efficiency vehicles and alternative fuels (Exhibit 13).

Exhibit 13

THERE IS A WIDE RANGE IN POTENTIAL FUTURE DEMAND FOR OIL
2030 global demand, million barrels per day



Source: McKinsey Global Institute Global Energy Demand Model; Petrosims; McKinsey analysis

At a global level, more fuel-efficient vehicles represent a 0.9 gigaton of CO_2e abatement opportunity, or 3 percent of the total under €40 per ton. Significant opportunities exist for fuel-efficiency increases with existing technologies, in particular engine optimization, weight and aerodynamic drag reduction, and substitution of high-efficiency diesel engines for gasoline engines. For example, such changes enable emissions from a prototype of a popular small car to be reduced from 176 grams per kilometer to 99 grams per kilometer, a 44 percent reduction. Hybrids and plug-in hybrids could offer further reductions with fuel economy of up to 113 miles per gallon, although their abatement potential depends on the steepness of cost declines, and—for plug-in hybrids—the availability of low-carbon electricity sources.

The challenge in increasing fuel efficiency in vehicles is that, while there may be significant payoffs from a societal perspective, the high upfront costs are a deterrent and consumers have historically shown unwillingness to pay them. In Germany for example, McKinsey estimates that 40 percent of the abatement potential from vehicles (14 megatons of CO_2e out of a total potential of 37 megatons) had positive payoffs but that these payoffs were too long to be attractive to consumers.[17] We thus need to ask:

- What incentives are needed for the auto sector to view dramatic increases in fuel efficiency as a major business opportunity?
- Does capturing the potential depend on forcing changes in consumer behavior and accelerating the turnover of the existing vehicle stock (i.e., forced retirement for low-efficiency vehicles)? If so, how is the oil industry likely to respond?

Biofuels offer significant, but at present controversial, potential for decarbonizing energy for vehicles and some types of industrial production. We estimate its potential at 1.4 gigatons or 5 percent of the total abatement opportunity. Currently, Brazilian sugar cane offers the highest energy output relative to energy input—a ratio of 8.3 versus 1.3 for US corn-based ethanol or 1.9 for European sugar beet.[18] The lack of energy efficiency of corn, beets, and other feedstocks means that their carbon impact may actually be negative despite their renewability.[19] In addition, the sudden shift to low-energy biofuel crops, particularly in the United States, may be contributing to rising food prices.

However, second-generation "lignocellulosic" biofuels, which may become available as early as 2010, have the potential to boost energy outputs from a wider variety of feedstocks dramatically, reduce biofuel competition with agriculture, and make biofuels viable in new geographies. For example, these

17 "Costs and Potentials of Greenhouse Gas Abatement in Germany," McKinsey & Company on behalf of "BDI Initiative – Business for Climate," September 2007 (http://www.mckinsey.com/clientservice/ccsi/pdf/Costs_And_Potentials.pdf).

18 Presentation by Petrobras to *Financial Times* Conference, June 19, 2007.

19 See, for example, Searchinger et al, "Use of US Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change"; and Fargione et al, "Land Clearing and the Biofuel Carbon Debt," both in *Science*, February, 2008.

second-generation biofuels could drop biofuel costs in China from $1.80 per gallon to $0.60.[20]

Going forward, there are several questions we can ask about biofuels strategy:

- Should we lower trade barriers for carbon-efficient biofuels?
- How do we manage competition between biofuels and agriculture and the impact on deforestation and water?
- What can be done to speed the development of next-generation biofuels?

3. Accelerating the development and deployment of new technologies

In the analyses we have outlined thus far, we have been conservative in assuming no significant or unforeseen breakthroughs in technology. We calculated all of the abatement potentials and costs in the cost curve using either existing technologies or technologies with a highly visible path and timeframe to commercialization. Yet economic history tells us that technological innovations have been critical in driving all major increases in productivity. This therefore poses two important questions:

- How much extra R&D investment will be required to drive the required increases in carbon productivity?
- What will be the right mechanisms to mobilize that R&D spending and channel it in ways that are effective in generating innovation?

A group of researchers affiliated with the Center for Economic Policy Research (CEPR) have modeled the R&D flows required for various levels of carbon stabilization.[21] They estimate that global R&D investments aimed at increasing energy efficiency and decarbonizing energy sources are currently $10 billion per year. These investments would need to double by 2020 to support a path to 450 ppmv and reach $80 billion by 2050—nearly four times the estimated business-as-usual path (Exhibit 14). For 550 ppmv, the incremental R&D investments are much smaller—doubling by 2035 and reaching approximately $30 billion per year by 2050.

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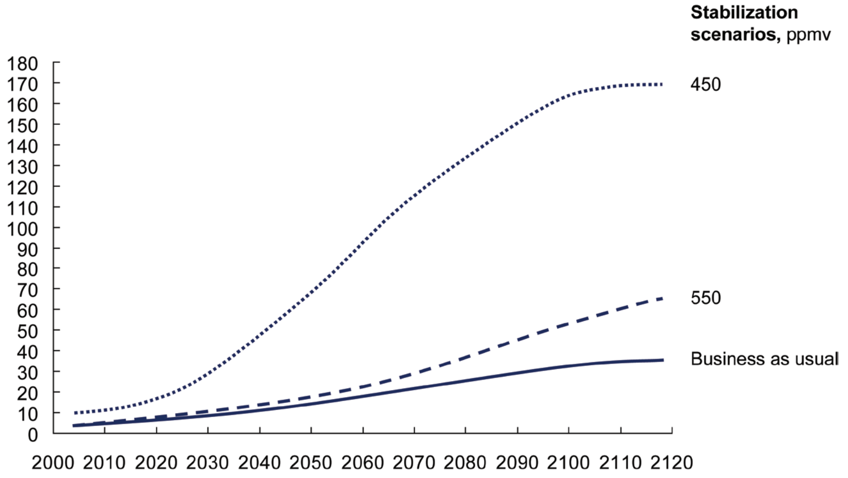
20 “Betting on biofuels,” *The McKinsey Quarterly*, May 2007 (www.mckinseyquarterly.com).

21 Valentina Bosetti, Carlo Carraro, Emanuele Massetti, and Massimo Tavoni, “Optimal Energy Investment and R&D Strategies to Stabilize Greenhouse Gas Atmospheric Concentrations,” Center for Economic Policy Research Discussion Paper No. 6549, November 2007.

Exhibit 14

GLOBAL R&D INVESTMENTS ARE REQUIRED TO SUPPORT CO_2e STABILIZATION

Annual energy R&D investments, $ billion



Source: V. Bosetti, C. Carraro, E. Massetti and M. Tavoni, *Optimal Energy Investment and R&D Strategies to Stabilize Greenhouse Gas Atmospheric Concentrations,* 2007

The key swing factors in the level of R&D required for the 450 ppmv versus 550 ppmv scenarios were that a 450 ppmv target would require much faster development and deployment of integrated combined cycle gasification (ICCG) and CCS to enable a rapid ramp-down of traditional coal. The 450 ppmv target would also require either substantial R&D investments to support a tenfold increase in nuclear generation or, if nuclear were restricted, large investments in as yet unidentified technologies that could economically provide up to a quarter of the world's energy by the end of the century. If the choice is the latter, given the lead times in discovery, development, commercialization, large-scale deployment, and global diffusion in the energy sector, these new technologies would need to be ramped up very quickly (to 18 times present levels) over the next two decades to support a 450 ppmv path.

We thus face four very different types of R&D problem:

- **Developing the "next generation" for a mature technology**—if nuclear energy is to be a significant part of the solution, substantial investments will be required in new plant designs and in addressing safety, proliferation, and disposal concerns in the entire fuel cycle

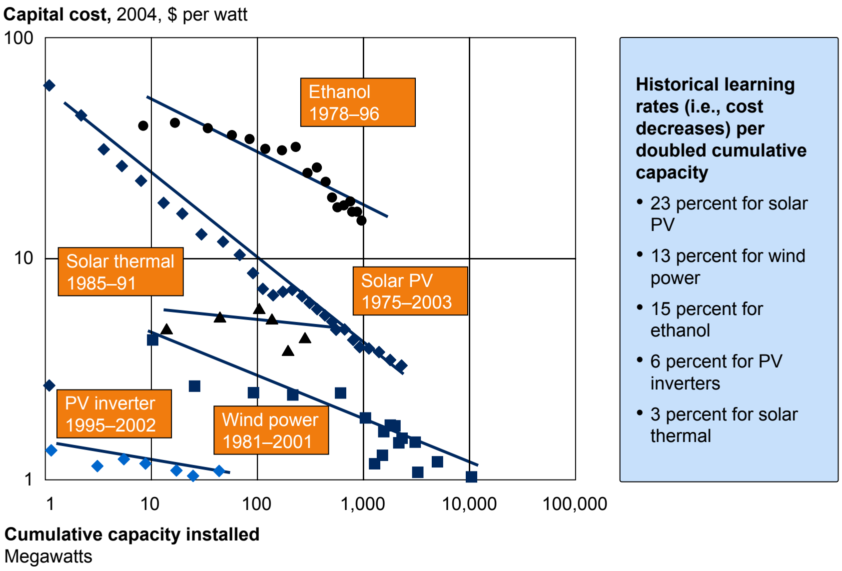
- **Scaling up, commercializing, and deploying emerging technologies**—ICCG and CCS play critical roles in all scenarios and large investments are still required in the R&D phase as well as massive investments in deployment ($100 billion per year by 2020, according to the CEPR study)

- **Driving existing high-cost technologies down the learning curve**—portions of the "unidentified" energy source component could come from existing technologies if learning-curve cost declines are steep enough (Exhibit 15)

- **Creating a dynamic innovation portfolio across a broad array of promising new technologies**—other portions of the "unidentified" piece could come from new technologies arising out of basic R&D activity and a broad portfolio of innovation initiatives, e.g., innovations arising out of solar, biotech/bio-energy, or from improved use of information technology in power and energy management.

Exhibit 15

ONE R&D CHALLENGE IS DRIVING EXISTING HIGH-COST TECHNOLOGIES DOWN THE LEARNING CURVE



Source: UC Berkeley Energy Resource Group; Navigant Consulting

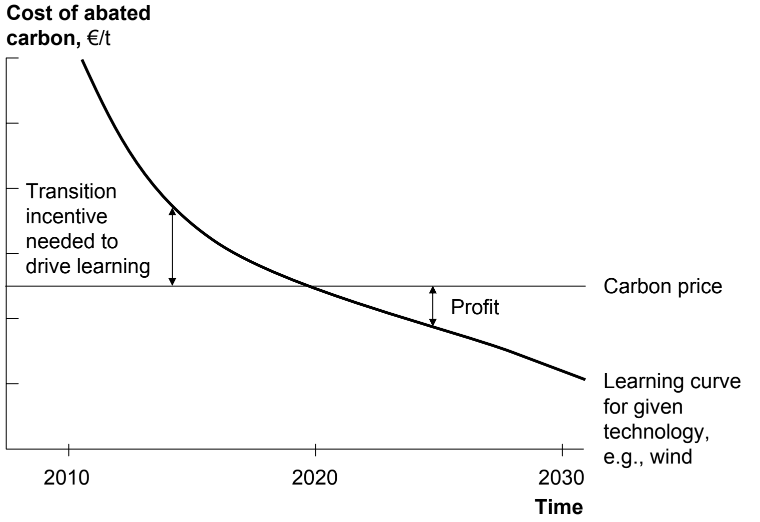
Each of these problems would require significantly different R&D strategies for governments and business.[22] Neither of the first two will be solved without significant government intervention and partnerships with the private sector.

22 See Nicholas (Lord) Stern, "Key Elements of a Global Deal on Climate Change," chapter 6, April 30, 2008 (www.lse.ac.uk/collections/climateNetwork/publications).

Public R&D money will be required, and uncertainties around future regulation, legal liabilities, and other issues will need to be addressed. The second two problems require incentives for the private sector, but a lighter touch from governments. In addition to creating a carbon price, key government roles for these latter two include support for basic R&D, and education in key scientific and engineering skill areas, as well as help in creating a critical mass of demand through energy-efficiency standards and government purchasing. In addition, "transition incentives" might also be needed to help private-sector companies drive technologies down the learning curve to make them economic under a carbon price (Exhibit 16). The history of technological innovation shows, however, that governments should avoid efforts to pick technology "winners" as these are less likely to be successful.

Exhibit 16

TRANSITION INCENTIVES ARE REQUIRED TO DRIVE LEARNING CURVE IN NEW TECHNOLOGIES ILLUSTRATIVE



Source: McKinsey analysis

A number of questions remain to be answered:

- Even if we assume significant CCS deployments, most scenarios show that power generation requires either expansion of nuclear, or a significant investment in yet to be proven low-emissions technologies. Which strategy should we choose?

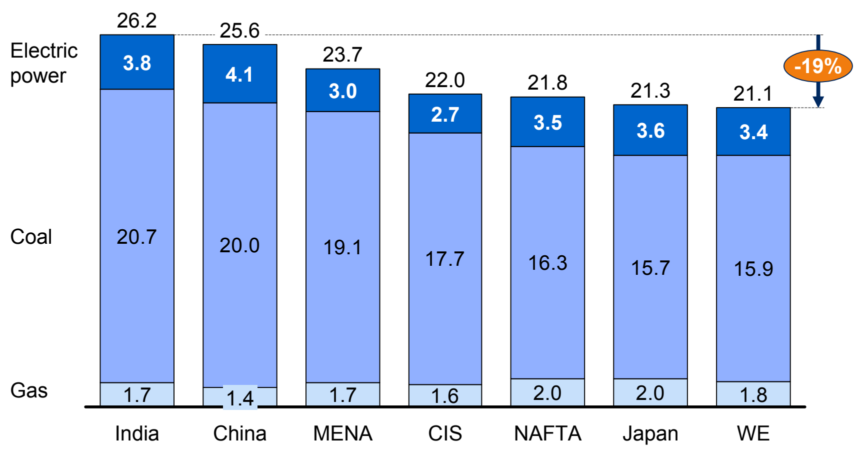
- What can be done to increase the odds of significant new technologies emerging and what role should government and business respectively play in promoting such technologies?

The final technology issue is that of technology transfer. The large variations in energy and carbon productivity between the developed and developing worlds highlight the need for low-emissions technologies to flow to the developing world. For example, India and China use approximately 20 percent more energy to manufacture a ton of steel than do Western Europe or Japan (Exhibit 17). Likewise, given China's dependence on coal it will be in the world's interest to ensure China has access to the most advanced and cost-effective CCS technology. Technology transfer was adopted as an element of the Bali Action Plan. The United States, United Kingdom, and Japan jointly launched what is intended to become a $30 billion "Marshall Plan" to pay for clean technologies in the developing world; and a group of companies including Sony and Nokia have created an "eco-patent commons" with initial donations of 31 energy-efficiency patents.

Exhibit 17

VARIATIONS IN ENERGY INTENSITY WITHIN THE STEEL SECTOR SHOW OPPORTUNITY FOR TECHNOLOGY TRANSFER

MBTU per metric ton of crude steel



Source: J. F. King; McKinsey Global Institute analysis

A long history of attempts to raise technology levels in low- and middle-income countries shows the challenges that will be faced. A recent World Bank study on technology diffusion (technology in general, not green technologies specifically) sheds light on the difficulties in the effective transfer of technology to the developing world.[23] The study found that market forces and globalization are driving technology diffusion in the developing world at a more rapid rate than ever before and are closing the gap with the developed world in many areas; some technologies have been adopted very quickly (e.g., mobile phones). However, the World Bank notes that the gap in absolute terms across a broad set of technologies remains large, due primarily to the fact that the adoption of technology closely tracks overall economic development and income levels; that technology diffusion within a country depends on the quality of governance, institutional structures, availability of infrastructure, property rights, education, human capital, and a host of other factors; and that technology "leapfrogging" is rare (mobile phones are the exception rather than the rule). The more typical pattern is technology advancing with rising income and moving from low- to intermediate- to high-tech.

One sobering interpretation of the report is that technology transfer will not be solved by market incentives, funding from developed-world governments, and the sharing of intellectual property (IP) rights alone. Rather, success in technology transfer will be linked closely to broader development issues in the developing countries themselves. This leaves us with a number of questions:

- Which technology-transfer issues will market forces likely address with a carbon price, and which will require other mechanisms?
- Do we believe that existing international institutions such as the World Bank are the best vehicles for channeling technology-transfer funds, or are new vehicles needed?
- Are there opportunities to encourage effective technology transfer through sector-level schemes?
- Do trade policies need to change to encourage technology transfer?
- Are IP rights a serious barrier to technology transfer or a side issue?
- Finally, how can we make technology transfer more effective through links to overall country development?

23 *Technology Diffusion in the Developing World*, World Bank Global Economic Prospects, 2008.

4. Changing the attitudes and behaviors of managers and consumers

To a large extent, carbon emissions are the product of billions of decisions made by individual managers and consumers around the world every day. The history of productivity growth and changes caused by previous environmental issues shows that it will be critical to influence and change many of these micro-level decisions. Because many of these decisions are small and scattered throughout the economy, they are difficult to measure and their impact is often hard to predict in advance.

One example is laundry detergents. Retail success for packaged goods such as laundry detergents depends to a large extent on supermarket shelf-space and on convincing consumers of a product's value for money. Producers thus have strong incentives to use ingredients in laundry detergents that have no cleaning function ("fillers") but increase the volume of detergent and thus make the boxes and bottles look bigger. The packaging then takes up more shelf space and creates an impression of providing more detergent for a given price. The carbon impact of "filled" detergents is significant through the value chain. Filler materials need to be produced and transported to the detergent manufacturer, the detergents are then heavier, which adds to transportation fuel use, and more packaging is needed. An independent study of the environmental impact of laundry detergents showed that concentrated detergents have 20 percent lower CO_2 emissions through their lifecycle than traditional products.[24]

In a three-year period Wal-Mart alone sells approximately 800 million units of liquid laundry detergent. The company recently made a commitment through the Clinton Global Initiative to sell only concentrated detergents and estimates that this will save more than 400 million gallons of water, 95 million pounds of plastic resin, and 125 million pounds of cardboard, not to mention the energy required to manufacture and transport this unnecessary material. Wal-Mart also committed to educate consumers on the benefits of concentrated detergents. Proctor & Gamble, which has collaborated with Wal-Mart on the laundry detergent initiative, have taken laundry carbon reduction further down the consumer value chain. In addition to reducing packaging and weight by using concentrates, it has formulated its detergents to be more effective at lower wash temperatures and conducted a public awareness campaign to encourage consumers to reduce wash temperatures from 40 to 30 degrees Celsius, providing significant energy savings per load.

24 Gert van Hoof, Diederik Schowanek, and Tom C. J. Feijtel, *Comparative Life-Cycle Assessment of Laundry Detergent Formulations in the UK*, Tenside Surf. Det. 40, 2003.

The key point is that these abatement savings involved no new technology, no significant capital investments, no loss of functionality for consumers and, in economic terms, no loss of GDP. Rather, these savings required taking CO_2 impact into consideration as an objective in the design for the product and its supporting value chain; this, in turn, required managers and consumers to change their mindset. In this particular case, the mindset change was driven by Wal-Mart and Proctor & Gamble's broader initiatives to reduce their carbon impact and that of their suppliers.

More generally the carbon price would drive a change in mindset. With a sufficiently high carbon price, large numbers of such opportunities would surface. But the Wal-Mart and Proctor & Gamble examples also show why a carbon price alone may not be enough to drive behavioral changes. With a carbon price of €40, the difference between a standard and a concentrated bottle of detergent would be in the order of €0.10 on a product that sells for between €3 and €5—too small a difference to exert an influence on the choices that many consumers make. Furthermore, the difference might not offset producers' incentives to fight for shelf space with large packaging. We see similar issues in energy efficiency where gains that are small individually but sizeable in aggregate go uncaptured despite high energy prices.

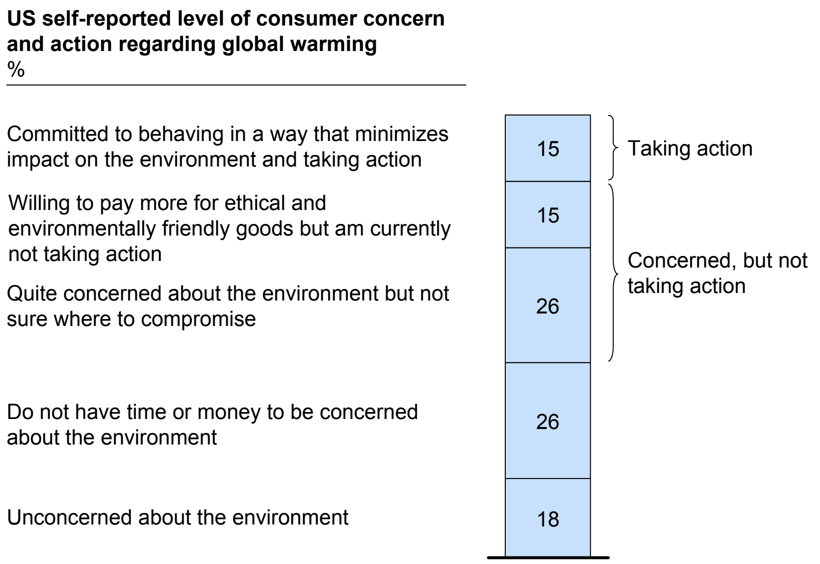
The implication is that efforts to educate consumers—such as British retailer Tesco's recent initiative to provide carbon-footprint information on all of its products—are also critical. Indeed, surveys show that consumers are open to being influenced on the climate issue. For example, a McKinsey survey of 4,000 US consumers showed that 56 percent of consumers are motivated to take action, but many are unsure of how they can do so (Exhibit 18). So we need to ask:

- What more can companies do to initiate mindset and behavior changes and raise consumer awareness, creating social norms around "green" behavior, resulting in carbon abatement?

- What incentives and help could governments provide? We already know that governments can also play critical roles in educating consumers about the impact of their choices (as they have in successful anti-smoking and pro-recycling campaigns) and by setting standards to break producers' incentives to follow inefficient practices.

Exhibit 18

THE VAST MAJORITY OF US CONSUMERS ARE NOT CHANGING THEIR BEHAVIOR DESPITE DECLARING CONCERN FOR THE ENVIRONMENT



Source: McKinsey Business in Society consumer survey of US consumers, 2007 (n=~4,000)

5. Preserving and expanding the world's carbon sinks

Preserving and expanding the world's carbon sinks must be a critical element of any strategy to abate emissions and raise carbon productivity. Beyond CCS, discussed in section 2, the world's critical carbon sinks are its forests, particularly in its tropical and subtropical regions. Forestation and avoided deforestation together offer the single largest abatement lever at 25 percent of the global total under €40 per ton. Avoided deforestation offers about 3.3 gigatons of CO_2e abatement potential beyond business as usual by 2030 (12 percent of the total opportunity), while afforestation offers about 3.5 gigatons CO_2e per year (13 percent of the total).

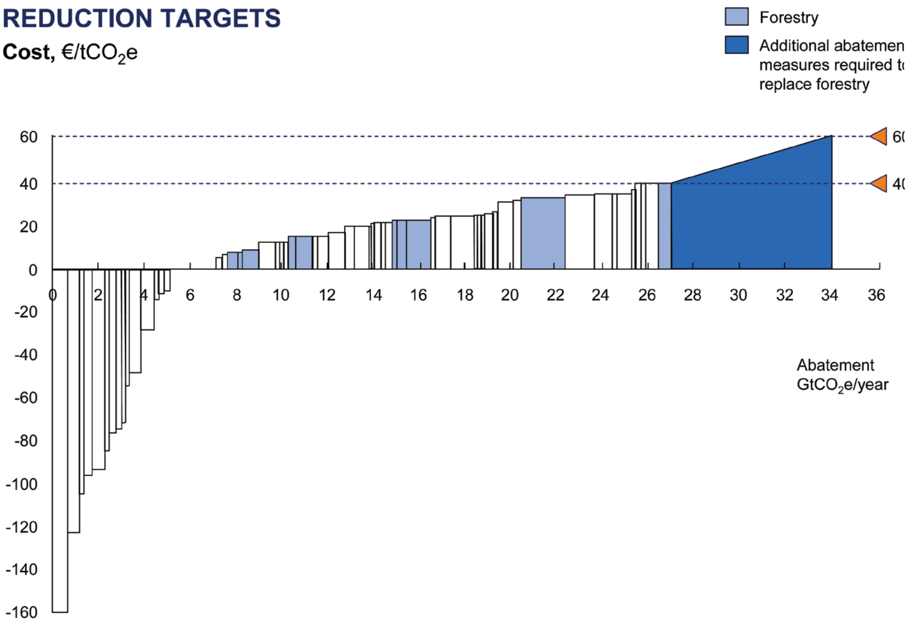
If this opportunity is not captured, the marginal cost of carbon would potentially increase 50 percent to €60 per ton, and other higher-cost sources of abatement will need to be found. As these other sources of abatement lie above the €40 per ton level on the cost curve, we estimate that the impact would be to increase the marginal cost of abatement in the region of €20 per ton to €60 per ton, a 50 percent increase (Exhibit 19).

Satellite and field-based methods allow increasingly precise measurement of net forestry changes. This could enable international compensation for countries that preserve and increase net forest cover. Forestation is already eligible for project-based Clean Development Mechanism (CDM) credits under the Kyoto protocol. However, there are two issues with forestation. First, CDM eligibility has had limited impact to date, suggesting that project-based mechanisms for forestation may be too unwieldy. A number of experts believe that simpler market-based incentives might prove more effective although the evidence suggests that there are multiple challenges in creating such incentives. Second, forests take a long time to grow. This means that the impact of forestation on carbon abatement develops over a longer timeframe than is the case with avoiding deforestation where the impact is immediate.

Exhibit 19

SUCCESS IN FORESTRY IS VITAL TO MEETING GLOBAL EMISSIONS REDUCTION TARGETS

Cost, €/tCO_2e



Source: McKinsey analysis

Unfortunately no general framework for reducing emissions from deforestation and forest degradation (together referred to as REDD) exists today. Unlike forestation where market incentives may be workable, any viable framework for REDD may require national policies and baselines, as well as intergovernmental agreements. Such a framework would need to address issues such as deforestation leakage from one region to another, high year-on-year forest-cover variation (e.g., from forest fires), and uncertainty about the permanence of CO_2 sequestration from REDD. A further challenge for forestation and REDD measures is that many forest-rich developing countries lack an efficient bureaucracy capable of administering, monitoring, and enforcing forestry schemes and tackling illegal logging and agricultural clearing.

Finally, forestation and REDD tend to result in economic displacement for some of the world's poorest people (although there may be economic gains for others, particularly in traditional tribal communities). Avoiding social problems and potentially violent backlashes requires involving key stakeholders and creating other opportunities for people using forests and the relevant areas. Approaches will need to be tailored as the economic drivers of deforestation vary significantly by country, for example, commercial timbering in Southeast Asia; cultivation of crops and cattle pasture in South America; and small-scale subsistence agriculture and demand for fuel wood in Africa.

As we think collectively about how to achieve significant carbon abatement, we need to ask:

- What do national governments need to do to move the forestry issue forward, what key hurdles need to be overcome, and what role could nongovernmental organizations play?
- Although forestation issues do not directly affect most businesses, companies still all have a stake in these issues due to their impact on the future carbon price. What can businesses do to support progress on this issue?
- Finally, what mechanisms do we need to compensate and find new opportunities for those displaced as a result of forestation and avoided deforestation efforts?

ENABLING AND ENCOURAGING CARBON PRODUCTIVITY GROWTH

Reconciling the twin objectives of carbon stabilization and continuing economic growth requires us to drive significant changes in a broad range of microeconomic decisions throughout all sectors and geographies of the global economy. The carbon cost curve provides a map of where those changes are likely to yield the greatest impact for the least cost, and helps us identify issues and barriers to making those changes. The final question is how government and business need to intervene to drive those changes. We group these actions into four categories.

Creating market-based incentives. The first area of action is the need to create market-based incentives. There is a growing consensus that a carbon price is fundamental to driving increased carbon productivity and there is significant political momentum behind various national cap-and-trade initiatives. But critical questions remain as to the degree such systems will be global versus regional or national, what they will cover, and the timing of implementation.

There is also growing momentum at the global level behind the creation of a cap-and-trade system with binding targets, versus other mechanisms such as carbon taxes. The United Nations Framework Convention on Climate Change (UNFCCC) will likely in some way integrate national (e.g., potential US legislation), and regional (e.g., the EU's Emissions Trading Scheme (EU-ETS) schemes. While there are concerns about a fragmented carbon market, or national schemes reducing pressure for a global cap, others argue that regional and national schemes will provide highly valuable learning as well as near-term abatement gains while the world works toward a global deal. The key in the near-term is to ensure national and regional schemes are mutually compatible, thus enabling eventual integration into a highly efficient global carbon market.

It is also important to remember that there are other mechanisms for creating carbon prices that may be appropriate at the national or sectoral level. For example, a critical issue for businesses currently making long-term investment decisions is uncertainty over the future price of carbon and when (and whether) such a price would come into effect. One innovative proposal is for "carbon contracts" where governments auction promises to buy a stream of emissions reductions over time—in effect providing a put option for companies on the price of carbon.[25] The auction mechanism ensures the lowest-cost abatement opportunities are addressed first, while the price of the contract gives companies certainty that enables them to make investment decisions and access financing. Although governments would be the most credible counterparty in such contracts, large foundations or international organizations interested in kick starting abatement investments could also write them.

A number of questions arise in the area of creating market-based incentives:

- Will global, national, and regional mechanisms create a carbon price that is sufficiently high to drive abatement at a level that is consistent with the required level of stabilization?

25 Dieter Helm and Cameron Hepburn, "Carbon Contracts and Energy Policy: An Outline Proposal," New College and St. Hugh's College, Oxford, Working Paper, October 6, 2005.

- Will the inevitable compromises in designing such systems allow low-cost opportunities to "leak out" and thus raise the overall costs? What can be done to prevent this?
- Will an evolving patchwork of national or regional carbon markets help or hinder progress toward a global market?
- Will the timing of establishing pricing systems be consistent with the timing needed to achieve stabilization goals, or will it be "too little, too late"?
- How can we create a system with the institutional stability required for businesses to make long-term decisions?

Addressing market failures. A significant portion of low- and negative-cost abatement potential will be resistant to price signals due to market failures, particularly in energy efficiency. Addressing these failures will require a broad array of actions including efficiency standards and new forms of financing at global, national, regional, and sectoral levels. Most of these actions will take place at national level although regions and industry sectors can play a useful role, such as in setting global energy-efficiency standards for particular industries. Governments will need to lead in these efforts, but businesses can be active partners in designing standards, generating better information for consumers, and creating innovative new mechanisms to finance investments. We need to establish those areas in which there is sufficient consensus between government and industry to take near-term action, ascertain which specific actions will create "early wins" on energy efficiency, and identify what failures are due to lack of information, and what investments would be appropriate to fill these information gaps.

One further challenge for governments will be to remove distortions in the market created by subsidies, existing regulations and trade policies and to ascertain how these can take account of the impact on emissions.

Resolving allocation and fairness issues. The microeconomic changes that this paper describes will create massive shifts in economic rents across company, industry, and national boundaries (on a par with developments in labor productivity during the Industrial Revolution, but faster). The transition to a low-carbon economy will inevitably create stranded assets and stranded people.

There are also significant allocation and fairness issues between the developed and developing worlds. Many developing nations argue that the developed world is primarily responsible for the current stock of atmospheric GHGs. Furthermore, while the developing world contains 72 percent of the world's future abatement opportunities, even by 2030 these regions will account for only 21 percent of its GDP.[26] If the costs for abatement were allocated based on GDP shares, the developed world would be transferring $205 billion per year to the developing world by 2030 in payments for carbon abatement. Issues of allocation and fairness cut along three dimensions: geography (e.g., developed versus developing world), industry (e.g., winning versus losing companies), and stakeholder (e.g., society versus shareholders), and will be among the most difficult that governments and businesses will need to address. Yet the political reality is that taking the initiative on this front will be essential for progress at the global and national level.

Regulation and institutions will need to address some of these shifts for ethical and economic reasons, and many others for political reasons to avoid powerful stakeholders with vested interests from blocking required changes. In framing a response, we need to ask ourselves what constitutes a legitimate "fairness" issue. Economics create winners and losers all the time—for example, we don't compensate people every time there is a technology change. Among the questions we need to ask are:

- What distinguishes cases where we make some form of allowance or give assistance compared with cases in which we simply let the market decide?
- Which constituencies truly have the power to block progress at the global or national level, and thus present a political rather than an economic case for addressing their concerns?
- In addressing economically and politically driven questions of fairness, how do we compensate losers without destroying incentives for winners?

Accelerating progress. Lastly, we need active and urgent intervention to ensure that we take account of critical timing issues. One key area for action is seizing the "window of opportunity" presented by the rapid infrastructure build-out underway in developing countries, particularly China and India. There is a large opportunity to incorporate low-emissions technologies in new capital stock.

26 Developed world is defined as the United States, OECD Europe, and other industrialized nations; developing world includes China, India, and all other nations not included in the developed world definition. GDP data and projections are from IMF World Economic Outlook Database, April 2003.

Given the long lifecycle of much of that stock, once that infrastructure is built it will be a long time before the replacement cycle opens the window again. We also need to address the possible mismatch in the pace of development of commercially scalable CCS technology with when that technology will be needed to meet abatement targets. And the cost of abatement in many areas would be lowered by accelerating the creation of a critical mass of consumer demand to drive costs down the learning curve. We should begin to think about:

- What practical steps can we take to accelerate progress on developing world infrastructure and CCS?
- How can companies and governments help break the "chicken and egg" problem of a lack of consumer demand for low-carbon technologies and accelerate learning curve cost reductions?

* * *

Increasing carbon productivity tenfold in less than 50 years will be one of the greatest tests humankind has ever faced. But both history and economics gives us confidence it can be done—the world can abate carbon and continue to grow. We have many of the technologies we need, the world has the investment capital required, and it is clear that if the right incentives are in place and behaviors change, a wave of innovation will be unleashed.

The world is waiting—a recent BBC Globescan survey of 22,000 people in 21 countries found that 65 percent of respondents felt it was necessary to take major steps to address climate change very soon, while only 6 percent believed action was not necessary. What is missing are the policy, regulatory, and institutional structures to drive a revolution in carbon productivity in the timeframe required by the health of the planet. These will not be created without a close partnership between government and business. In the end, addressing climate change is neither a scientific nor even an economic challenge—it is a human challenge.

Updates from the original briefing paper

As noted in the Preface, an earlier version of this report was provided as a briefing paper to a meeting between a group of legislators from the G8+5 countries and the European Union who are members of GLOBE International, and a group of company chief executives.

The current version provides two updates from the original. First, we have used more current data for baseline emissions. The original used 2002 data while this version uses 2004 actual data and an estimate for 2008. Second, where the original scenario assumed reductions in annual emissions to 10 $GtCO_2e$ by 2050, the current scenario assumes reductions to 20 $GtCO_2e$ of annual emissions by 2050 (approximately consistent with a 500 ppmv stabilization outcome).

These two updates together change the calculations for carbon productivity. Baseline carbon productivity declines from $1,130 GDP per ton CO_2e in the original report to $740 in the current version. The level of carbon productivity increase required to meet the abatement scenario changes from 6.7 percent per annum in the earlier report, or a 15-fold increase by 2050, to 5.6 percent per annum or a tenfold increase in the current report. This reduction in the required carbon productivity increase is primarily due to the higher level of 2050 emissions in the abatement scenario.

These changes should not be interpreted as an endorsement of a particular stabilization target or abatement scenario. There is still much debate about targets and abatement paths. However, it should be noted that, at the level used for illustration in this report, the IPCC AR4 Synthesis Report still shows significant risks of adverse climate effects, and at higher levels the risks increase substantially. Rather, the target and path analyzed in the report were selected to provide an example of the degree of carbon productivity increase required for one of the more commonly discussed abatement scenarios. We are assessing the impact of other targets and scenarios in our ongoing research.

Exhibit 20

CARBON PRODUCTIVITY REQUIREMENTS VARY UNDER DIFFERENT SCENARIOS

	2008 estimated emissions, $GtCO_2e$	2050 BAU* emissions, $GtCO_2e$	2050 target emissions, $GtCO_2e$	Annual carbon productivity improvement required, %	Carbon productivity multiple required 2008–2050
Original GLOBE report [1] 450 ppmv, no overshoot	42	85	10	6.7	15 times
Updated baseline and target 450 ppmv, no overshoot	55	85	13	6.7	15 times
MGI report [3] 450 ppmv with overshoot to 500 ppm, updated baseline and target	55	85	20	5.6	10 times

* Business as usual.
1 Emissions baseline from IEA (2002).
2 Emissions baseline from IPCC (2008); 2050 target based on Stern Review 450 ppmv scenario.
3 2050 target based on Meinshausen (2007) and consistent with G8 proposals.

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