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Resource Revolution: Meeting the world's energy, materials, food, and water needs

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Preface

Over the past century, progressively cheaper resources have underpinned global economic growth. Although demand for resources such as energy, food, water, and materials grew, this was offset by expanded supply and increases in the productivity with which supply was used.

But that relatively benign picture has now changed. The unprecedented pace and scale of economic development in emerging markets means demand for resources is surging, and prices for most resources have risen since the turn of the century. Resource price inflation—and volatility—could increase as new supplies of some resources become more expensive to extract, resource prices become more linked, and environmental spillover effects impact crop yields and the availability of water. These trends could fuel protectionism and political unrest. The result? Without action to expand supply and boost resource productivity, the global economy could enter an era of higher, more volatile resource prices and increased risk of resource-related shocks. This would have negative consequences for economic growth, the welfare of citizens (particularly those on low incomes), public finances, and the environment.

This report, *Resource Revolution: Meeting the world's energy, materials, food, and water needs*, looks in detail at this critical challenge. The report is a joint effort between the McKinsey Global Institute (MGI), McKinsey's business and economics research arm, and McKinsey & Company's Sustainability & Resource Productivity practice (SRP). It aims to offer new insights into how demand for resources has evolved and how it is likely to develop over the next 20 years. It analyzes how demand can be met through expanded supply and higher resource productivity with innovation potentially playing a central role as new technologies scale up across resource systems. It discusses the major resource and environmental risks and quantifies options for addressing them. The report also examines what policy makers and the private sector might do to overcome potential resource constraints.

The research was led by Jeremy Oppenheim and Richard Dobbs. Jeremy is head of the SRP practice. Richard Dobbs is a director of MGI. The work was co-led by Marcel Brinkman, a partner of McKinsey in London; Fraser Thompson, an MGI senior fellow; and Marc Zornes, a McKinsey project manager. The project team comprised Daniel Clifton, Nicholas Flanders, Kay Kim, Pranav Kumar, and Jackson Salovaara.

This research has built on extensive past McKinsey work and that of our affiliates. It includes SRP's greenhouse gas abatement cost curve and biomass model, the steel demand model of McKinsey's Basic Materials Institute, the Global Energy & Materials Practice's global energy perspective, and the 2030 Water Resources Group's global water supply and demand model.

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While we believe the analysis in the report to be directionally correct, we recognize that there is considerable scope to expand research in the field of integrated resource economics. McKinsey plans to undertake a more detailed analysis of how accelerating technology innovation could enhance access to new resources, such as shale gas, and increase resource productivity. Our aim is to work with others to develop a deeper understanding of the resource system, looking at other resources beyond energy, food, water, and steel—the focus of this report. We plan to take this global-level analysis down to the regional and country levels to better understand local constraints and opportunities. We would like to understand more dynamics effects such as how the expectations of future resource prices impact the conduct of investors on the one hand and consumer behavior on the other. Finally, we aim to build a stronger analytic basis for incorporating the resilience or vulnerability of key ecosystem services such as nutrient cycles and crop pollination.

As with all MGI research, we would like to emphasize that this work is independent and has not been commissioned or sponsored in any way by any business, government, or other institution.

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3 billion more middle-class consumers expected to be in the global economy by 2030

80% rise in steel demand projected from 2010 to 2030

147% increase in real commodity prices since the turn of the century

44 million people driven into poverty by rising food prices in the second half of 2010, according to the World Bank

100% increase in the average cost to bring a new oil well on line over the past decade

Up to **$1.1 trillion** spent annually on resource subsidies

The challenge

$2.9 trillion

of savings in 2030 from capturing the resource productivity potential… rising to

$3.7 trillion

if carbon is priced at $30 per tonne, subsidies on water, energy, and agriculture are eliminated, and energy taxes are removed

70%

of productivity opportunities have an internal rate of return of more than 10% at current prices… rising to

90%

if adjusted for subsidies, carbon pricing, energy taxes, and a societal discount rate of 4%

At least $1 trillion

more investment in the resource system needed each year to meet future resource demands

15 opportunities

deliver about 75% of total resource productivity benefits

The opportunity

Contents

Executive summary

During most of the 20th century, the prices of natural resources such as energy, food, water, and materials such as steel all fell, supporting economic growth in the process. But that benign era appears to have come to an end. The past ten years have wiped out all of the price declines that occurred in the previous century. As the resource landscape shifts, many are asking whether an era of sustained high resource prices and increased economic, social, and environmental risk is likely to emerge.

Similar concerns have appeared many times in the past, but, with hindsight, the perceived risks have proved unfounded. In 1798, land was at the center of popular worries. In his famous *An essay on the principle of population*, Thomas Malthus expressed concern that the human population was growing too rapidly to be absorbed by available arable land and that this would lead to poverty and famine.[1] But the dire vision he outlined did not come to fruition as the agro-industrial revolution swept across Britain and then the rest of Europe and North America, breaking the link between the availability of land and economic development. Malthusian theories have enjoyed brief revivals, notably in the Club of Rome's report on the limits to growth in the early 1970s. But the dominant thesis of the 20th century was that the market would ride to the rescue by providing sufficient supply and productivity.

This thesis—and hope—has largely proved correct. Driven by a combination of technological progress and the discovery of, and expansion into, new, low-cost sources of supply, the McKinsey Global Institute's (MGI) commodity price index fell by almost half during the 20th century when measured in real terms. This was astonishing given that the global population quadrupled in this century and that global economic output expanded roughly 20-fold, resulting in a jump in demand for different resources of anywhere between 600 and 2,000 percent.

The rise in resource prices over the past decade and the scale and pace of economic development sweeping across emerging markets have revived the debate about resources. The market and the innovation it sparks may once again ride to the rescue and will clearly be an important part of the answer. The ability to generate, communicate, share, and access data has been revolutionized by the increasing number of people, devices, and sensors that are now connected by digital networks. These networks can help to transform the productivity of resource systems, creating smarter electricity grids, supporting more intelligent building, and enabling 3D and 4D seismic technology for energy exploration. Digital networks could potentially have an impact on even small-scale farmers in sub-Saharan Africa. Techniques from the aerospace industry are transforming the performance of wind-turbine power generation. Developments in materials science are dramatically improving the performance of batteries, changing the potential for electricity storage, and, over time, will diversify energy choices for

1 Thomas Malthus, *An essay on the principle of population* (New York: Penguin, 1970; originally published in 1798).

the transport sector. Organic chemistry and genetic engineering may help to foster the next green revolution, transforming agricultural productivity, bio-energy provision, and terrestrial carbon sequestration. In short, there is no shortage of resource technology, and higher resource prices are likely to accelerate the pace of innovation.

However, the size of today's challenge should not be underestimated; nor should the obstacles to diffusing more resource-efficient technologies throughout the global economy. The next 20 years appear likely to be quite different from the resource-related shocks that have periodically erupted in history. Up to three billion more middle-class consumers will emerge in the next 20 years compared with 1.8 billion today, driving up demand for a range of different resources. This soaring demand will occur at a time when finding new sources of supply and extracting them is becoming increasingly challenging and expensive, notwithstanding technological improvement in the main resource sectors. Compounding the challenge are stronger links between resources, which increase the risk that shortages and price changes in one resource can rapidly spread to others. The deterioration in the environment, itself driven by growth in resource consumption, also appears to be increasing the vulnerability of resource supply systems. Food is the most obvious area of vulnerability, but there are others. For example, changes in rainfall patterns and greater water use could have a significant impact on the 17 percent of electricity supplied by hydropower, as well as fossil fuel power plants and water-intensive methods of energy extraction. Finally, concern is growing that a large share of the global population lacks access to basic needs such as energy, water, and food, not least due to the rapid diffusion of technologies such as mobile phones to low-income consumers, which has increased their political voice and demonstrated the potential to provide universal access to basic services.

This research has established that both an increase in the supply of resources and a step change in the productivity of how resources are extracted, converted, and used would be required to head off potential resource constraints over the next 20 years. The good news is that this research has identified sufficient opportunities to expand supply and improve productivity to address the resource challenge. The open question is whether the private sector and governments can implement the steps needed to deliver these opportunities sufficiently quickly to avoid a period of even higher resource prices, increased volatility, and potentially irreversible environmental damage.

Our analysis shows that there are resource productivity improvements available that would meet nearly 30 percent of demand for resources in 2030. Successful implementation of these productivity opportunities could more than offset the expected increase in land demand over the next 20 years in our base case. Their implementation would also address more than 80 percent of expected growth in demand for energy, 60 percent of anticipated growth in demand for water, and one-quarter of expected growth in demand for steel. We estimate the total value to society associated with these productivity improvement opportunities—including the market value of resources saved—to be $2.9 trillion in 2030, at current prices before accounting for environmental benefits and subsidies. The value of the opportunity would increase to $3.7 trillion assuming a $30 per tonne price for carbon as well as the removal of energy, agriculture, and water subsidies, as well as the removal of energy taxes. Just 15 opportunity areas, from improving the energy efficiency of buildings to moving to more efficient irrigation, represent roughly 75 percent of this productivity prize. There is an opportunity to achieve a resource productivity revolution comparable with the progress made on labor productivity during the 20th century. However, capturing these productivity opportunities will not be easy. We estimate that only 20 percent are readily achievable and about 40 percent are difficult to capture, facing many barriers to their implementation. Of course, if resource prices were to increase significantly, market forces would naturally drive greater resource productivity.

Boosting productivity alone would not be enough to meet likely demand requirements over the next 20 years. Supply would also need to grow. In the case of energy, a sizable proportion of the supply increase could come from the rapid development of unconventional gas supplies, such as shale gas. However, growing the supply of other fossil-fuel energy sources is more challenging, and the overall supply of energy would still need to expand by 420 quadrillion British thermal units (QBTU) from 2010 to 2030, almost entirely to replace the decline in existing sources of supply. For example, many of the world's giant oil fields, especially outside the Middle East, are mature and, absent a major improvement in recovery rates, are likely to experience significant declines over this period.

While increasing supply and resource productivity would meet projected global resource demand, it would likely not be sufficient to prevent further global warming above the two degrees Celsius that may already be inevitable, or to alleviate the resource poverty that affects so many citizens. Further changes in the mix of resource supply sources and additional investment would be required to meet the challenges of climate change and resource poverty. This investment could in itself result in a step change in cost. For example, our research suggests that a much more rapid scaling up of renewable energy technologies could lead to rapid declines in cost. Solar power capacity could become available at around $1 per watt by 2020, down from more than $8 per watt in 2007 and $4 per watt in 2010.

Delivering the required productivity improvements and supply growth required is a very large and complex agenda. Putting it into practice will be far from easy because there are hurdles to all the major opportunities. Overcoming these obstacles would require action at the local, national, regional, and global levels. Tackling the resource agenda must start with new institutional mind-sets and mechanisms that can develop more coordinated approaches to the challenge of resources, reflecting stronger interconnectedness of resource systems. Beyond this shift to a more integrated approach to resource management, policy makers might consider taking action on three broad fronts to address the resource challenge. First, they should look to history, which shows that stronger, sustained price signals are a key driver of improved performance in resource systems. Governments need to consider unwinding the more than $1 trillion of subsidies on resources, including energy and water, that today keep prices artificially low and encourage the inefficient use of these commodities. To address climate change, governments would also need to ensure, through mechanisms such as carbon pricing, that resource prices capture the cost of their impact on the environment.

Second, although getting prices right would go a long way toward addressing the resource challenge, action would also be necessary to ensure that sufficient capital is available and to address market failures associated with property rights, incentive issues, and innovation. Third, public policy can play a useful role in bolstering the long-term resilience of society in the face of the resource challenge, including taking measures to raise awareness about resource-related risks and opportunities, creating appropriate safety nets to mitigate the impact of these risks on the poorest members of society, educating consumers and businesses to adapt their behavior to the realities of today's resource-constrained world, and increasing access to modern energy, so improving the economic capacity of the most vulnerable communities.

This new era presents opportunities and risks for business. Companies in most sectors were able to benefit from declining resource prices over the past century. This allowed management to focus attention primarily on capital and labor productivity. But resource-related trends will shape the competitive dynamics of a range of sectors in the two decades ahead. Many companies need to pay greater attention to resource-related issues in their business strategies and adopt a more joined-up approach toward understanding how resources might shape their profits, produce new growth and disruptive innovation opportunities, create new risks to the supply of resources, generate competitive asymmetries, and change the regulatory context.

We now summarize the main findings of the seven chapters in this report.

1. Progressively cheaper resources underpinned global economic growth during the 20th century

During the 20th century, the price of key resources, as measured by MGI's index, fell by almost half in real terms. This was astounding given that the global population quadrupled in this era and global economic output increased by approximately 20-fold, together resulting in a jump in demand for different resources of between 600 and 2,000 percent. Resource prices declined because of faster technological progress and the discovery of new, low-cost sources of supply. Moreover, in some cases resources were not priced in a way that reflected the full cost of their production (e.g., energy subsidies or unpriced water) and externalities associated with their use (e.g., carbon emissions).

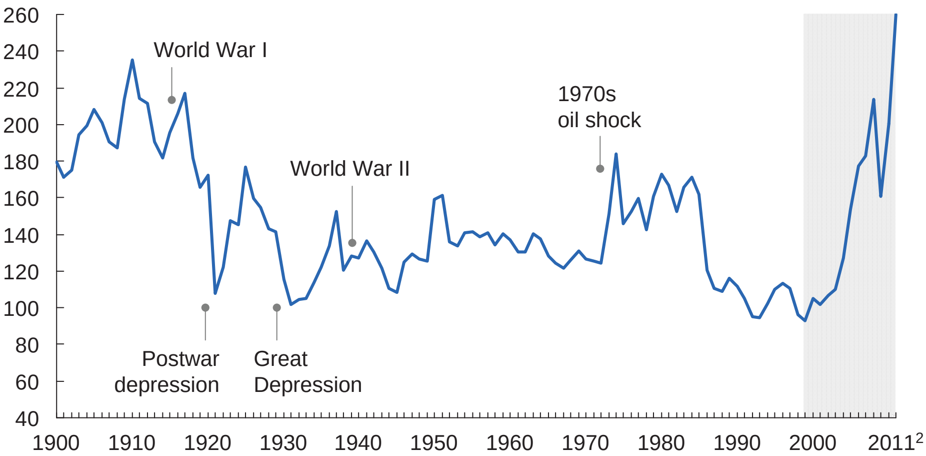
2. The world could be entering an era of high and volatile resource prices

The past decade alone has reversed a 100-year decline in resource prices as demand for these commodities has surged (Exhibit E1). With the exception of energy in the 1970s, the volatility of resource prices today is at an all-time high.

Exhibit E1

Commodity prices have increased sharply since 2000, erasing all the declines of the 20th century

MGI Commodity Price Index (years 1999–2001 = 100)[1]



1 See the methodology appendix for details of the MGI Commodity Price Index.
2 2011 prices are based on average of the first eight months of 2011.
SOURCE: Grilli and Yang; Stephan Pfaffenzeller; World Bank; International Monetary Fund (IMF); Organisation for Economic Co-operation and Development (OECD); UN Food and Agriculture Organization (FAO); UN Comtrade; McKinsey analysis

The resource challenge of the next 20 years will be quite different from any we have seen in the past in five main ways:

- **Up to three billion more middle-class consumers will emerge in the next 20 years.** The rapid economic development in emerging markets, especially China and India, could result in up to three billion more middle-class consumers in the global economy over the next 20 years.[2] The growth of India and China is historically unprecedented and is happening at about ten times the speed at which the United Kingdom improved average incomes during the Industrial Revolution—and on around 200 times the scale. These citizens will escalate demand for cars—we expect the global car fleet to double to 1.7 billion by 2030. They will be able to afford higher levels of nutrition. In India, we expect calorie intake per person to rise by 20 percent over the next 20 years, and China's per capita meat consumption could increase by 40 percent to 75 kilograms (165 pounds) a year (and still be well below US consumption levels). Demand from the new middle classes will also trigger a dramatic expansion in the global urban infrastructure, particularly in developing economies. China could every year add floor space totaling 2.5 times the entire residential and commercial square footage of the city of Chicago. India could add floor space equal to another Chicago annually.

- **Demand is soaring at a time when finding new sources of supply, and extracting them, is becoming increasingly challenging and expensive.** Our analysis suggests that, within the next 20 years, there are unlikely to be absolute shortages in most resources. In any case, history shows us that the mere expectation by governments, companies, and consumers of a material risk that shortages might develop has been an effective catalyst for innovation. However, demand for many resources today has already moved to the limits

2 Homi Kharas, *The emerging middle class in developing countries*, OECD Development Centre Working Paper No. 285, January 2010. This research defines "middle class" as having daily per capita spending of $10 to $100 in purchasing parity terms.

of short-run supply curves where supply is increasingly inelastic—in other words, a point at which it is more difficult for supply to react quickly to meet rising demand. This means that even small shifts in demand can drive greater volatility. We believe that this trend will persist because long-run marginal costs are also increasing for many resources. This is due to the fact that the depletion of supply is accelerating and, with the notable exception of natural gas and renewable energy, new sources of supply are often in more difficult, less productive locations. Feasible oil projects are mostly smaller than they were in the past, and more expensive. The average real cost per oil well has doubled over the past decade. New mining discoveries have been broadly flat despite a quadrupling in spending on exploration. Increasing demand for water could mean that some countries will face significantly higher marginal costs for adding new supply from sources such as gravity transfers or even desalination. As urbanization proceeds on an unprecedented scale, new and expanding cities could displace up to 30 million hectares of the highest-quality agricultural land by 2030—roughly 2 percent of land currently under cultivation.

- **Resources are increasingly linked.** The price and volatility of different resources have developed increasingly tight links over the past ten years. Shortages and price changes in one resource can rapidly impact other resources. The correlation between resource prices is now higher than at any point over the past century, and a number of factors are driving a further increase. The energy intensity of water, for instance, has been rising due to the lowering of the groundwater table, the increasing use of desalination processes, and the development of mega-projects for the surface transfer of water (such as China's South-North Water Transfer project, designed to move 45 billion cubic meters of water per year). Unconventional energy sources will require more inputs of resources such as steel. Industry data show that unconventional methods such as horizontal drilling use more than four times as much steel as traditional vertical drilling.[3] Future developments could further increase these linkages. For example, if carbon had a price of $30 per tonne, products produced or transported with energy would have a higher share of energy in their total costs.

- **Environmental factors constrain production.** Increased soil erosion, the excessive extraction of groundwater reserves, ocean acidification, deforestation, declining fish stocks, the unpredictable risk-multiplying effects of climate change, and other environmental effects are creating increasing constraints on the production of resources and on economic activity more broadly. Fish stocks are an example. The UN Food and Agriculture Organization (FAO) estimates that 25 percent of fish stocks are overexploited today and an additional 50 percent fully exploited. A recent study by the Economics of Climate Adaptation Working Group focused on the economic impact of current climate patterns and potential scenarios of climate change in 2030. This study found that some regions were at risk of losing 1 to 12 percent of their GDP annually as a result of existing climate patterns. A study by The Economics of Ecosystems and Biodiversity (TEEB) estimates that 11 percent of the world's remaining natural areas could be lost by 2050 due particularly

3 Colin P. Fenton and Jonah Waxman, "Fundamentals or fads? Pipes, not punting, explain commodity prices and volatility," J. P. Morgan Global Commodities Research, *Commodity markets outlook and strategy*, August 2011.

to the conversion of land for agricultural use.[4] This could have economic implications for many sectors. One example is health care. The pharmaceutical industry makes heavy use of biodiversity. Of all the anti-cancer drugs available today, 42 percent are natural and 34 percent are semi-natural.

- **Growing concern about inequality might also require action.** An estimated 1.3 billion people lack access to electricity and 2.7 billion people still rely on traditional biomass for cooking food. Roughly 925 million people are undernourished in the world, and about 884 million people lack access to safe water. Concern is growing that such a large share of the global population lacks access to basic needs such as energy, water, and food. The rapid diffusion of technologies such as mobile phones to low-income consumers has given these people a stronger political voice and demonstrated the potential to provide them with universal access to basic services.

Tighter markets, rising prices, and growing demand for key resources could slow economic growth, damage the welfare of citizens (particularly those on low incomes), strain public finances, and raise geopolitical tensions.

Rising commodity prices increase manufacturers' input costs and reduce discretionary consumption by households. Of course, countries that export key resources will receive an economic boost from higher prices, but this would be unlikely to offset fully the negative impact in commodity-importing countries. Overall, increasing commodity prices could have a negative impact on short-run global economic growth as consumers and businesses adjust to those higher prices. High prices are one issue; their volatility is another. Higher volatility in resource prices can dampen economic growth by increasing uncertainty, and this may discourage businesses from investing—or prompt them to delay investment—and increase the costs of hedging against resource-related risks.

Rising resource prices also hit the (urban and rural) poor disproportionately because they spend a larger share of their income on energy and food. India's rural poor, for instance, devote around 60 percent of household income to food and an additional 12 percent to energy. The World Bank estimates that recent increases in food prices pushed 44 million people into poverty in the second half of 2010 (although some farmers, typically the larger ones, benefited from higher food prices). It is important to note that the three billion additional middle-class consumers that could emerge over the next 20 years are also likely to be susceptible to price increases in food and energy. At $10 per day in purchasing power parity (PPP) terms, 35 percent of expenditure goes to food and at least 10 percent to energy.[5] An increase in food and energy costs of just 20 percent implies a 16 percent reduction in remaining income available to be spent on other goods and services. Many academic studies have linked sudden food price hikes

4 The Economics of Ecosystems and Biodiversity (TEEB) study is an international initiative aimed at drawing together expertise from the fields of science, economics, and policy to enable practical action to mitigate the growing costs of lost biodiversity and degradation of the ecosystem.

5 Using India as a proxy, see *Key indicators of household consumer expenditure in India, 2000–10,* National Sample Survey Organization, Government of India, 2011. Purchasing power parity measures long-term equilibrium exchange rates based on relative prices across countries. It is best used to understand the relative purchasing power of currencies in their local context.

to civil unrest.[6] In 2007 and 2008, increases in food prices triggered protests and riots in 48 countries, and similar bouts of unrest have occurred in 2011.

Many countries are heavily reliant on some resources, and today's concerns about how to secure sufficient supplies could intensify. From October 2010 to April 2011, China, India, and Vietnam, among other countries, imposed at least 30 export curbs on mineral resources, up from 25 during the previous 12 months, according to the World Trade Organization (WTO).

Many governments, particularly those in developing countries, could find their already pressed public finances exacerbated by rising demand for resources and their higher prices. The budget position of governments in many countries would take a direct hit from rising prices because they currently subsidize resources. Today, governments are subsidizing the consumption of resources by up to $1.1 trillion. Many countries commit 5 percent or more of their GDP to energy subsidies.

3. Meeting future demand would require a large expansion of supply

In this research, we discuss three illustrative cases for how the global economy might address its expanding resource requirements. The first of these scenarios is a supply expansion case. This assumes that resource productivity does not grow any faster than our base-case projections and leaves the remaining strain of meeting demand on expanding supply.[7] In this scenario, the supply of key resources expands to meet rising global demand at the same time as compensating for the depletion of existing supply. It is important to stress in this, and all our cases, that we do not allow for dynamic effects such as price rises in response to higher demand, helping to dampen demand.

Water and land are likely to present the largest challenges on the supply side. We estimate that the annual pace at which supply is added over the next 20 years in water and land would have to increase by 140 percent and up to 250 percent, respectively, compared with the rate at which supply expanded over the past two decades. This expansion of supply could have a wide range of potentially negative effects on the environment. In this case, there would be an additional 1,850 cubic kilometers of water consumption by 2030, 30 percent higher than today's levels; 140 million to 175 million hectares of added deforestation;[8] and carbon dioxide emissions of 66 gigatonnes in 2030 that could, according to some

6 Rabah Arezki and Markus Brückner, *Food prices and political instability*, International Monetary Fund Working Paper No. 11/62, March 2011.

7 Our base-case assumptions allow for productivity improvements consistent with current policy approaches and projected economic development. In agriculture, we assume that yields per hectare improve at 1 percent per annum. In water, we assume that agriculture water productivity (i.e., crop-per-drop) increases at 0.8 percent per annum, and industrial water use at around 0.5 percent a year (i.e., water withdrawals relative to the economic output of these sectors measured by gross dollar value added). In energy, the main productivity opportunities include a base-case productivity improvement. In transport, for example, we expect the fuel economy of the average new passenger vehicle to increase from 33 miles per gallon today to 48 miles per gallon in 2030 on the basis of current policy and anticipated technology improvements. If these base-case productivity improvements were not achieved, the strain on resource systems would be correspondingly greater.

8 Assuming that 80 percent of cropland expansion leads to deforestation.

estimates, lead to a rise in global average temperatures of more than five degrees Celsius by the end of the century.[9]

Expanding supply at this rate could also face capital, infrastructure, and geopolitical challenges. Meeting future demand for steel, water, agricultural products, and energy would require roughly $3 trillion average capital investment per year, assuming no exceptional sector-specific inflation. This is $1 trillion more than spent in recent history and will be at a time when global capital is likely to become increasingly expensive. Additional investment will also be necessary to help populations adapt to the potential effects of climate change. Such investment could include addressing the risk of flooding and desertification. Estimates of the annual costs of such efforts vary widely from less than $50 billion a year to more than $150 billion.[10] In addition to the considerable extra capital required, there are practical and political difficulties in expanding supply. For example, almost half of new copper projects are in countries with a high degree of political risk. More than 80 percent of the remaining unused available arable land is in countries with insufficient infrastructure or political issues. There is also a significant risk that supply-chain bottlenecks could increase the cost of expanding supply as well as prolong the effort, creating significant lags and increased risks for investors.

However, there is also considerable scope for innovation to generate new sources of supply. Shale gas is an example. Advancements in horizontal drilling techniques, combined with hydraulic fracturing, have led to the rapid development of shale gas in the United States. Its share of the overall US natural gas supply has increased from just 2 percent in 2000 to 16 percent in 2009. This development has supported lower electricity prices and created 260,000 jobs in four major shale production sites.[11] Shale gas could play a more significant role in the global primary energy mix of the future, with the contribution of natural gas to the primary energy mix rising from 22 percent today to 25 percent in 2030, according to the International Energy Agency's (IEA) "golden age of gas" scenario. There are, however, risks related to the potential environmental impact of shale gas production on air, water, and land that have not yet been fully understood. These risks have led to moratoriums on shale gas production in five countries.[12]

A rapid expansion of supply could create both economic opportunities and challenges. If used wisely, demand for resources could potentially transform those countries with rich resource endowments. The countries most likely to feel an adverse impact in this scenario would be those that import a high proportion of their resources and whose economies are resource-intensive—notably China and India and other countries whose economic development is in the industrialization phase. China and India may need to import 5 and 15 percent of their 2030 cereal demand, respectively, having been modest net exporters of this commodity in 2010.

9 *The emissions gap report: Are the Copenhagen Accord measures sufficient to limit global warming to 2 degrees Celsius or 1.5 degrees Celsius? A preliminary assessment*, UN Environment Program, November 2010.

10 *Farewell to cheap capital? The implications of long-term shifts in global investment and saving*, McKinsey Global Institute, December 2010 (www.mckinsey.com/mgi).

11 Timothy J. Considine, et al., "The economic opportunities of shale energy development," *Energy policy and the environment report*, Manhattan Institute, May 2011.

12 "Are we entering a golden age of gas?" *World energy outlook*, International Energy Agency Special Report, 2011.

4. A step change in resource productivity is possible

A range of opportunities to boost the productivity of resource extraction, conversion, and end use can be tapped. Our second case—the productivity response—takes the base-case productivity growth assumed in our first scenario and adds a range of opportunities to boost resource productivity, filling the remaining gap with supply. There are opportunities in energy, land, water, and materials that could address up to 30 percent of total 2030 demand (Exhibit E2).[13]

The envisaged efficiency improvements do not allow for dynamic behavioral impacts that could at least partially offset productivity gains—a "rebound effect." Lower resource prices and therefore more spending power could lead to increased consumption, eventually boosting prices and compromising consumption. Policy would need to be designed to mitigate the impact of such an effect.

Capturing the total resource productivity opportunity—including the more difficult levers—could amass annual savings to society of $2.9 trillion a year in 2030, at current market prices. The value of the opportunity would increase to $3.7 trillion if we assume a $30 per tonne price for carbon as well as the removal of energy, agriculture, and water subsidies, and the removal of energy taxes. Today, governments rarely price water at its true cost, there are large energy and agriculture subsidies, and there is no global carbon price. The value of the benefits would be even greater if market resource prices were to be higher than they are today. Of the opportunities that are available, 70 percent have an internal rate of return of more than 10 percent at current prices. This proportion would rise to 80 percent if the externalities of resource use and subsidies were included in prices. This share reaches 90 percent if we exclude energy taxes and assume a societal discount rate of 4 percent.

Delivering on resource productivity reduces the need to expand supply but does not eliminate it. In the case of energy, improving productivity could cut incremental demand to only 20 QBTU. However, 400 QBTU of new supply would still be necessary due to declining sources of existing supply. The output of oil and natural gas could fall by approximately 6 percent per annum. The decline in coal output could be 3 percent a year. To put this in perspective, 1 QBTU is enough energy to power all of the cars, trucks, buildings, homes, infrastructure, and industry of New York State for more than three months.

Despite these potentially high returns, this scenario requires more capital than the supply expansion scenario. The capital required to implement the resource productivity opportunity in full could be an additional $900 billion a year. However, the capital required to expand supply would fall to $2.3 trillion (from $3 trillion in a supply expansion case). Overall, this implies that the capital costs could be roughly $100 billion per annum higher than the supply expansion case—$1.2 trillion a year above historical expenditure. The institutional and managerial challenges of delivering on a productivity response approach are likely to be as

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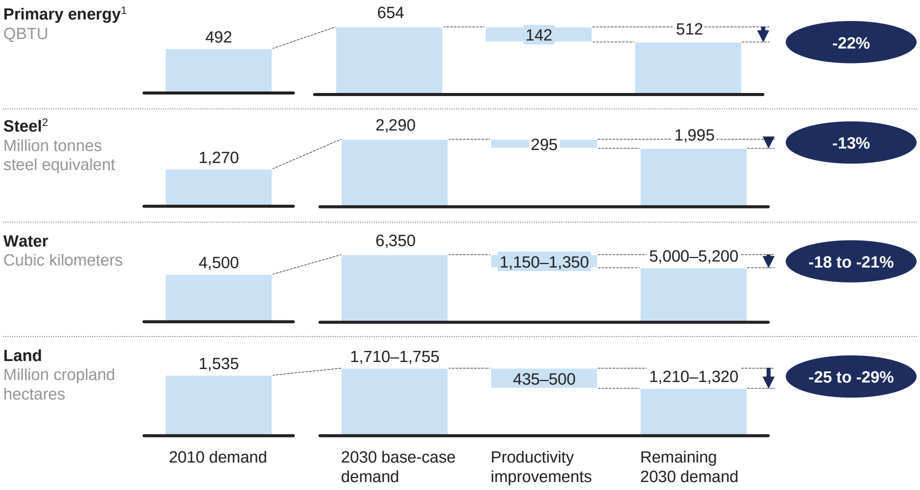
13 Given steel's importance to the global economy and its linkages with other resources, we focus on it as a proxy for materials overall (see Box 2, "Why steel matters"). For all resources, we reviewed levers across the whole value chain including extraction efficiency (i.e., more output from the same source), conversion efficiency (i.e., transformation of a raw material into another usable form such as coal to electricity), and end-use efficiency (i.e., lower end-use consumption through measures such as building efficiency or reducing food waste).

high as, or even higher than, the supply response case due to the fragmented nature of the opportunities.

Exhibit E2

In a productivity response case, opportunities could meet 13 to 29 percent of resource demand



1 Productivity improvements include supply-side measures, such as enhanced oil recovery, that lower effective remaining demand.
2 Supply-side levers such as improving recovery rates and the conversion rate in mining and coke do not save steel and are not reflected in this exhibit. We have included effective steel savings from higher scrap recycling.

SOURCE: McKinsey analysis

Concerns about energy security would potentially diminish somewhat in the productivity response case. Chatham House research finds that the Asia-Pacific region and Europe today could need imports to meet about 80 percent of their oil demand by 2030.[14] However, in a productivity response case, oil demand would be 20 percent lower than it would otherwise have been (83 million barrels per day versus 103 million). Oil would still account for 79 percent of fuel demand for road transport in 2030 (compared with 96 percent today). Oil demand could drop by an additional seven million barrels per day, from 83 million barrels to 76 million, if there were to be an aggressive move to ramp up the production and use of second-generation biofuels and if the power-sector mix shifted sufficiently to nearly eliminate oil-fired power by 2030. This would reduce oil's share of the energy used by road transport to 63 percent, with the remaining energy provided by biofuels (23 percent), electricity (13 percent), and other fuels (1 percent).

Carbon emissions would decline to 48 gigatonnes per annum in 2030, getting halfway to a 450 parts per million (ppm) pathway, which would require carbon emissions of only 35 gigatonnes by 2030. Higher yields on smallholder farms and large-scale farms, in addition to other productivity opportunities such as reducing food waste, would mean a net reduction of 215 million to 325 million hectares, from today's levels, in the land needed for cultivation of crops. This would have broader benefits for biodiversity and mean significantly lower water consumption as the productivity of rain-fed land and crop-per-drop where irrigation is in use would both increase. Reduced demand for food and energy due to higher productivity in their conversion and end use could lower prices, creating a range of economic and welfare benefits. The requirement for investment in climate adaptation could also be somewhat reduced.

14 John V. Mitchell, *More for Asia: Rebalancing world oil and gas*, Chatham House, December 2010.

The $900 billion of investment needed in a productivity response case could potentially create 9 million to 25 million jobs. Over the longer term, this investment could result in reduced resource price volatility that would reduce uncertainty, encourage investment, and also potentially spur a new wave of long-term innovation.[15] By reducing expenditure on imported resources and improving the cost competitiveness of businesses, these productivity opportunities could also strengthen trade balances in many net resource-importing economies.

To help prioritize the resource productivity initiatives that are available, we have developed an integrated resource productivity cost curve (Exhibit E3).[16] In this curve, we have grouped more than 130 potential resource productivity measures into areas of opportunity, prioritizing the top 15 that account for roughly 75 percent of the total resource productivity prize (Exhibit E4). The top three opportunities would deliver roughly one-third of the total potential. While each opportunity has one resource as its primary benefit, there are often important spillover benefits across multiple resources, including carbon.

These 15 opportunities are:

1. Building energy efficiency
2. Increasing yields on large-scale farms
3. Reducing food waste
4. Reducing municipal water leakage
5. Urban densification (leading to major transport efficiency gains)
6. Higher energy efficiency in the iron and steel industry
7. Increasing yields on smallholder farms
8. Increasing transport fuel efficiency
9. Increasing the penetration of electric and hybrid vehicles
10. Reducing land degradation
11. Improving end-use steel efficiency
12. Increasing oil and coal recovery
13. Improving irrigation techniques
14. Shifting road freight to rail and barge
15. Improving power plant efficiency

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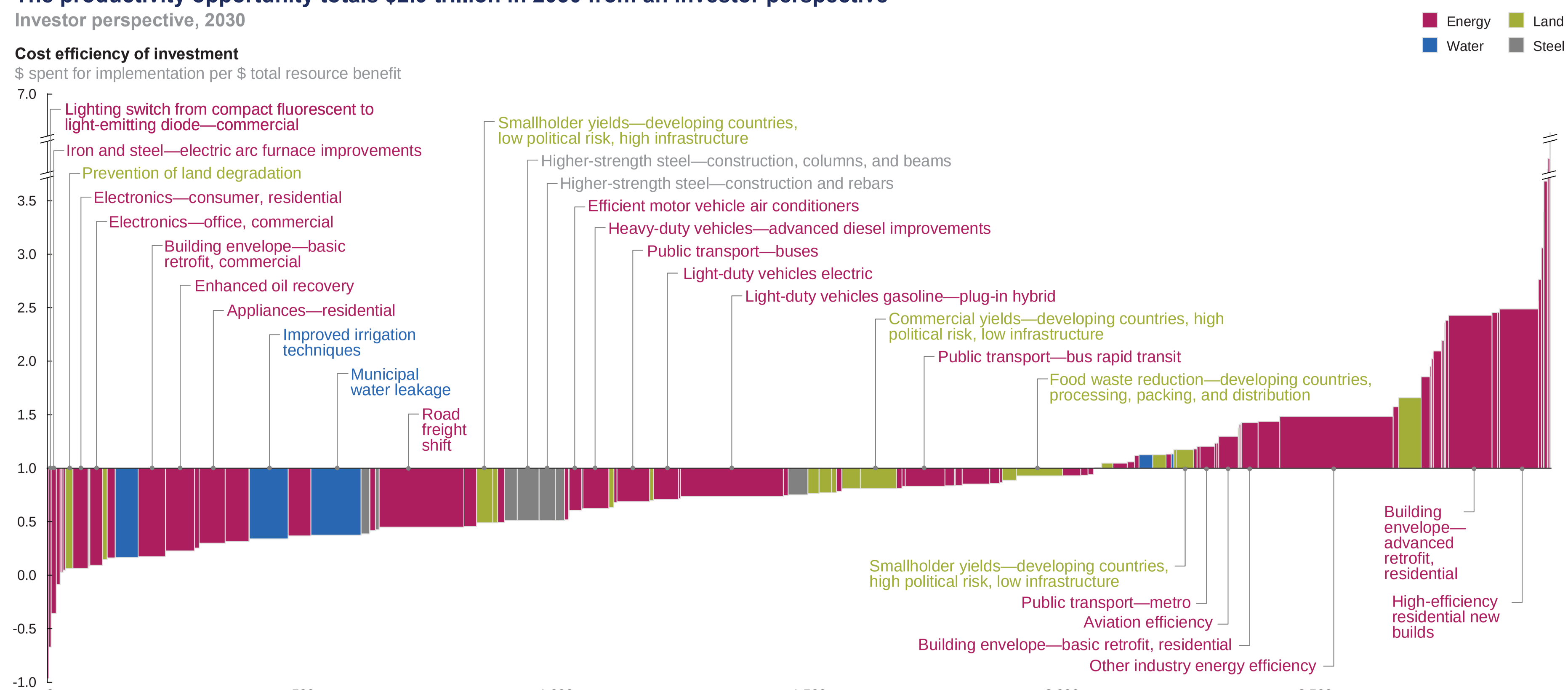
15 Some academics have discussed the possibility that resource productivity opportunities could create a new Kondratiev cycle—a long-term growth cycle typically lasting 30 to 50 years that can be attributed to major technological innovations such as the invention of steam power, railroads, and software information technology. For further details, see Ernst Von Weizsäcker, et al., *Factor five: Transforming the global economy through 80% improvements in resource productivity* (London: Earthscan, November 2009).

16 The integrated resource productivity cost curve shows the resource benefits and costs associated with productivity opportunities in energy, land use, steel, and water (see Box 10, “The integrated resource cost curve”).

Exhibit E3

The productivity opportunity totals $2.9 trillion in 2030 from an investor perspective

Investor perspective, 2030



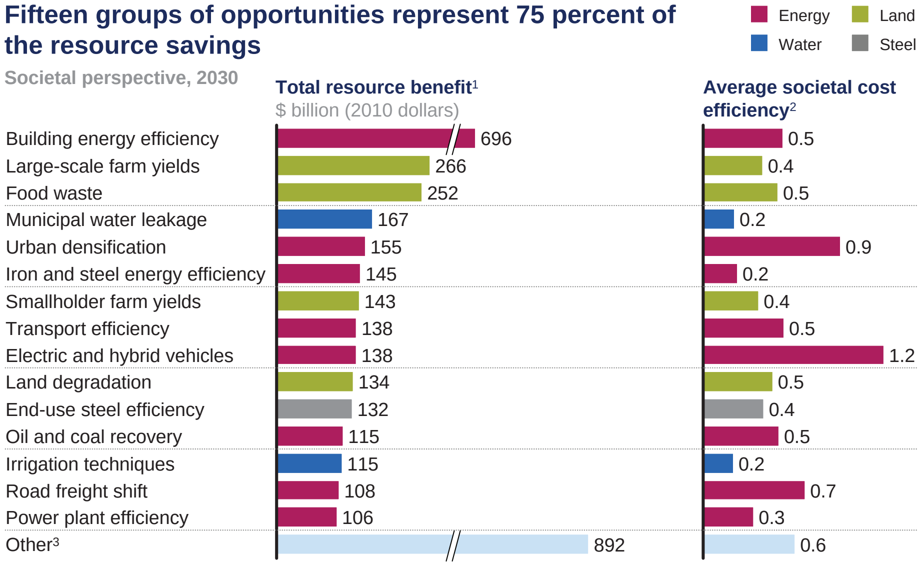
1 Based on current prices for energy, steel, and water at a discount rate of 10 percent per annum. All values are expressed in 2010 prices.

SOURCE: McKinsey analysis

Exhibit E4

Fifteen groups of opportunities represent 75 percent of the resource savings

Societal perspective, 2030



1 Based on current prices for energy, steel, and food plus unsubsidized water prices and a shadow cost for carbon.
2 Annualized cost of implementation divided by annual total resource benefit.
3 Includes other opportunities such as feed efficiency, industrial water efficiency, air transport, municipal water, steel recycling, wastewater reuse, and other industrial energy efficiency.

SOURCE: McKinsey analysis

We have excluded shale gas and renewable energy from this analysis, treating them as sources of new supply rather than as opportunities to improve the extraction, conversion, or end use of energy resources. While there is considerable uncertainty on the potential resource benefits of unconventional gas (including shale gas) and renewable energy, a rough sizing suggests that these could be in the top ten opportunities. In the case of unconventional gas, lower natural gas prices as well as some additional carbon benefits could mean savings as high as $500 billion per annum in 2030. In renewable energy, the scaling up of wind, solar, and geothermal could be worth $135 billion per annum from reductions in carbon alone (assuming a carbon price of $30 per tonne). There are other benefits that are difficult to quantify such as providing a hedge for volatile fuel prices and lower health costs than would be the case with today's levels of use of fossil fuels. Finally, if there were technological breakthroughs in renewables, total savings could increase by another $75 billion.

To accompany the cost curve, we have also begun to compile metrics to assess how different countries perform on resource productivity. From the evidence thus far, performance varies very widely. No one country outperforms others on all of the opportunities. This suggests that every country has scope to make further progress on resource productivity, learning from others how best to go about it.

5. Additional efforts would be necessary to address climate change and universal access to energy

A productivity response case would not be sufficient to achieve a 450-ppm carbon dioxide equivalent pathway that, according to the Intergovernmental Panel on Climate Change (IPCC), is consistent with limiting global warming to no more than two degrees Celsius in a median case. This report therefore presents a third scenario—a climate response case.[17] To achieve a 450-ppm pathway, carbon emissions would need to be reduced from 48 gigatonnes a year in the productivity response case to 35 gigatonnes in 2030. There would have to be a greater shift from high-carbon power such as coal to low-carbon power delivered through renewables and the incremental production of biofuels for use in road transport. There would also need to be further abatement of carbon emissions in land use through the reforestation of degraded land resources (estimated at more than two billion hectares globally today), the improved management of timberland, and measures to increase the productivity of pastureland.

Depending on the rate of technological advance in renewable energy, an additional $260 billion to $370 billion a year would need to be invested over the next two decades to put this plan into action, compared with the productivity response case. This would be only 60 to 90 percent of current fossil fuel subsidies and could also allow for reductions in adaptation investments. Universal energy access—providing all people with access to clean, reliable, and affordable energy services for cooking and heating, lighting, communications, and productive uses)—at an "entry level" of 250 to 500 kilowatt hours per person per year would cost around $50 billion a year over the next two decades.[18] The welfare benefits from such an investment could make a substantial contribution to economic growth and education (e.g., making it possible to read at night), and accelerate the diffusion of technology into poorer rural communities. Yet the increased demand for energy resulting from universal access would increase carbon emissions by less than 1 percent.

6. Tackling this resource agenda must start with a shift in institutional mind-sets and mechanisms

How might policy makers find their way through this complex maze? Overcoming barriers will require new institutional mind-sets and mechanisms that can develop crosscutting systemic approaches to the management of resources, incorporated into broader economic policy making. The relevant core ministries—energy, water, agriculture—may need additional resources to help them deal with the challenges they face.

Many governments tend not to take an integrated approach to resources. For example, issues related to water often fall between the ministries for water, agriculture, urban development, and the environment (e.g., on river quality). Land-use issues often fall between agriculture, forestry, and environment at the national level, with many other stakeholders at provincial and district levels. In the case of land use, many countries are struggling to put in place the right coordination mechanisms to tackle sustainable rural and agriculture development, reduce deforestation, and enhance food security in a single integrated agenda. At times, the international system for official development assistance can contribute to this fragmentation, since it has its own parallel set of international agencies, each

17 A 450-ppm pathway describes a long-term stabilization of emissions at 450-ppm carbon dioxide equivalent, which is estimated to have a 40 to 60 percent chance of containing global warming below the two degrees Celsius threshold by the end of the 21st century.

18 Our definition draws on *Energy for a sustainable future: Summary report and recommendations*, The Secretary-General's Advisory Group on Energy and Climate Change, United Nations, April 28, 2010.

focused on its own part of the agenda. Bilateral aid agencies, which tend to reflect different institutional interests in their own funding countries, can further complicate the picture.

This fragmented institutional approach runs the risk of governments failing to prioritize opportunities effectively. Indeed, public discourse does not seem to reflect the 15 priorities that we have highlighted in this report. A media review suggests that there is limited awareness of the full set of resource productivity opportunities. The energy efficiency of buildings, the largest opportunity identified in this analysis, attracts many column inches, while other areas such as food waste and improving the yields on large-scale farms receive little attention compared with their potential impact.

Beyond transforming institutional mind-sets and mechanisms, governments should consider action on three fronts. First and foremost, market signals would need to be strengthened, not dampened. Second, a range of other non-price market failures need to be corrected. Third, the long-term resilience of society needs bolstering.

A. STRENGTHEN PRICE SIGNALS

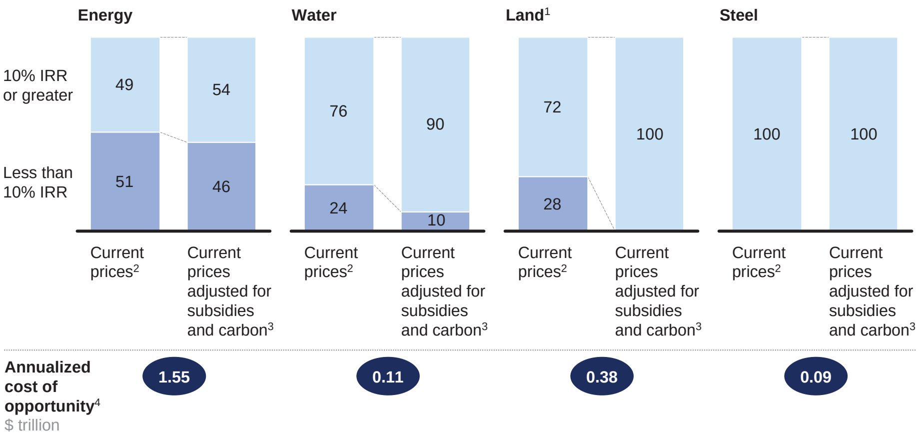
Despite the fact that capturing many productivity opportunities would have sizable benefits for society, a significant number of them are not attractive to private-sector investors. There are a number of reasons for this. One factor is that uncertainty about the future path of resource prices at a time when they are particularly volatile means that it is difficult for investors to judge what returns they might make on their investment, and this acts as a deterrent. Another is that fiscal regimes in many countries provide a disincentive to the productive use of resources because the world is subsidizing resources by more than $1 trillion a year and often failing to put a price on externalities of production such as carbon emissions. Removing agriculture, energy, and water subsidies and putting a price of $30 per tonne on carbon emissions would significantly improve the attractiveness of productivity opportunities to private-sector investors (Exhibit E5). Finally, uncertainty about whether financial support from governments for opportunities such as renewable energy will continue often means that investors demand higher returns to compensate for this risk. Governments could benefit from putting in place stable, effective policy regimes that strengthen market signals and ensure sufficiently attractive returns to engage the private sector.

Exhibit E5

Relatively low investor returns, especially for energy, make the resource productivity agenda even more challenging

Return distribution of productivity levers by resource

%



1 Agricultural levers such as yields and food waste that save both land and water have been shown only under land.
2 Internal rate of return (IRR) based on current prices including taxes and subsidies.
3 IRR based on current prices adjusted for subsidies in water, energy, and food plus a price of $30 per tonne of carbon dioxide equivalent emissions.
4 Assuming a 10 percent discount rate.

SOURCE: McKinsey analysis

B. ADDRESS (NON-PRICE) MARKET FAILURES

Governments can play a role in dismantling a range of barriers that do not relate to price. A lack of clear property rights, particularly in agriculture and fisheries, is one obstacle that engagement with local communities to strengthen governance of common resource pools and more effective planning can help. Many profitable energy-efficiency opportunities are not implemented because of agency issues where, for instance, a landlord bears the cost of installing energy-efficient insulation but the tenant enjoys lower energy bills. Government efficiency standards can be an effective, low-cost way of overcoming principal-agent barriers, but standards need to be designed to encourage rather than stifle market-based innovation.

Access to capital is a vital barrier to tackle given that much of the additional capital needed to finance the resource revolution will need to be in developing countries that may have under-developed capital markets. Between 70 and 85 percent of opportunities to boost resource productivity are in developing countries (Exhibit E6).[19] A number of mechanisms, including loan guarantees and other risk-sharing tools, can encourage financial institutions to lend. Multilateral development banks can play a useful role in offering concessional or blended lending. Some governments have also started to encourage collaboration among energy service companies, mortgage companies, and underwriters to pool

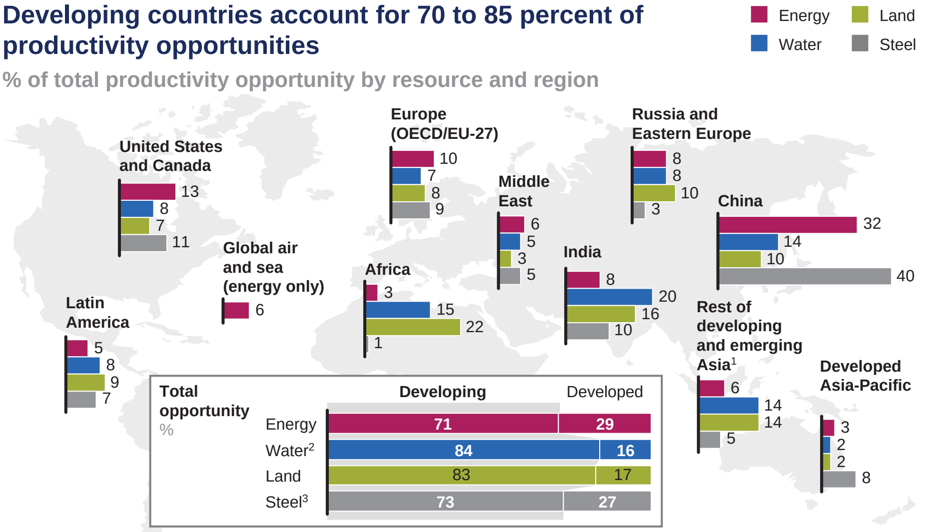
19 This is driven by the large share of future resource demand coming from developing countries and the generally larger opportunities to improve resource productivity in developing countries compared with developed countries (as resource productivity in developed countries is generally higher and many of the future expected productivity improvements in developed countries are captured in our base-case projections). It is important to stress that this analysis does not include behavioral changes that could lead to a welfare loss (e.g., living in smaller houses, reducing meat consumption), where opportunities are likely to be largest in developed countries.

technical expertise and long-term financing. New forms of regulatory and country risk insurance may also be necessary.

Exhibit E6

Developing countries account for 70 to 85 percent of productivity opportunities

% of total productivity opportunity by resource and region



1 Rest of developing Asia includes Central Asia (e.g., Uzbekistan), South Asia (e.g., Bangladesh), Southeast Asia (e.g., Laos), and North Korea.
2 Includes water savings from water-specific levers as well as water savings from improved agricultural productivity.
3 For steel, the chart represents all the demand-side levers and the scrap recycling lever but excludes supply- and conversion-side levers.
NOTE: Numbers may not sum due to rounding.
SOURCE: McKinsey analysis

Enabling innovation will also be crucial. We base our productivity analysis on technology that is already available. However, more innovation is necessary to meet the resource challenge beyond 2030. Many of the enablers for resource-related innovation are the same as for the broader economy: a stable macroeconomic environment, vigorous competition, more open international trading rules, and a sound financial system. Removing barriers to innovation would be important, but more investment in resource-related R&D would also be required. Government procurement rules can support the ramp-up of green technologies, and governments can make targeted investments in enabling infrastructure such as the use of smart grids to link the higher penetration of electric vehicles (EVs) to the increased deployment of renewable power.

C. BUILD LONG-TERM RESILIENCE

Societies need to bolster their long-term resilience in the face of the resource challenge, raising their awareness of resource-related risks and opportunities, creating appropriate safety nets to mitigate the impact of these risks on their poorest members, and educating consumers and businesses to adapt their behavior to the realities of today's resource-constrained world.

There is no effective early-warning system across resources that could give investors the necessary combination of national and integrated global intelligence on demand, supply, and potential risks. Putting such a system in place would require significant public investment in capturing primary data on the availability of resources, indicators of environmental health, the dynamics of the climate system, and more sophisticated modeling tools for analyzing the dynamic relationships between economic growth, resource systems, and the environment. Major advances in remote sensing tools and big data management can help in this effort. Strengthening the metrics that relate to the major productivity opportunities would deliver significant benefits. Governments could also help businesses and households to inform themselves about productivity opportunities through instituting the mandatory energy-efficiency labeling of appliances and by scaling up mechanisms (such as the C40 cities forum) that share best practice across regions and cities.

Increasing access to resources would be an important component of making society more resilient in the face of resource-related trends. Providing global universal energy access at an "entry level" of 250 to 500 kilowatt hours per person per year would cost less than $50 billion a year over the next 20 years. Alongside greater access, social protection schemes should be ramped up, as should investment in the resilience of key production systems, if people are to be able to deal more effectively with resource- and climate-related shocks.[20]

Change happens most decisively when individuals alter their way of thinking and therefore their behavior. In many developed countries, resource prices are only a small share of overall household budgets, except for the bottom 20 to 30 percent of households. This means that action beyond price signals will be necessary to alter the choices people make about the resources they use. The report identifies four critical elements to changing behavior. First, there is demonstration and role modeling of the behavior change. Morocco launched pilot programs to show how the country's new contract farming approach would work and to help make the argument for the transformation.[21] Second, governments can foster conviction and understanding about sustainability issues among not only up to three billion new middle-class consumers, but also the relatively more affluent consumers in OECD economies whose resource footprint is a multiple of that generated by these new middle classes. For example, in North America and Oceania, one-third of the fruit and vegetables that are purchased is thrown away.[22] Third, incentives and formal mechanisms can encourage change, particularly by mitigating the negative impact on some stakeholders during the transition process. A central element of the Danish energy tax reform was compensation (conditional on improving energy productivity at preset targets) for those industries most heavily affected. Fourth, there is a need to develop new talent and skills to support any change in behavior. During Australia's water reforms, for example, the government put significant funds into the retraining of farmers in more water-efficient techniques.

7. Firms should consider how to adjust strategy to take account of resource-related risks and opportunities

For much of the 20th century, private-sector companies have been able to plan their strategies and business models on the (often implicit) assumption that the implications for real costs of resource prices would be constant or fall. As a result, they have tended to focus on raising labor and capital productivity, given the increasing cost of labor and competition for capital. However, companies now

20 Alex Evans, *Globalization and scarcity: Multilateralism for a world with limits*, Center on International Cooperation, New York University, November 2010.

21 Contract farming is carried out according to an agreement between a buyer and farmers, which establishes conditions for the production and marketing of farm products.

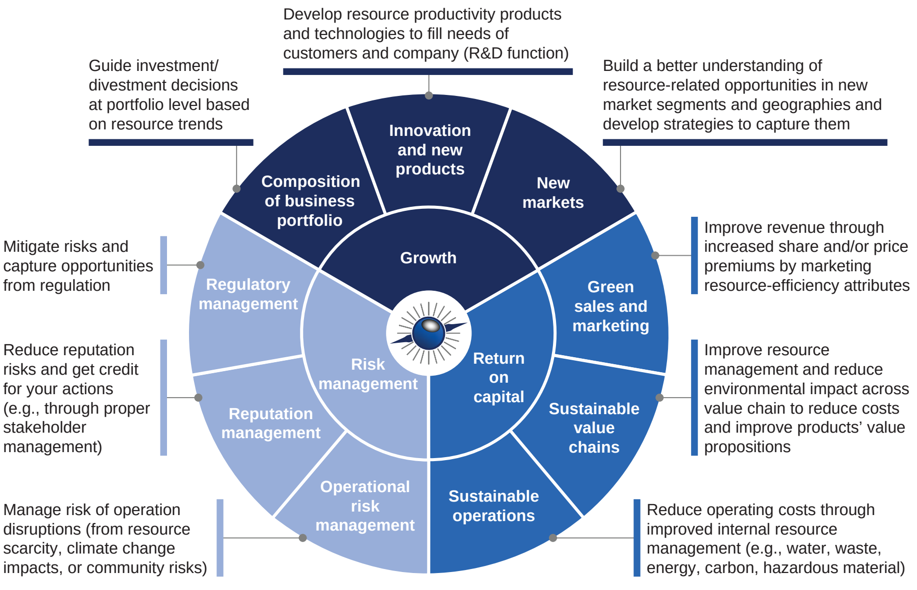
22 Food and Agriculture Organization, *Global food losses and food waste*, 2011.

need to increase their strategic and operational focus on resource productivity. Companies that succeed in improving their resource productivity are likely to develop a structural cost advantage; improve their ability to capture new growth opportunities, especially in resource-scarce, rapidly growing developing markets; and reduce their exposure both to resource- and environment-related interruptions to their business and to resource price risk. Increased resource productivity would clearly benefit customer-facing companies including those in the consumer goods, consumer electronics, and retail sectors. Higher resource prices may not translate automatically into higher profits for resource-supply companies through the cycle—but higher prices are almost certain to lead to increased regulatory action from governments and the upstream taxation of resources.

The strategic implications of resource-related trends are likely to vary from sector to sector, of course. Nevertheless, all companies are likely to benefit from adopting a more systematic approach toward understanding how resources might shape their profits, produce new growth opportunities and technological discontinuities, and generate new stresses on their management of risk and regulation (Exhibit E7). Industry leaders could usefully go one step further and strive to shape industry standards in a way that generates greater transparency throughout the supply chain about resource productivity and the end-to-end measurement of that industry's environmental footprint.

Exhibit E7

There are several resource-related value-creation levers for businesses



SOURCE: McKinsey analysis

1. The resource-intensive growth model of the past

In this chapter, we examine changes in the trends of resource supply, demand, and prices during the 20th century. Our main findings include:

- Despite substantial growth in demand for resources such as energy, food, water, and materials over the past century, resource prices have either been flat or have declined and underpinned global GDP growth.

- This reduction in resource prices came through a combination of technological progress and the discovery of new, low-cost sources of supply. A subsidiary—but nevertheless important—reason that resource prices were stable or declined in the face of increasing demand is that resource prices do not actually reflect their full economic value. Governments commonly subsidize the cost of resources. Moreover, resource prices rarely take into account the secondary consequences of their production and use, including carbon emissions and the loss of biodiversity.

Progressively cheaper resources have underpinned global economic growth over the past century

Throughout the 20th century, resource prices declined in real terms or, in the case of energy, were flat overall despite periodic supply shocks and volatility. The real price of MGI's index of the most important commodities fell by almost half (Exhibit 1).[23] This decline is startling and impressive when we consider that, during this 100-year period, the global population quadrupled and global GDP increased by roughly 20 times.[24] The result was strong increases in demand for resources of 600 to 2,000 percent, depending on the resource.[25]

While it is true that resource prices fell over the 20th century as a whole, there were, in fact, a number of distinct eras with different drivers of demand, supply, and prices. After World War I, and with the onset of the Great Depression in the 1930s, prices fell rapidly as a result of declining demand. From the end of World War II until the 1970s, over a period of around 30 years, prices were largely stable. These were decades that, in general, experienced strong

23 The McKinsey Global Institute's commodity price index is a price index comprising 28 key commodities. We break this index into four commodity subgroups: energy, metals, food, and agricultural raw materials. We weight commodities within each subgroup based on their share of global exports by value and take a simple average of the subgroups to build the aggregate index. Prices are in real terms and adjusted for changes in exchange rates. Without exchange-rate adjustments, the fall from 1900 to 1999 was 67 percent instead of 48 percent, due to appreciation of the US dollar relative to other currencies in the 20th century. For more detail, see the methodology appendix.

24 Economic and population data come from Angus Maddison, *The world economy: Historical statistics*, Organisation for Economic Co-operation and Development, 2003.

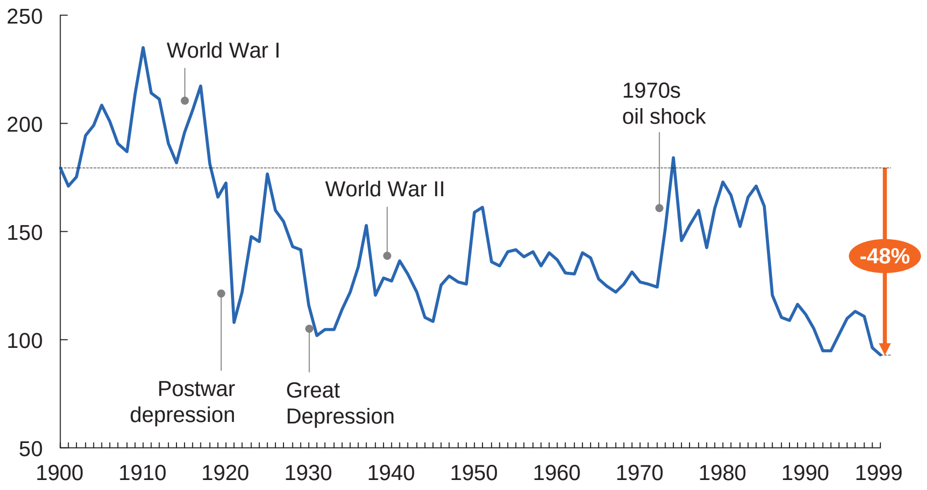
25 Fridolin Krausmann, et al., "Growth in global materials use, GDP and population during the 20th century," *Ecological Economics* 68(10): 2696–2705, 2009.

economic growth, matched by improvements in transport infrastructure. These infrastructural improvements led, in turn, to the integration of global markets and access to low-cost sources of supply from Argentina to South Africa. The 1970s marked an abrupt end to this era of stable prices in energy and food. Oil prices spiked in response to the Yom Kippur War and then to the subsequent imposition of an oil embargo by the Organization of Arab Petroleum Exporting Countries (OAPEC).[26] But then further disruptions to supply, related to the Iranian Revolution and the Iran-Iraq War, exacerbated this rising price trend. After those successive shocks came a period of generally declining prices that lasted for the rest of the century. This era was marked by the fall of the Soviet Union and its resource-intensive economic system in 1991 and by continued improvements in the productivity with which resources are used from energy to agriculture.

Exhibit 1

Average commodity prices have fallen by almost 50 percent over the past century

MGI Commodity Price Index (years 1999–2001 = 100)[1]



1 See our methodology appendix for details of the MGI Commodity Price Index.
SOURCE: Grilli and Yang; Pfaffenzeller; World Bank; IMF; OECD statistics; FAO; UN Comtrade; McKinsey analysis

Over the past 100 years as a whole, demand for resources grew more slowly than GDP. The first reason for this is that a declining share of global income was devoted to resource-intensive consumption. As people get richer—generally when incomes exceed a threshold of around $15,000 to $20,000 per capita in PPP terms—they typically spend less of their household income on resource-intensive consumption. We can observe this kind of consumption curve in the case of many resources, including energy (Exhibit 2). Much of the global economic growth generated over the past century has been in countries with incomes above this threshold. The second reason that demand grew more slowly than GDP is due to improved end-use productivity of resources. For instance, the average fuel economy of US light-duty vehicles rose by almost 60 percent between 1975 and 1981, partly in response to higher energy prices and CAFE fuel economy standards, according to the US Environmental Protection Agency. From 1980 to 2000, the period for which we have data across energy, land, materials, and

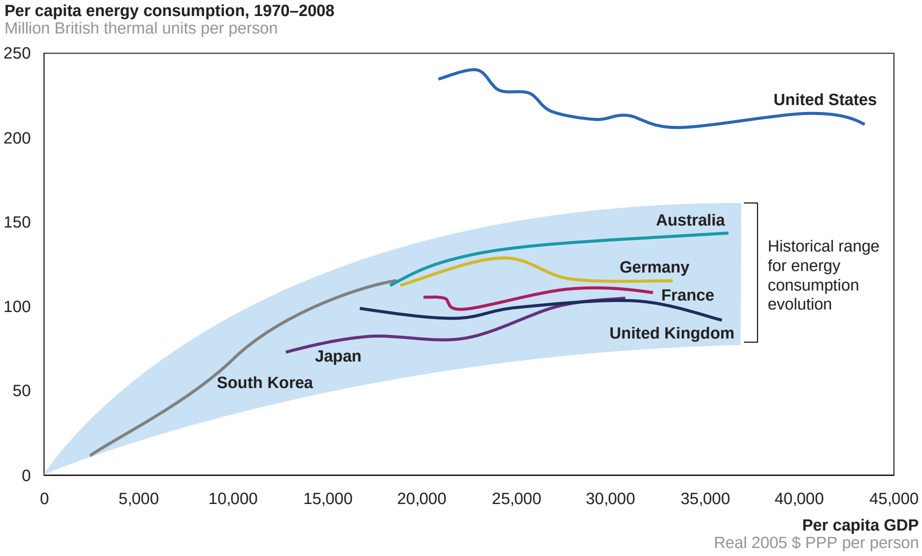
26 OAPEC consists of the Arab members of the organization plus Egypt, Syria, and Tunisia.

water, resource intensity declined on average by 0.5 to 2.0 percent.[27] The fall of the Soviet Union in 1991 made a significant contribution to this improvement in resource intensity.[28]

Exhibit 2

Many countries have shown that, as incomes rise, demand for resources increases

ENERGY EXAMPLE



SOURCE: International Energy Agency (IEA); Global Insight; McKinsey analysis

The price of resources did not rise to reflect increased demand during the 20th century. Part of the reason for this, again, was productivity. A widely adopted wave of innovation has improved the productivity with which resources are extracted. Examples of such innovation include the use of solvent-extraction technology that allows the low-cost processing of copper-oxide resources, and 3-D seismic technology and horizontal drilling in oil exploration and production. Supply-side productivity improvements have been particularly important in agriculture. Demand for grain increased by 2.2 percent per annum from 1961 to 2000, while land use grew at just 0.1 percent a year. Growing demand was met largely through improving yields due to more effective farming techniques, the increased use of fertilizer, more irrigation of cropland, and the introduction of improved genetic crop varieties. Grain yields grew at an annual rate of 2.1 percent from 1961 to 2000.[29]

Another important explanation is the discovery of, and expansion into, low-cost forms of new supply. In the case of oil, Saudi Arabia in 1948 found its huge Ghawar oil field, which accounted for 60 to 65 percent of all Saudi oil produced until 2000.

27 Resource intensity is the amount of resource inputs (e.g., tonnes of steel) relative to economic output.

28 Kenneth S. Corts, "The aluminum industry in 1994," *Harvard Business School case study*, 1999.

29 Considering all crops (including fruit and vegetables, pulses, etc.), global supply increased by 2.3 percent per annum. The use of land expanded by 0.7 percent a year, and yields increased by 1.6 percent.

On top of this, some prices simply didn't reflect their true costs. Agricultural subsidies have been prominent since the end of World War I and appear to have been on a general upward trend. According to data from the OECD, agricultural subsidies rose by 4.2 percent per annum from 1995 to 2010.[30] Energy subsidies have been increasingly widespread since the 1970s oil crisis. Today, subsidies (of which a majority are producer subsidies) in energy, agriculture, and water total as much as $1.1 trillion, and they have kept prices artificially low.[31]

The drivers of declining real prices vary significantly depending on the resource

The overall decline in resource prices during the 20th century masks significant variations in trends between resources. The price of cotton, copper, and wheat declined between 1900 and 1999 by 1.0 percent a year, 0.9 percent, and 0.8 percent, respectively. In contrast, the price of oil increased by 0.3 percent during these years—with a sharp rise since the 1970s oil crisis (Exhibit 3). The drivers of declining real prices also vary according to the resource (Exhibit 4). In this section, we look at the four major resources we discuss in this report. While there are growing similarities and links between these resource systems, there are also very important differences in their structure, conduct, and performance.

---

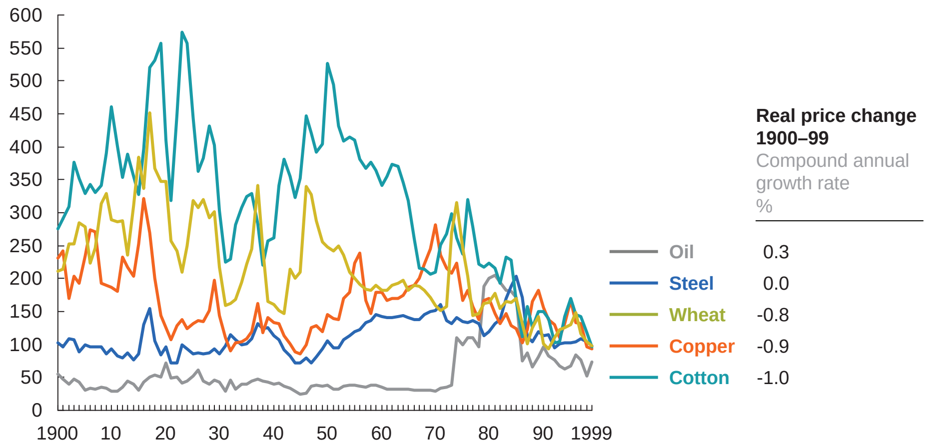
30 We define subsidies as outlays directly tied to government spending. We do not include market-price support.

31 The OECD estimates that annual agricultural subsidies (excluding market-price supports) in OECD economies, plus Brazil, Russia, China, South Africa, and Ukraine were $370 billion in 2010. The United Nations Environment Program estimates that subsidies to fisheries total £27 billion ($38 billion). In October 2011, the International Energy Agency estimated that energy subsidies in 2010 were $410 billion, down from $558 billion in 2008. The OECD estimates that water costs covered by tariffs vary widely between countries (e.g., Egypt, 10 percent of water costs; South Korea, 40 percent; France, 95 percent). Based on an assumed global average of 40 to 60 percent and the market value of water estimated by the Global Water Institute to be around $500 billion, this suggests subsidies of $200 billion to $300 billion per annum. It is important to stress that these estimates refer only to direct cash payments to producers and ignore a range of other indirect support mechanisms including tax measures and other government interventions on prices received by producers and paid by consumers.

Exhibit 3

The changes in price of different commodities during the 20th century varied widely

Indexed commodity prices (1999–2001 = 100)[1]



1 Deflated using the World Bank's Manufacturers' Unit Value Index, which adjusts for both inflation and changes in currency prices.

SOURCE: Grilli and Yang; Pfaffenzeller; World Bank; Commodity Price Data; IMF; OECD statistics; FAO; UN Comtrade; McKinsey analysis

Exhibit 4

The drivers of prices during the 20th century depended on the resource

Strong driver
Medium driver
Weak driver

		Major supply-side drivers of resource price changes (mainly post-1960)				Demand drivers (post-1980)
Natural resources	Annual price change 1900–2000 %	New sources of supply	Supply-related technological progress	Industry structure	Producer subsidies	Changes in demand
Energy	0.3	Discovery of large sources of supply	Unit cost reduction of 10–20% with doubling of capacity	Rise of OPEC and supply-side shocks increased oil costs in 1970s	Large energy subsidies in developing countries	Global energy intensity of growth fell 1.4% p.a. 1980–2000
Materials	-0.2	Large new mine discoveries	Use of low-cost extraction technologies			Global steel intensity of growth fell 1% p.a. 1980–2000
Food	-0.7	Cropland for grains increased 0.1% p.a. 1961–2000	Grain yield per hectare increased 2.1% p.a. 1961–2000		Large agricultural subsidies in developed countries	Demand for wheat relative to GDP fell 1.5% p.a. 1980–2000
Water[1]	~0	Large investment in new supply			Public subsidies of up to 90% of actual water costs	Global water intensity of growth fell 1% p.a. 1980–2000

1 Approximation based on much of water being heavily subsidized.

SOURCE: Grilli and Yang; Pfaffenzeller; World Bank; IMF; OECD; FAO; UN Comtrade; McKinsey analysis

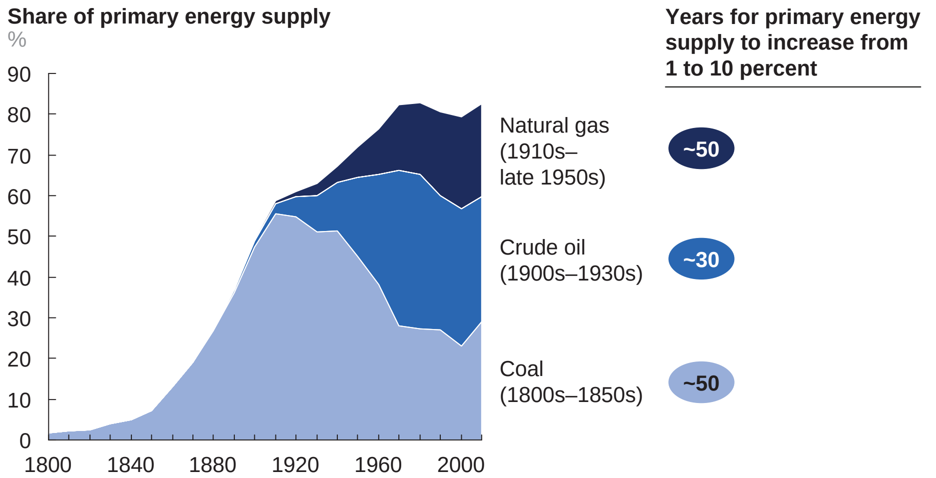
ENERGY

Prior to the 1970s, real energy prices (including those of coal, gas, and oil) were largely flat as supply and demand increased in line with each other. During this time, there were discoveries of new, low-cost sources of supply, energy producers had low pricing power, and improvements were made in the efficiency of conversion from energy sources in their raw state to their usable form. After the sevenfold increase in real oil prices in the 1970s, energy prices declined for a number of reasons. First, developed countries moved away from using oil to generate electricity. In the United States, for instance, oil's share of electricity generation fell from 12 percent in 1970 to 3 percent in 2000 and to only 1 percent today. Second, OPEC's pricing power was squeezed as non-members expanded their own (albeit more costly) supply. OPEC's share of global oil production declined from 51 percent in 1974 to 42 percent in 2000 and less than 41 percent today. Third, there was a large fall in demand following the collapse of the Soviet Union. Finally, governments in developing countries supported lower energy prices by introducing significant consumption subsidies for energy, particularly during the 1970s oil crisis. Today, the value of these subsidies ranges from $300 billion to $550 billion, depending on the oil price.

We should note that the transportation sector's demand for oil bucked the more general trend. Energy demand from this sector has more than doubled since the 1970s. In relative terms, too, transportation's share of overall final oil consumption has risen from 46 percent in 1990 to 53 percent in 2010. Another observation is that it has taken a long time for the overall primary energy mix to shift significantly in response to differences in the cost of supply. It took more than 50 years for coal's share of the primary energy mix to increase from 2 percent to around 10 percent in the mid-1850s. In the case of natural gas, it took 50 years to rise from a 1 percent share in 1910 to 11 percent in 1960 (Exhibit 5).[32]

Exhibit 5

Major energy sources have taken 30 to 50 years to increase from 1 to 10 percent of global energy demand



SOURCE: Vaclav Smil, *Energy transitions*; McKinsey analysis

FOOD

Food prices fell by an average of 0.7 percent a year during the 20th century despite a significant increase in food demand. For example, demand for grain increased by 2.2 percent per annum from 1961 to 2000. Declining food prices were not due to large increases in the use of cropland—in fact, use of cropland

32 Vaclav Smil, *Energy transitions: History, requirements, prospects* (Santa Barbara, CA: Praeger, 2010).

for grains increased by just 0.1 percent a year during this period.[33] Instead, prices fell because grain yields increased at a rapid rate of 2.1 percent from 1961 to 2000, largely as a result of greater use of fertilizers and capital equipment, and the diffusion of better farming technologies and practices. In the latter part of that period, however, the rate of yield growth decelerated—potentially a sign of things to come. From 1961 to 1970, yields grew at 3.0 percent per annum but then increased at a rate of only 1.1 percent from 1990 to 2000. When we take into account mix effects in which lower-yielding crops are substituted for those with higher yields, growth in cereals yields slowed even more significantly to just 0.4 percent a year from 1991 to 2000.

There are three major reasons for the deceleration. First, yields in developed countries have begun to converge with "best practice" yields—these are constrained by agro-ecological conditions and the prevailing level of technology. For large-scale farms, there appear to be diminishing, and in some cases negative, marginal returns to additional inputs. Second, public investment in R&D aimed at increasing attainable yields, in many countries, has been declining. Third, a range of political, infrastructure, and supply-chain bottlenecks have limited the spread of best practice in agricultural techniques to developing countries. Generous state subsidies to farmers in developed countries have supported this trend of declining food prices. In 2010, the OECD estimated that agricultural subsidies totaled $370 billion.[34] Agricultural subsidies have been growing at around 4.2 percent per annum since 1995.[35]

MATERIALS

Materials prices fell by 0.2 percent a year during the 20th century with some variation between different mineral resources. Steel prices were flat, but aluminum prices declined by 1.6 percent a year. Aluminum prices dropped sharply in the 1910s due to the commercialization of the low-cost process of refining alumina from bauxite. In the 1990s, with the collapse of the Soviet Union, the curtailing of military spending freed up 80 to 90 percent of aluminum production capacity, subsequently flooding the world market.[36] The main drivers of declining metals prices overall include the discovery of large, relatively low-cost deposits. One example is Chile's Chuquicamata copper mine, which began production in 1915 and is the largest copper mine by total production in the world. Another driver

33 Although demand for cropland grew slowly, the impact of changes in land use was still significant. Annual growth of 0.1 percent implies an expansion of cropland of 146 million hectares from 1961 to 2000. This figure underestimates the degree of land-use change as cropland has shifted due to urban expansion, growth in mining and energy extraction, and some land degradation. From 1980 to 2000, tropical regions added about 100 million hectares of pasture and arable land, about 80 percent of which came from the clearing of primary and secondary forests. Considering all crops, global demand increased by 2.3 percent per annum with land use expanding by 0.7 percent a year and yields increasing by 1.6 percent. See Holly K. Gibbs, et al., "Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s," *Proceedings of the National Academy of Sciences* 107(38): 16732–37, September 21, 2010.

34 This total includes OECD economies plus Brazil, China, Russia, South Africa, and Ukraine, but excludes support for market prices.

35 Country shares of global agriculture subsidies have changed significantly. From 1997 to 2007, the EU share of total global agricultural subsidies fell from 39 to 31 percent and the US share from 30 to 23 percent. China's share grew from 6 percent in 1997 to 19 percent in 2007 (annual growth of almost 19 percent). Despite this change in shares, the value of subsidies across all of the major agriculture markets has grown.

36 Kenneth S. Corts, "The aluminum industry in 1994," Harvard Business School case study, 1999.

has been technological progress such as the development in the 1960s of solvent extraction technology (SX/EW, or the solvent extraction and electrowinning hydrometallurgical process) that has enabled the relatively low-cost processing of copper-oxide resources. Stagnating demand for metals from developed countries as they began to emerge from their resource-intensive phase of growth has also played a role. History suggests that the consumption of metals typically grows in line with income until a threshold of $15,000 to $20,000 per capita (in PPP-adjusted dollars) is reached as countries go through a period of industrialization and infrastructure building. At higher incomes, growth typically becomes more services-driven and the per capita use of metals starts to stagnate.[37]

WATER

Water prices vary according to the purposes for which the water is needed, local conditions, and subsidy policy. This means it is very difficult to make global generalizations. The price of water for agricultural use may vary from zero in parts of India to $0.05 per cubic meter in the United States. The price of water for municipal use ranges from zero to more than $5 per cubic meter, the median being $0.9. Industrial water prices vary from $0.03 to $1.5 per cubic meter in OECD countries.[38] The OECD suggests that subsidies vary widely among countries, ranging from 5 percent of total costs in France to 90 percent in Egypt.[39] In many countries, the price of bulk, or "upstream," water (particularly for agricultural use) has been largely static in real terms because the increasing costs of abstraction have not been passed on to end users. However, in the case of industrial and municipal use, water prices have been rising steadily across the world in recent years. This is because the cost of abstraction and treatment has been increasing due to the higher amount of energy necessary to pump at greater depths and to transport longer distances.

□ □ □

Despite substantial growth in demand for resources such as energy, food, water, and materials over the past century, resource prices have either been flat or have declined. In the next chapter we will explore how the resource landscape has changed since the turn of the century and the outlook over the next 20 years.

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37 Martin Sommer, "The boom in nonfuel commodity prices: Can it last?" in *World Economic Outlook 2006: Financial systems and economic cycles*, International Monetary Fund, September 2006.

38 We base our estimates of water prices on data from Global Water Intelligence, the Organisation for Economic Co-operation and Development, and the UN Food and Agriculture Organization.

39 *Managing water for all: An OECD perspective on pricing and financing*, Organisation for Economic Co-operation and Development, 2009.

2. The looming resource challenge

Since the turn of the century, the resource picture has changed and become more challenging. In this chapter, we look at the prospects for demand and supply, the growing linkages between resources, and the potential impact of these trends on the global economy and the environment. Our main findings are:

- In the past decade alone, a 100-year decline in the price of resources has been reversed as demand for them has surged. Moreover, with the exception of energy in the 1970s, the volatility of resource prices today is at an all-time high.

- Five factors could potentially make the next 20 years quite distinct from other episodes of high and volatile resource prices that proved to be relatively short-lived as supply caught up and high prices curtailed demand:

  — Assuming no major, protracted slowdown in growth, up to three billion more middle-class consumers will emerge over the next 20 years, fueling demand for a range of resources.

  — Expanding the supply of resources could run into logistical and political difficulties, making adding capacity more costly.

  — The world's resources are increasingly linked. Price shocks in one resource in one market can easily and rapidly spread to others.

  — The impact of strongly rising demand for resources on the environment could restrict supply.

  — Policy makers may face new demands from a billion consumers who still lack access to basic needs such as energy, food, and water.

- These five factors could impose a significant negative impact on economic growth, the welfare of citizens (particularly those on low incomes), and public finances, and could raise geopolitical concerns.

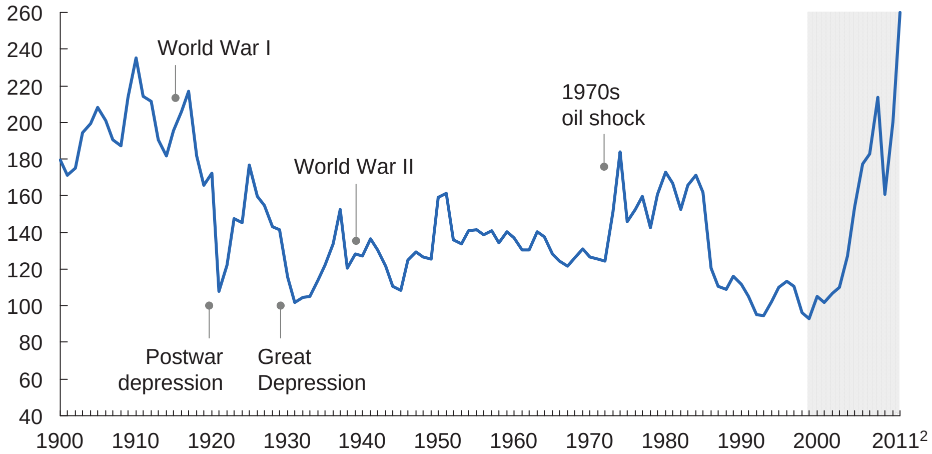
Since 2000, resources appear to have entered an era of higher prices and volatility

Increases in resource prices over the past decade have already wiped out the price declines of the whole 20th century (Exhibit 6).[40] Price rises have varied significantly, depending on the resource. For example, energy prices have increased by 190 percent over the past decade, food prices by 135 percent, and materials prices by 135 percent. The volatility of food, agricultural raw materials, and metals has also increased over the past decade. With the exception of energy, the volatility of resource prices is at an all-time high (Exhibit 7).[41] Since the turn of the century, the average annual volatility of resource prices has been more than three times that witnessed over the course of the 20th century and more than 50 percent higher than in the 1980s.

Exhibit 6

Commodity prices have increased sharply since 2000, erasing all the declines of the 20th century

MGI Commodity Price Index (years 1999–2001 = 100)[1]



1 See the methodology appendix for details of the MGI Commodity Price Index.
2 2011 prices are based on average of the first eight months of 2011.
SOURCE: Grilli and Yang; Stephan Pfaffenzeller; World Bank; International Monetary Fund (IMF); Organisation for Economic Co-operation and Development (OECD); UN Food and Agriculture Organization (FAO); UN Comtrade; McKinsey analysis

40 Prices are in real terms and adjusted for changes in exchange rates. Without exchange-rate adjustments, the fall from 1900 to 1999 was 67 percent rather than 48 percent, due to appreciation of the US dollar relative to other currencies in the 20th century.

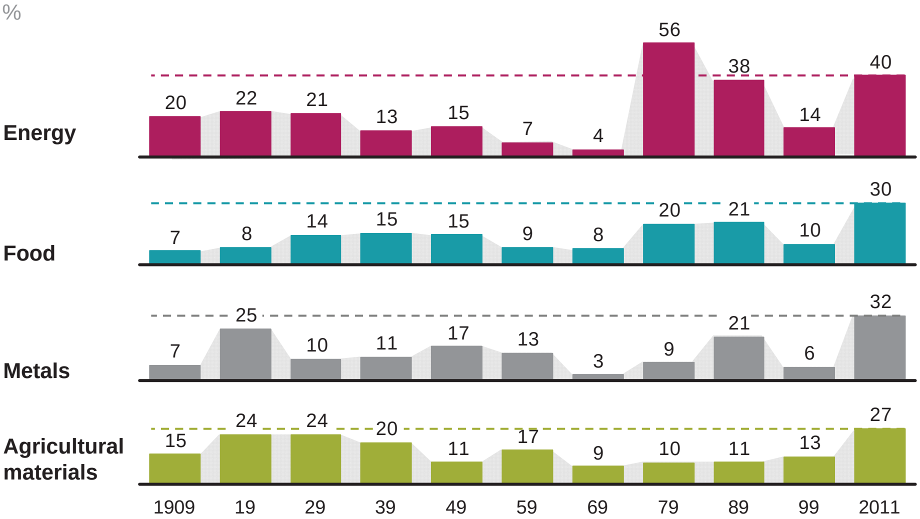
41 The contribution of financial markets and commodity trading to this volatility is disputed. For example, Kenneth Singleton has claimed to have found evidence of a statistically significant effect of investor flows on futures prices of crude oil (see Kenneth J. Singleton, *Investor flows and the 2008 boom/bust in oil prices*, Stanford Graduate School of Business working paper, June 22, 2011). However, the International Energy Agency has recently refuted the role of speculation in shaping oil prices (IEA, *Oil market report*, September 13, 2011). Academic evidence for other resources is also divided on the role of speculation on commodity prices. The Institute for Agriculture and Trade Policy has claimed that speculation has strongly influenced food prices (Institute for Agriculture and Trade Policy, *Commodities market speculation: The risk to food security and agriculture*, November 2008). However, past research by the International Monetary Fund has suggested speculation has played a minimal role in influencing a broad range of commodities, including food prices (International Monetary Fund, “The boom in nonfuel commodity prices: Can it last?” *World economic outlook*, September 2006).

Exhibit 7

Resource price volatility is at an all-time high, with the exception of energy in the 1970s

Annual price volatility[1]

%



1 Calculated as the standard deviation of the commodity subindex divided by the average of the subindex over the period.

SOURCE: Grilli and Yang; Pfaffenzeller; World Bank; IMF; OECD statistics; FAO; UN Comtrade; McKinsey analysis

THE SCALE OF RESOURCE CHALLENGES IN THE NEXT 20 YEARS APPEARS UNPRECEDENTED IN FIVE MAIN WAYS

The rise in resource prices over the past decade has revived debates about resources. Will market-based innovation support the expansion of the global economy at affordable resource prices? Will this be achieved in a way that also recognizes the environmental risks and the increasing scarcity of natural capital? Or is this a fundamental break point in the history of resources? Will there be a new era of high and volatile resource prices in which environmental factors add to that volatility?

The next 20 years seem likely to be quite different from the resource-related shocks that have periodically erupted in history. The challenges are unprecedented in their scale in five main ways:

1. **Up to three billion more middle-class consumers will emerge in the next 20 years.** Incomes, particularly in Asia, are rising on a scale and at a pace that is unprecedented. For example, China's economy is growing ten times as fast as the United Kingdom's economy grew during the Industrial Revolution and with 100 times as many people.

2. **Demand is soaring at a time when finding new sources of supply, and extracting them, is becoming increasingly challenging and expensive.** Demand for many resources today has already moved to the limits of short-run supply curves where supply is increasingly inelastic—in other words, a point at which it is more difficult for supply to react quickly enough to meet rising demand. This means that even small shifts in demand can drive greater volatility.

3. **Resources have increasingly close links.** The correlation between resource prices is now higher than at any point over the past century, and a number of factors are expected to drive a further increase. Local decision makers face increasingly complex trade-offs across energy, land, and water systems as industrial, urban, and agricultural users all compete for the same resources. The impact of this is that shortages and price changes in one resource can rapidly spread to other resources.

4. **The impact of strongly rising demand for resources on the environment could restrict supply.** Increased soil erosion, the excessive extraction of groundwater reserves, ocean acidification, declining fish stocks, deforestation, the unpredictable effects of climate change, and other environmental concerns are creating increasing constraints on the production of resources and broader economic activity. These trends are putting at risk many unpriced ecosystem services (such as coastal protection, watershed management, and renewable energy supplies) that matter to economic activity.

5. **Growing concern about inequality might also require action.** A large share of the global population still lacks access to basic needs such as energy, food, and water. An estimated 1.3 billion people do not have access to electricity, 2.7 billion people still rely on traditional biomass for cooking food, 925 million people remain undernourished, 884 million people lack access to safe water, and 2.5 billion people do not have access to improved sanitation.

We now analyze each of these emerging trends in further detail.

1. UP TO THREE BILLION NEW MIDDLE-CLASS CONSUMERS ARE LIKELY TO DRIVE RESOURCE DEMAND HIGHER

Over the next two decades, we are likely to see up to three billion more middle-class consumers emerge on top of the 1.8 billion today (see Box 1, "The emerging middle class"). Almost 90 percent of the new middle-class consumers will live in the Asia-Pacific region (mainly in China and India). This wave of global citizens with increased spending power is a game-changing development in the global economy. It is a measure of the importance of these economies in the resource landscape that they are expected to account for 90 percent of growth in primary energy over the next two decades.

Box 1. The emerging middle class

Research by the OECD forecasts that the global middle class will increase by three billion people over the next 20 years. The research defines middle class as having daily per capita spending of $10 to $100 in PPP terms.[1] Using a comparable definition of the middle class, MGI's Cityscope database of more than 2,000 metropolitan areas around the world arrives at a similar estimate. There are other definitions of the middle class. For instance, the Asian Development Bank (ADB) uses consumption of $2 to $20 per day in PPP terms.[2] The ADB also projects significant growth in Asia's middle class, but its forecast of an increase of about one billion by 2030 is on a smaller scale given that the ADB has a higher estimate for the number in the middle class today.

We have opted to use the definition of middle class used by the OECD because this more closely aligns with the most resource-intensive period of economic growth where per capita GDP in PPP terms stands between $3,000 and $15,000. The OECD estimates that the global middle class will increase from 1.85 billion in 2009 to 4.88 billion in 2030, with almost 90 percent of growth coming from the Asia-Pacific region. That region's middle-class population is expected to expand from 0.53 billion in 2009 to around 3.23 billion in 2030. In contrast, the OECD envisages that the number of middle-class consumers in Europe and North America in 2030 will remain at similar levels to today.

The OECD forecast has some sensitivities. First, the analysis assumes no change in income distribution. If inequality were to increase, the OECD argues that the size of the middle class would probably expand more rapidly than forecast. Second, the research bases growth assumptions on a classification of countries into four categories that have an overall real growth rate of 4.7 percent per annum in PPP terms.[3] This compares with global growth of just 3.7 percent per annum from 1996 to 2006. The research argues for a growth rate that is higher than historical growth because rapidly growing economies today account for a higher share of global output.

1 Homi Kharas, *The emerging middle class in developing countries*, OECD Development Centre Working Paper No. 285, January 2010.

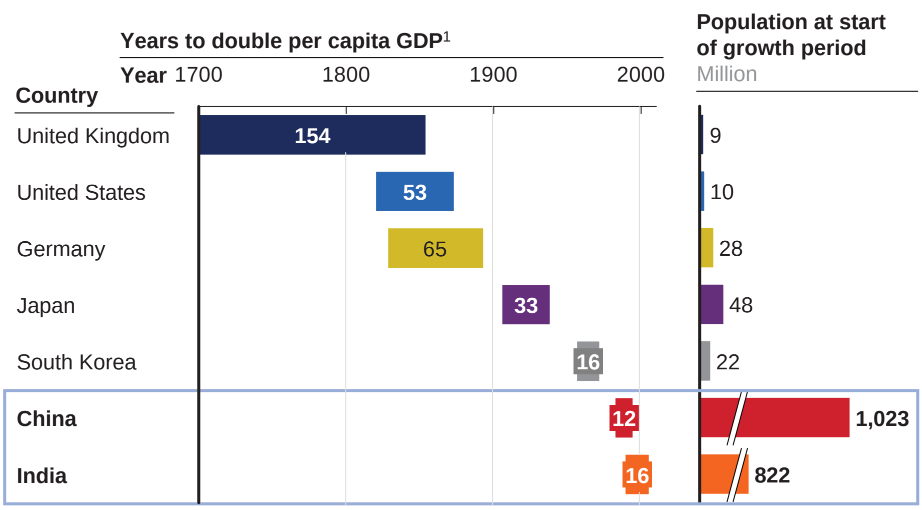
2 *Key indicators for Asia and the Pacific 2010*, Asian Development Bank, 2010.

3 In contrast, we base the estimates of resource demand in this paper on a real GDP growth rate (based on market exchange rates) of 3.4 percent per annum (or roughly 4.1 percent in PPP terms).

The increase in average incomes is happening on an unprecedented scale and at a speed that has never before been witnessed. The pace of real per capita income growth has been increasing as the world economy develops and is happening on a different scale. For instance, the United Kingdom doubled real per capita GDP from $1,300 to $2,600 in PPP terms in 154 years with a population of less than ten million. The United States, starting 120 years later, achieved this feat in 53 years with a population of a little over ten million. In the 20th century, Japan doubled its real per capita income in 33 years with a population of around 50 million. Now China and India, whose combined population today is more than 2.5 billion, are doubling real per capita incomes every 12 and 16 years, respectively. This is about ten times the speed at which the United Kingdom achieved this transformation—and on around 200 times the scale (Exhibit 8).

Exhibit 8

Incomes are rising in developing economies faster—and on a greater scale —than at any previous point in history



1 Time to increase per capita GDP (in PPP terms) from $1,300 to $2,600.
SOURCE: Angus Maddison; University of Groningen; McKinsey analysis

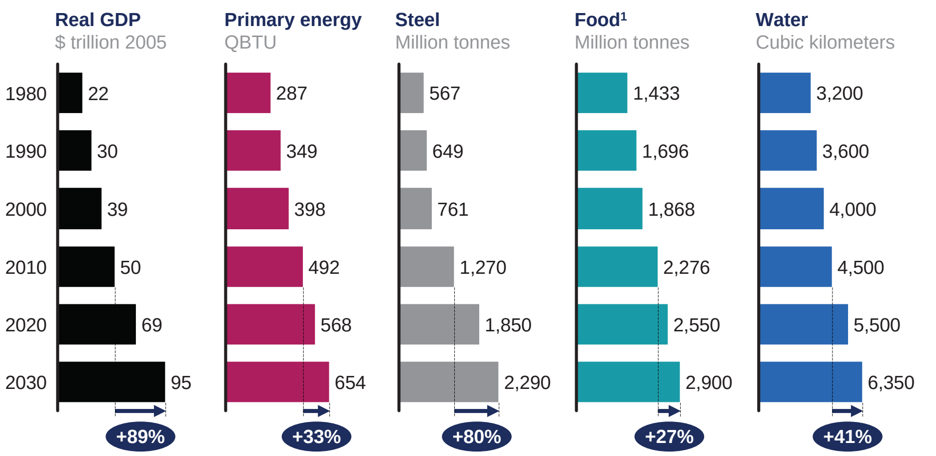
Demand for energy, food, water, and materials (steel) is likely to rise rapidly as these new waves of middle-class consumers emerge (Exhibit 9).[42] By 2030, the global car fleet is expected to roughly double to 1.7 billion. In India, estimates see calorie intake per person rising by 20 percent during this period, while per capita meat consumption in China could increase by 40 percent to 75 kilograms (165 pounds) a year—which would still be less than per capita meat consumption in the United States today. Demand for urban infrastructure is expected to soar. Every year, China is adding floor space totaling 2.5 times the entire residential and commercial square footage of the city of Chicago. India could potentially add floor space equal to another Chicago each year to meet the needs of its urban citizens. Past MGI research has predicted that 136 new cities will enter the top 600 by their contribution to global output by 2025. All of these will be in developing economies, and the vast majority—100 new cities—in China.[43]

42 Given steel's importance to the global economy and its linkages with other resources, we focus on it as a proxy for materials overall (see Box 2, "Why steel matters").

43 For a complete discussion, see *Urban world: Mapping the economic power of cities*, McKinsey Global Institute, March 2011 (www.mckinsey.com/mgi).

Exhibit 9

Demand for most resources has grown strongly since 2000, a trend that is likely to continue to 2030



1 Only cereals.
SOURCE: Global Insight; IEA; UN Environment Program (UNEP); FAO; World Steel Association; McKinsey analysis

Although demand for resources has been growing rapidly over the past decade, today's emerging markets are still in the early stages of their development. This has major implications for future demand for resources. Based on the historical patterns we have noted, China, whose real 2005 per capita GDP in PPP terms stands at around $6,900, and India, whose current per capita income is about $3,000, will continue to drive growth in resources for many years to come.

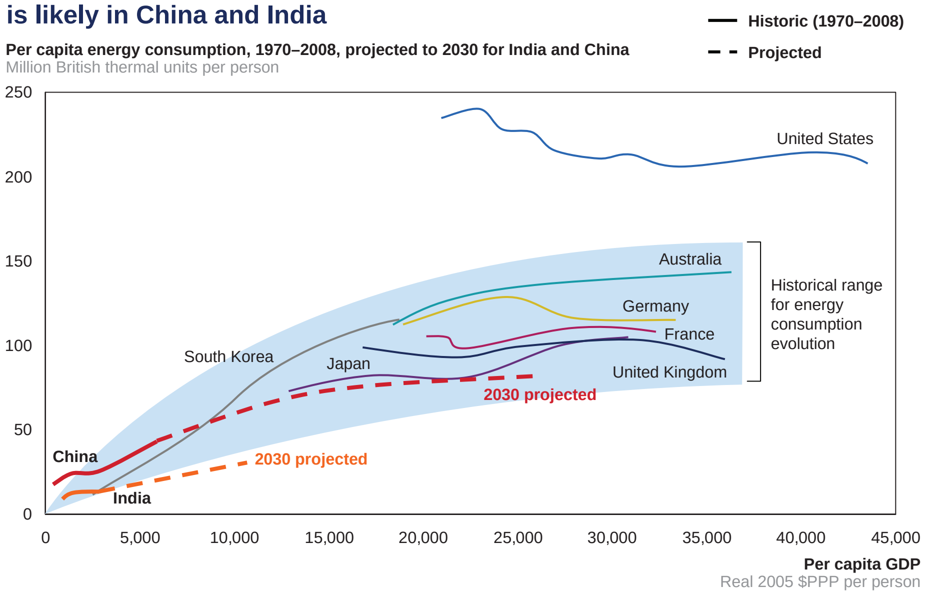
The world's new middle-class consumers are likely to have more resource-efficient levels of consumption than past consumers with the same level of income, largely because of advances in technology. For example, although the global car fleet is expected to double in the next 20 years, our base case assumes that this car fleet will be at a fuel efficiency of close to 6 liters per 100 kilometers compared with current levels of roughly 9 liters per 100 kilometers in the United States. It is important to note that China's resource growth path may be slightly different from global averages because of the heavy presence of exports in the economy, which can lead to more resource-intensive economic development. Despite this, China's overall energy per capita consumption is projected to grow to 2030 levels that are about 10 percent lower than the United Kingdom's energy consumption today and approximately 25 to 35 percent lower than consumption in Germany or Australia when those countries were at a similar stage of economic development (Exhibit 10). Similarly, meat consumption in China is projected to be 75 kilograms per capita. This is 25 to 30 percent lower than consumption in Germany and the United States at similar levels of per capita income.

Exhibit 10

Many countries have shown that as incomes rise, demand for resources increases—and a similar curve is likely in China and India

ENERGY EXAMPLE

Per capita energy consumption, 1970–2008, projected to 2030 for India and China
Million British thermal units per person



SOURCE: IEA; Global Insight; McKinsey analysis

We now review prospects for demand in the four types of resources we highlight. There are significant uncertainties around these prospects. These uncertainties relate especially to overall GDP growth; the income elasticity of resource demand in China and other large, fast-growing developing countries; and the extent to which demand responds to both higher prices and policy action. Each of these drivers has the potential to shift demand by at least 5 to 10 percent within the next 20 years, and therefore each has a significant impact on resource scarcity and the evolution of resource prices. We express demand growth throughout the chapter using an assumption of a global real GDP growth rate of 3.4 percent per annum to 2030 and a population growth rate of approximately 0.9 percent per annum to 2030.[44]

Energy

We project primary energy demand will grow by 33 percent, or 162 QBTU, from 2010 to 2030.[45] To put this in perspective, this additional projected demand for energy is equivalent to the current annual consumption of the United States and European members of the OECD combined. The main driver of this growth is developing economies as their per capita energy consumption converges toward the levels of developed economies. The 162-QBTU growth in demand expected over the next two decades is significantly higher than the 100-QBTU growth in energy demand in the last 20 years of the millennium.

44 We use IHS Global Insight economic and population forecasts. Population forecasts are in line with those from the United Nations. Uncertainty around forecasts are based on changes in fertility and mortality rates. UN estimates vary by 10 percent in 2030 and 30 percent in 2050, based on the difference between the high-variant forecast and low-variant forecast.

45 Our projections for primary energy in 2030 are in line with forecasts in the IEA's *World energy outlook* published in November 2011. At 654 QBTU, our projection falls between the IEA's "new policies" case at 643 QBTU and its "current policies" scenario at around 684 QBTU. See the methodology appendix for a further discussion of the data sources and assumptions used in this analysis.

China and India together are expected to account for 60 percent of the total increase in primary energy growth worldwide. China's industrial and transport sectors are likely to be major contributors to the economy's overall energy consumption. We expect Chinese industry to be the single largest driver of final energy demand growth, accounting for more than 15 percent of the global increase. Within Chinese industry, the chemicals industry is likely to be the most important subsector, accounting for more than half of China's growth in industrial energy demand. Transport, too, could be a major driver of increased demand for energy, given that the number of passenger vehicles in China is expected to increase from around 58 million vehicles today to about 450 million in 2030. If we also include commercial vehicles, this would imply a total vehicle penetration of 375 vehicles per 1,000 people by 2030—roughly in line with Croatia and South Korea today. Industry could also play a significant role in India, accounting for two-thirds of India's increase in primary energy demand and 13 percent of global growth in primary energy demand. Iron and steel could drive nearly 30 percent of the growth in India's industrial energy demand. India's passenger vehicle fleet is expected to remain smaller than China's, although it is still projected to expand significantly from around 15 million vehicles in 2010 to more than 135 million in 2030. This 2030 total is equivalent to the current passenger vehicle fleets of France, Germany, Italy, and the United Kingdom combined.

In developed countries, the energy demand story is quite different. As these economies continue to improve energy productivity and to shift away from manufacturing to services, growth in energy demand could slow. Energy demand in the United States is projected to increase marginally from 2010 to 2030, although there are likely to be shifts across sectors. Road transport is expected to decrease its share of total energy in the United States relative to industry and buildings. Across advanced OECD economies as a whole, we expect primary energy demand to grow at 0.1 to 0.3 percent per annum, on the basis of a projected 2.2 percent average real GDP growth rate.[46]

Global growth in energy demand from 2010 to 2030 assumes significant embedded productivity improvements compared with a scenario that we might call "frozen technology." For example, even the most pessimistic projections for China's energy efficiency put the economy on a much more efficient path than other countries have managed over the past 40 years. There are a number of factors behind China's relatively rapid shift toward energy efficiency. These include concerns about energy security and the fact that China is able to use technologies that are significantly more efficient than those that were available when other countries went through the same phase of development. For example, a refrigerator built in 2000 consumed 70 percent less energy than one built in 1970, and a new car could travel the same distance with 40 percent less fuel (although some of this benefit was "consumed" in heavier, larger cars with more elaborate features). Additional improvements to internal combustion engines (ICEs) in passenger vehicles will unfold over the next decade. A review of policies in major regions, including the European Union (EU), the United States, China, and Japan, suggests a 30 percent improvement in fuel economy by 2030 on a basis of liters per 100 kilometers.

46 Data centers could be a significant driver of future energy consumption. Data center power consumption increased by 56 percent from 2005 to 2010, accounting for 1.1 to 1.5 percent of all electricity use globally. See Jonathan Koomey, *Growth in data center electricity use 2005 to 2010* (Oakland, CA: Analytics Press, August 2011).

There are major, irreducible uncertainties in these projections. Many factors will determine the energy demand of the next 20 years, and even slight differences in key drivers can make a difference. To illustrate, if we were to apply the regional real GDP growth estimates that the US Energy Information Administration (EIA) uses in its energy forecasts—which average 3.0 percent per annum globally—we would arrive at 2030 energy demand of 625 QBTU or 5 percent less than our base-case forecast, even with the same 2010 energy demand and the same assumptions about regional energy intensity.[47]

The largest uncertainty is the rate of growth in energy demand in China. This depends on China's overall economic growth and the energy intensity of its growth path. In most developed countries, per capita energy consumption generally grows consistently until a household's income hits a threshold of $15,000 to $20,000 in PPP terms. Then consumption typically flattens as economies shift from energy-intensive industries such as manufacturing toward less energy-intensive service industries. In developed Asia, for instance, we project primary energy demand growth will grow only slightly, increasing from 37 QBTU in 2010 to 39 QBTU in 2030.[48] This is in marked contrast to the outlook in China.

We project that China's primary energy demand will increase from 99 QBTU in 2010 to 166 QBTU in 2030, growth of 2.6 percent per annum. We base this projection on growth in China's real GDP of 6.8 percent per year.[49] At about 54 million British thermal units (MBTU) per capita in 2010, China's current energy intensity is around the levels seen in South Korea and Singapore in the late 1980s.[50] But we assume that China will reach a per capita energy intensity of 86 MBTU by 2030. That is around the level of South Korea and Singapore in the late 1990s. Incremental world energy demand could swing up to 15 percent depending on a range of plausible published projections of China's future growth rate and energy intensity (i.e., energy inputs per unit of economic output).

Land

We analyze agriculture through the common measure of cropland demand rather than agricultural products for two reasons. First, different types of agriculture require different land intensity. The use of land puts them on a common basis. Second, looking at cropland displays more clearly the linkages with other resources such as energy, carbon, and water. Analyzing land also allows us to discuss the implications for a range of other resources of factors, including crop production, the development of the modern bioenergy sector, deforestation, and land degradation.[51]

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47 *International energy outlook 2011*, US Energy Information Administration, 2011.

48 Developed Asia consists of Japan, Australia, New Zealand, and South Korea.

49 This projection comes from IHS Global Insight. Some economists, including Michael Spence and Barry Eichengreen, argue that China may find it difficult to sustain its fast growth rate as it makes the transition to a middle-income country. See Michael Spence and Sandile Hlatshwayo, *The evolving structure of the American economy and the employment challenge*, Council on Foreign Relations Working Paper, March 2011, and Barry Eichengreen, Donghyun Park, and Kwanho Shin, *When fast growing economies slow down: International evidence and implications for China*, NBER Working Paper No. 16919, March 2011.

50 We base historical per capita energy intensity on final, not primary, energy demand.

51 We do not include pastureland (for grazing), although this is also an area with great opportunity for improving productivity. We consider improving the productivity of pastureland as a lever for reducing carbon emissions and discuss this in Chapter 5.

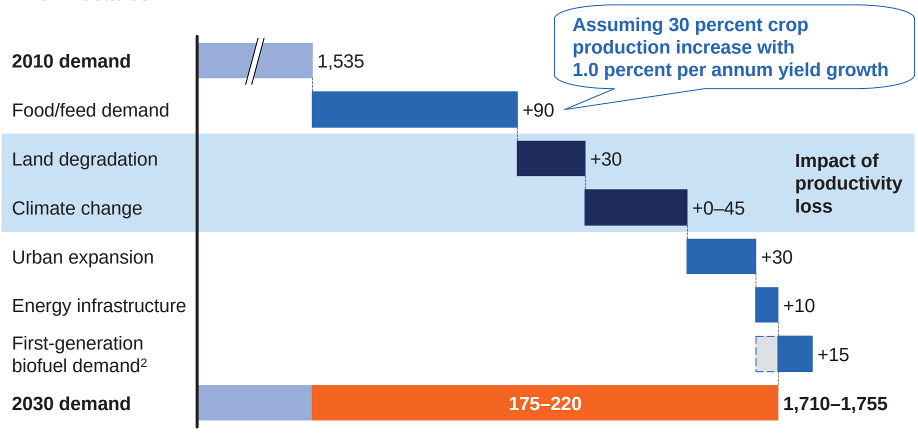
We find that a combination of rising demand for agricultural products and slowing agricultural productivity growth—we assume only 1 percent annual growth in productivity over the next two decades—could mean that there is a need for an additional 175 million to 220 million hectares of cropland from 2010 to 2030.[52] This would be an increase of 10 to 15 percent from today's levels (Exhibit 11). A number of factors could drive demand for cropland higher. These include demand for food and feed; productivity losses due to land degradation, water scarcity, and climate change; the loss of arable land due to the expansion of the world's cities; and the increasing use of biofuels.

Exhibit 11

To meet 2030 food, feed, and fuel demand would require 175 million to 220 million hectares of additional cropland

Base-case cropland demand[1] by 2030

Million hectares



1 Defined as "arable land and permanent crops" by the FAO.
2 As 30–80 percent of biomass input for biofuel production is fed back to livestock feed, the cropland required to produce feed crops would be reduced by about ten million hectares.

SOURCE: International Institute for Applied Systems Analysis (IIASA); FAO; International Food Policy Research Institute; Intergovernmental Panel on Climate Change; Global Land Degradation Assessment; World Bank; McKinsey analysis

- **Food and feed demand.** Meeting food and feed demand could require agricultural products equivalent to an additional 90 million hectares of cropland. A projected 35 percent increase in food demand is expected to come largely from the developing economies of China, India, and other Asian countries, as well as Africa. This strong demand is likely to be driven by increasing calorie consumption, rising populations, and increasing meat consumption, which requires more land per calorie to produce. Using FAO projections, we assume that yields will grow at 1 percent per annum, slower than historical trends.[53]

- **Productivity loss.** The productivity lost due to land degradation and climate change could require an additional 30 million to 75 million hectares by 2030. Serious land degradation affects more than 20 percent of the world's arable

52 Global growth in crop yields has been slowing since the 1970s and is now weaker than population growth. One of the reasons is that many developed countries, which have been driving the global growth of agricultural productivity through R&D and innovation, are now close to the maximum agro-climatically attainable yield—the yield per hectare that the International Institute for Applied Systems Analysis (IIASA) estimates is possible given current technology, rainfall, and soil.

53 Jelle Bruinsma, *The resource outlook to 2050: By how much do land, water and crop yields need to increase by 2050?* Prepared for Food and Agriculture Organization's High-Level Expert Forum on "How to Feed the World 2050," Rome, June 24–26, 2009.

land. There are many causes of such degradation, including the pollution of land and water resources, soil-nutrient mining, and soil salinization.[54] Soil salinization highlights the link between resources. The over-extraction of groundwater leads to a lowering of the water table. In coastal areas, this can allow the intrusion of marine water, causing the salinity of the water table to increase. The severity of the degradation varies, and therefore the extent of yield loss. We account for land degradation by calculating the amount of new cropland needed to compensate for an overall loss of productivity. We estimate this at 30 million hectares. Different studies offer a wide range of estimates for the impact of climate change on agricultural yields, from a loss of 27 percent to an increase of 22 percent by 2050. Varied assumptions on carbon dioxide fertilization are a major source of disagreement in these estimates.[55] In view of the wide range of estimates, we make a conservative, median assumption of a zero to 2 percent negative impact on yields by 2030. This could result in additional demand for cropland of as much as 45 million hectares.[56]

- **Urban expansion.** The global phenomenon of urbanization could encroach on an additional 30 million hectares of cropland. Urbanization could lead to the loss of an estimated two million hectares per year, with about three-quarters of that being agricultural land.[57]

- **Energy (biofuels and energy infrastructure).** Energy drives higher demand for land. Breaking that down into its constituent parts, we find that biofuels could be responsible for two-thirds of the energy impact on land demand, and other energy sources the remaining one-third. Biofuels could require the equivalent of an additional 15 million hectares of land by 2030.[58] We assume that demand for first-generation biofuels doubles over the next 20 years, led by demand in the United States and Brazil. These and other countries and regions have set targets to substitute crude oil with biofuels, often supported

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54 *The economics of desertification, land degradation, and drought: Toward an integrated assessment*, International Food Policy Research Institute, 2011.

55 Carbon dioxide fertilization describes the effect that increased concentration of carbon dioxide in the atmosphere has on crop yields. Its effect is debated across different sources where some claim it will have a positive effect while others cite recent studies that show the effect to be minimal due to other limiting constraints (such as nitrogen and phosphorous availability). See Gerald C. Nelson, et al., *Climate change: Impact on agriculture and costs of adaptation*, International Food Policy Research Institute, 2009, and Christoph Müller, et al., *Climate change impacts on agricultural yields*, Potsdam Institute for Climate Impact Research, 2010.

56 A 2 percent reduction in yields assumes that any gains improving climates in certain areas or increased fertilization are more than offset by worsening climates (e.g., higher volatility in rainfall, higher temperatures) globally. The global reduction of crop production caused by loss of productivity will need to be supplemented by production from areas with future potential for cropland expansion, as many of the current agricultural commons have extremely low potential for such expansion (e.g., in the United States, the EU, and East and South Asia). Because around 90 percent of future cropland expansion is projected to take place in Latin America and sub-Saharan Africa, whose yields will be about 35 percent lower than the global average, the world will require 15 million more hectares than the zero to 30 million hectares it needs to make up because of lost productivity from climate change.

57 Shlomo Angel, Stephen C. Sheppard, and Daniel L. Civco, *The dynamics of global urban expansion*, World Bank, September 2005.

58 The land directly put into production to grow the crops for biofuels would be around 25 million hectares as 30 to 80 percent of biomass input for biofuel production is fed back to livestock feed. However, there will also be an impact of reducing the cropland required to produce feed crops by about ten million hectares.

by large producer subsidies.[59] Our base case assumes that biofuel demand increases from about 110 billion liters in 2010 to around 350 billion liters by 2030. Of this, we project that about 30 percent will comprise demand for second-generation biofuels—we assume that production after 2020 will be second-generation biofuels. This incremental demand for second-generation biofuels would require an additional 15 million hectares of land for growing the required feedstock including switch grass and popular. However, we assume that demand for second-generation biofuels does not encroach on cropland.[60] Other energy sources, such as the construction of dams, could require an additional ten million hectares of cropland. In combination with demand for biofuels, we estimate that energy will account for more than 10 percent of incremental demand for cropland in 2030.

We have based these projections on a range of assumptions. In our base case, we project that yields will rise by 1 percent a year from 2010 to 2030. However, if that rate were to be only 0.8 percent, an additional 55 million hectares of land would be required. If second-generation biofuels do not become economically viable because of their slower commercialization and their lower relative competitiveness compared with first-generation biofuels, the land area needed to meet demand for transport fuels would increase by 30 million hectares above the 15 million we have projected. Dietary trends could also have an impact on demand for cropland. For example, if China's per capita meat consumption, which is projected to be 75 kilograms a year, were to reach the current level in the United States of around 120 kilograms a year, an additional 60 million hectares of cropland would be needed in 2030.

Water

We expect that demand to withdraw water will increase from 4,500 billion cubic meters in 2010 to 6,350 billion cubic meters in 2030.[61] Increased agricultural output is likely to account for 65 percent of incremental demand, growth in water-intensive industries an additional 25 percent, and municipal demand the remaining 10 percent. Agricultural demand will be most intense in India and sub-Saharan Africa, while China will account for the greatest growth in industrial use. We expect food consumption in India and Africa to grow by 1.3 percent per year due to the addition of 1.4 billion people to their populations by 2030, and increasing per capita incomes to drive higher consumption of meat as well as an increasing overall calorie intake. In China, the power sector alone will account

59 We expect cropland dedicated to biofuels to increase from 42 million hectares in 2010 to 69 million hectares in 2030. However, given that around 40 percent of biomass produced for biofuel production is returned to the feed system, the incremental land required for biofuels is reduced by around 11 million hectares.

60 We assume that 50 percent of second-generation biofuel production comes from residues, and the rest from crops, including switchgrass, grown on non-cropland.

61 We measure demand for water in two ways: withdrawal and consumption. Water withdrawal is actual water abstracted for agricultural, industrial, or municipal use. However, there are return flows—some of the water withdrawn flows back to the basin and could be available for downstream use. Water consumption refers to withdrawals adjusted for return flows. We expect water withdrawal to be 6,900 billion cubic meters in 2030 if we assume that productivity is frozen—see *Charting our water future: Economic frameworks to inform decision-making*, 2030 Water Resources Group, 2009. In our base case, with growth in yields and productivity of about 1 percent per year and crop-per-drop improving at a slightly slower rate of 0.8 percent per year, demand is expected to be somewhat lower at 6,350 billion cubic meters. This number is sensitive to the assumptions we make on climate change, population, yield growth, and meat consumption in Asia.

for 30 percent of the country's growing water use. We expect manufacturing and textiles to account for 15 percent and 10 percent, respectively. The impact of climate change on water demand and supply is a major uncertainty—lower-than-expected crop yields caused by irregular rainfall and deteriorating soil conditions could widen the water gap. By 2030, more than half of the world's population could live in regions that suffer from water scarcity.[62]

Materials

Given steel's importance to the global economy and its linkages with other resources, we use it as a proxy for materials overall (see Box 2, "Why steel matters"). We expect demand for steel to increase by about 80 percent from 1,270 million tonnes in 2010 to 2,290 million tonnes in 2030, primarily driven by increasing demand from China, India, and other emerging markets. Three sectors could account for 80 percent of the global growth in steel demand. The construction sector could generate 50 percent of global steel demand growth, with demand driven by urbanization. For instance, we project that 750 million more people could be living in the cities of China and India in 2030 than today. Floor space per capita is likely to rise as incomes increase, and steel intensity will probably increase as more high-rises are built. The machinery and engineering sector could account for around 20 percent of global demand growth as the industrial sectors of emerging markets, particularly China, expand. Finally, the transport sector could be responsible for around 10 percent of global growth in the demand for steel, reflecting the increasing penetration of cars in emerging markets.

Our estimates include some major uncertainties. The biggest of these relates to the rate of growth of steel demand in China, which will depend on the economy's GDP growth and the steel intensity of that growth. We find that incremental global steel demand could increase by up to 22 percent depending on our assumptions.

Box 2. Why steel matters

Large numbers of non-energy basic materials are produced today. To understand which could have the greatest implications for the global economy, we used two broad criteria—the potential for shortage of the resource, and the impact of a shortage on the global economic system (Exhibit 12). We assessed the potential for shortage using four sub-criteria: the number of years of proven reserves (at the 2010 production level); the potential for short-term supply shortages, as indicated by historical price volatility; geographical-concentration risk (measured by the share of reserves in the top ten countries); and the degree to which the resource is recyclable. We also used four sub-criteria for our assessment of the impact of any shortage: global market size; the availability of substitutes; the importance for the production process (i.e., the degree to which a resource is a critical input in industrial or agricultural production process compared with using it as a store of value or for luxury consumption as is the case with gold); and linkages with other resources such as energy and agriculture (e.g., potash and phosphate are critical inputs in the production of fertilizers that support agricultural development).

62 The United Nations estimates that 50 percent of the world's population is water-stressed, while the 2030 Water Resources Group's estimate is 60 percent.

(Why steel matters)

We evaluated a range of major materials including iron ore, coking coal, copper, gold, aluminum, zinc, nickel, silver, platinum group metals, lead, tin, rare earth, phosphate, and potash. We chose steel (including iron ore and coking coal) to analyze despite the fact that there is no long-term shortage of either iron ore or coking coal. Our reason was that coking coal may face short-term supply constraints and therefore have a critical influence on the world economy. The steel sector accounts for 40 percent of the global market for non-energy minerals by value and more than 80 percent by volume. Steel also has strong linkages with other resources. Its production accounts for about 5 percent of energy demand, for example.

Exhibit 12

Potential shortages of materials and the possible economic impact determined our focus on steel

Minimal concern
Some concern
Major cause for concern

	Potential for shortage				Impact of shortage			
Criteria	Reserves (based on USGS)	Short-term shortages	Geographic concen-tration risk	Recycla-bility	Global market size[1]	Lack of substitutes	Contribu-tion to production process	Resource linkages with energy/food
Unit	Number of years (2010 production)	Historical price volatility 2004–09; standard deviation/mean %	Low/medium/high risk	Recycling rate, United States %	2010, $ billion	Low/medium/high risk	Low/medium/high risk	Low/medium/high risk
Iron ore	75	30	Low	61	206	High	High	High
Coking coal	<50	34	Medium	Low	151	Medium	High	High
Copper	39	30	Medium	32	144	Medium	High	Medium
Gold	20	40	Low	High	104	Medium	Low	Low
Bauxite/Al[2]	133	18	High	48	72	Medium	High	Medium
Zinc	21	45	Low	30	28	Low	High	Low
Nickel	49	42	Low	43	29	Low	High	Low
Silver	23	29	Low	Medium	14	Low	Medium	Low
Platinum GM[3]	174	24	Medium	High	14	High	Medium	Low
Lead	20	30	Low	77	20	Medium	High	Low
Tin	20	24	Medium	34	7	Low	High	Low
Rare earth	846	42	High	Medium	11[4]	High	High	High
Phosphate	406	62	High	Low	21	High	High	High
Potash	283	68	Medium	Low	18	High	High	High

1 Wherever possible, market size represents finished/refined metal, e.g., market size is for aluminum metal and not alumina or bauxite.
2 Data for reserves and geographic risk pertain to ores (in this case, bauxite). Other data pertain to refined metal (in this case, aluminum).
3 Platinum group metals includes ruthenium, rhodium, palladium, osmium, iridium, and platinum and are grouped together because of their similar physical and chemical properties as well as tendency to occur together in the same mineral deposits.
4 Rare earth market size was only $1 billion in 2009 but has spiked to $11 billion in 2011.

SOURCE: US Geological Survey (USGS); McKinsey analysis

2. EXPANDING THE SUPPLY OF RESOURCES COULD BE INCREASINGLY DIFFICULT

Expanding supply to keep pace with rising demand looks increasingly difficult. According to our analysis, there may not be intrinsic shortages in many resources, and the risk of shortages has proved to be an effective catalyst for innovation (see Box 3, "Historical examples of scarcity-induced innovation"). However, supply now seems increasingly inelastic in the short term—it is more difficult for supply to react quickly enough to meet rising demand. Accessing resources is increasingly problematic; excess capacity and inventories are declining; and there are technical limits on the speed at which the types of productivity improvements that apply to supply can be improved. On top of this is evidence that the long-run marginal costs of many resources are increasing. With the likely exception of natural gas, new supply is located in lower-productivity locations that are more difficult to access.

We discuss the supply challenge in more detail in Chapter 3, but we provide an overview here. There are significant uncertainties in our analysis of supply. These relate to the potential for new discoveries, such as shale gas, the speed with which new technologies scale up and diffuse, and policy action. In addition, especially in the case of food, there are other swings that are hard to quantify but that could be large. These swings could result from changes in weather and rainfall patterns as well as from other ecological risk factors such as an accelerated collapse in key fish stocks.

Box 3. Historical examples of scarcity-induced innovation

Examples abound of innovation to find substitute resources in the face of pressing resource shortages. For example, in the early to mid-19th century, whale oil was the principal source of fuel for lighting. Demand led to the rapid depletion of whales, and the price increased from $200 a barrel in 1823 to almost $1,500 in 1855.[1] In response to the higher price, people started to experiment with alternatives. In 1849, Canadian geologist Abraham Gesner distilled bituminous tar to produce a different form of oil that was cheaper and more abundant, and his invention—kerosene—quickly replaced whale oil. Charcoal, made by burning wood, is another example. Because of its heavy use in Western Europe (and Britain in particular) in shipbuilding and because of the clearance of forestland for agriculture, charcoal had become scarce by the 17th century. Its price rose, and this led to a search for alternatives such as coal, which came into general use in Britain in the 18th century.[2]

In agriculture, natural fertilizers such as guano and nitrate deposits had largely been exhausted by the end of 19th century. Again, this led to a search for alternatives. In the early 20th century, German chemist Fritz Haber developed a method for harnessing the atmospheric abundance of nitrogen to create ammonia, which was then oxidized to make the nitrates and nitrites used in the production of nitrate fertilizer. Superphosphates, made from sulfuric acid and powdered phosphate rock, were also developed and quickly replaced earlier fertilizers. During World War II, the production of natural rubber fell by 90 percent because of the Japanese invasion of Malaysia and Indonesia at a time when demand was high for military purposes.[3] This catalyzed the development of synthetic rubbers. In the United States, the government subsidized the necessary R&D, and synthetic rubber soon became the material of choice because of its superior resistance to extreme temperatures.

1 Ugo Bardi, *Prices and production over a complete Hubbert cycle: The case of the American whale fisheries in 19th century*, Association for the Study of Peak Oil and Gas, November 2004.

2 Robert U. Ayres, *Resources, scarcity, growth and the environment*, Center for the Management of Environmental Resources, INSEAD, April 2001.

3 Paul Wendt, “The control of rubber in World War II,” *The Southern Economic Journal*, 13(3): 203–27, January 1947.

Energy

There is no absolute shortage of energy today. Proven conventional oil reserves could hold at least 45 years of production capacity at average demand between 2010 and 2030. When we add in recoverable unconventional reserves such as tar sands, this capacity grows to 55 years. In addition, more than 300 years of untapped potential exists in unconventional resources that are currently uneconomical to recover. In the case of gas, known conventional natural gas deposits represent 50 years of current demand. Moreover, an estimated 180 years of readily accessible unconventional sources remain to be tapped, as the recent discoveries and development of shale gas reserves in the United States illustrate. Rapid learning-curve effects in these gas resources have made them competitive with conventional drilling.[63] Coal also remains abundant with more than 110 years of estimated remaining reserves at average 2010 to 2030 consumption levels. Our energy base case assumes that the power mix remains fairly constant.[64] The case assumes that coal's share of power generation rises slightly from 40 percent today to 43 percent in 2030, that the share of gas remains fairly constant at just over 20 percent, and that the wind and solar shares of power generation slightly increase. We project that the shares of oil, hydropower, and nuclear will decrease.

However, there are several supply issues. Delivering marginal oil capacity will become increasingly expensive over the next 20 years, with oil sands and gas-to-liquids technology likely to be the marginal sources of supply. In the short term, supply also appears to be progressively less able to adjust rapidly to changes in demand because the level of spare capacity is lower and therefore producers can't respond as quickly to price changes. Sources of new supply are more challenging to access. This inelasticity can cause even more volatility in prices. As the quality of reserves deteriorates, production is shifting to more complex sources of supply, including tar sands and deepwater oil. This not only increases the risk of disruptions to supply but also makes supply even more inelastic. Deepwater offshore oil projects accounted for 24 percent of offshore oil wells in 2009, an increase from 19 percent in 2005.[65]

Longer-term supply costs may also be increasing. Some oil projects are becoming smaller and more expensive. The average real cost of bringing a new well on line doubled from 2000 to 2010—a cost increase of more than 7 percent per annum.[66] According to the IEA, increasing costs have been driven by soaring costs of drilling and oil-field services, skilled labor, materials, and energy, as well as a shift in spending toward more technically complex projects

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63 Learning-curve effects describe the reduced costs obtained by scaling up the installed capacity of a given technology. Figures are typically reported as a percentage reduction in unit costs from a doubling of capacity.

64 We base our energy base case on internal McKinsey estimates of energy consumption over the next 20 years. Our assumptions on energy policies generally rest on current policies. Specifically, we base our assumptions about the evolution in transport fuel efficiency on recent policy reviews of legislation in Europe, the United States, China, and Japan expected to start in 2015 to 2016. We assume that there is no global carbon price between 2010 and 2030, which leads to the relatively stable penetration of fossil fuels in the power sector technology mix in our base case. See the methodology appendix for further details.

65 Colin P. Fenton and Jonah Waxman, "Fundamentals or fads? Pipes, not punting, explain commodity prices and volatility," J. P. Morgan Global Commodities Research, *Commodity markets outlook and strategy*, August 2011.

66 IHS/CERA Upstream Capital Costs Index (UCCI), Cambridge Energy Research Associates, May 2011.

such as deepwater fields and smaller fields, where unit costs tend to be higher.[67] These factors have more than offset the reduction in costs due to technology improvements that helped lower costs in the 1990s. The situation for gas appears to be significantly more favorable. Substantial large-scale gas reserves have been discovered, and the cost of unconventional extraction methods such as shale gas has fallen. But significant uncertainty remains as to the degree to which technological advancements that improve cost efficiency can offset the rising costs associated with the decreasing quality of reserves. Indeed, while the doubling of upstream costs of 2000 to 2010 may be partly explained by an increase in input costs, Wood Mackenzie data on new oil and gas projects to 2015 suggest that real capital investment per barrel should continue to increase at a rate of 2 percent per annum.[68]

Across clean energy technologies, a doubling of installed capacity leads to unit cost reductions of around 20 percent for solar photovoltaic (PV) and around 10 percent for onshore and offshore wind, according to a 2007 review of historical technological improvement rates.[69] These improvements are roughly in line with learning curves in traditional manufacturing applications. It is likely that the medium-term yield performance of clean energy technologies will continue to improve substantially on the back of improved production engineering and technology (e.g., software/hardware integration that allows for much greater energy capture). However, supply-chain bottlenecks such as the availability of rare earth metals needed for turbines could potentially have a short-term impact on the rates of cost reduction in alternative technologies.

Environmental protection and action to ensure the safety of workers are also driving production costs higher. Extractive technologies have an impact on the environment from carbon emissions to water pollution. However, today's energy costs do not currently reflect many of these secondary effects. One recent report found that if the social and environmental costs associated with coal in the United States were added to the actual cost of coal, the coal price would rise by 175 percent from 3.2 cents per kilowatt hour to 8.8 cents. For new coal plants, adding in the unpriced environmental costs of coal boosts the price of coal from 6.2 cents per kilowatt hour to 9.6 cents. This makes coal more expensive in some locations than adding new capacity for wind, and that's before factoring in any cost of the carbon emissions produced. Including the carbon externality of coal, calculated at $30 per tonne, would increase the cost of coal-fired power to 12.1 cents per kilowatt hour.[70]

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67 *World energy outlook 2008*, International Energy Agency, November 2008.

68 Wood Mackenzie oil production database.

69 Tooraj Jamasb and Jonathan Köhler, "Learning curves for energy technology: A critical assessment," in Michael Grubb, Tooraj Jamasb, and Michael G. Pollitt, eds., *Delivering a low carbon electricity system: Technologies, economics and policy* (Cambridge, UK: Cambridge University Press, 2008).

70 Michael Greenstone and Adam Looney, *A strategy for America's energy future: Illuminating energy's full costs*, The Hamilton Project, Brookings Institution, May 2011. Note that the costs of coal-fired carbon have been adjusted up from $22.5 per tonne to $30.

Land

Overall, growing demand for agricultural products implies that 40 to 50 percent of all the remaining land available for agriculture needs to be brought into play.[71] Much of that land would come from developing countries with low levels of infrastructure in sub-Saharan Africa and Latin America, which could increase the cost of supply significantly. It is also likely that, in a scenario of high food prices and often uncertain property rights for land access, the easiest way to meet the extra demand for land in developing countries (where populations are growing fastest) would be through further deforestation. This would result in additional carbon emissions and potentially increase the rate at which biodiversity is lost. Deforestation could also adversely affect the almost one billion people whose livelihoods depend directly or indirectly on the forest ecosystem.

Water

Increasing water supply is likely to be costly and difficult. Sources of freshwater are already under stress. Lakes are drying up in many parts of the world. Rivers such as the Colorado in the United States and the Yellow River in China often dry up before they reach the ocean because of overconsumption of their water. Water pollution has also rendered a portion of surface water unusable. For example, 21 percent of available surface water in China is unfit for agriculture.[72] In addition, groundwater aquifers have declined as their depletion rate has accelerated from 150 cubic kilometers per year in 1960 to 340 cubic kilometers in 2000.

Measures to produce bulk water supply face a steep marginal cost curve. Surface and groundwater are relatively cheap sources of supply. In India, the costs are roughly 3 to 6 cents per cubic meter.[73] However, providing additional supplies from unconventional sources such as desalination and the harvesting of rainwater could be more than ten times as costly. Exacerbating the challenge of finding sufficient supplies of water to meet demand is the fact that water is a local product that cannot be traded easily between regions that have a surplus or a deficit. Water shortages are usually a highly specific local problem affecting areas within a country or even an individual water basin. Any rise in unconventional sources of water supply, which may be necessary in some regions, is likely to come at a significantly higher cost. Historical government expenditure for upstream water supply has been between $40 billion and $45 billion per annum, excluding distribution. However, as demand outstrips cheaper forms of supply, this bill could increase to around $200 billion a year by 2030. As this burden grows, governments are likely to give more serious consideration to ways of more fully recovering the cost of water.

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71 The quantification of remaining agricultural land is uncertain and lacks a common definition. For our work, we use the definition by the World Bank and the International Institute for Applied Systems Analysis, which estimate that the world still has 450 million hectares of "available"—uncultivated, unforested, and productive—land.

72 *Charting our water future: Economic frameworks to inform decision-making*, 2030 Water Resources Group, 2009. The 2030 Water Resources Group was formed in 2008 and comprises the International Finance Corporation, McKinsey & Company, and an extended business consortium including The Barilla Group, The Coca-Cola Company, Nestle S.A, SABMiller plc, New Holland Agriculture, Standard Chartered Bank, and Syngenta AG.

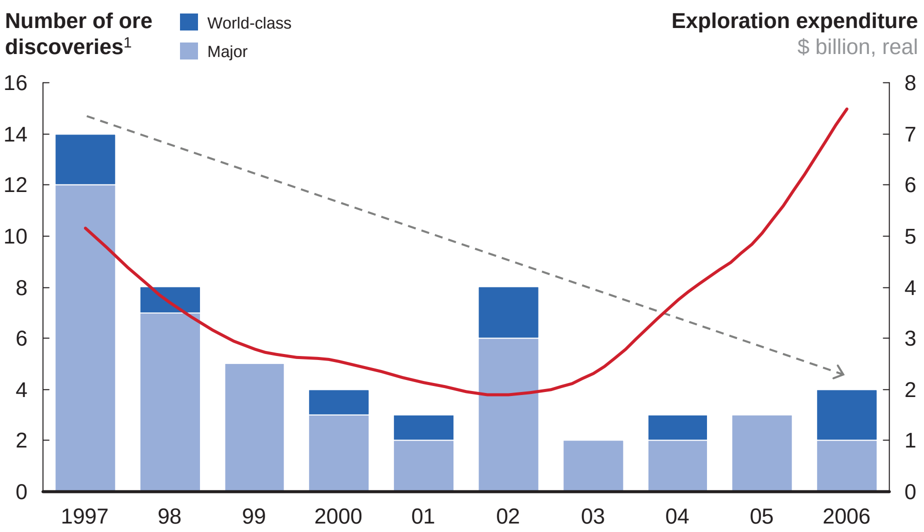
73 *Charting our water future: Economic frameworks to inform decision-making*, 2030 Water Resources Group, 2009.

Materials

Although there are no imminent shortages in most mineral reserves and resources, including iron ore and coking coal, both key inputs into steel, the mining capacity for the extraction of these resources has been under pressure over the past decade. Increased demand for iron ore and coking coal has led to margins shifting upstream in the steel value chain. Iron ore and coking coal represented only 22 percent of the profit pool in 2000, but that share had increased to 65 percent by 2008. Despite sufficient reserves of iron ore globally to meet future demand, the failure of mining capacity to keep pace with increasing demand may keep margins high. Furthermore, there are medium-term concerns about the mining capacity of coking coal. Spending on exploration had increased prior to the financial crisis, but discoveries of major ore reserves have been declining because easy sources of supply have already been tapped (Exhibit 13). There are also indications that long-term production costs for materials across the board are increasing. Shortages in some kinds of mineral resources, such as rare earths, have been a concern in recent times (see Box 4, "Not-so-rare earths").

Exhibit 13

Replenishing reserves of materials is increasingly difficult and expensive



1 All metal and mining materials; latest data available to 2006.

SOURCE: BHP Billiton; USGS; MEG Minerals 2009

Box 4. Not-so-rare earths

Rare earths are 17 chemical elements: 15 lanthanides plus scandium and yttrium. A number of manufactured products need these elements. The automotive sector uses rare earths as powerful permanent magnets in lightweight electric motors and in rechargeable batteries for hybrid and electric cars. Other users of rare earths include color television and flat-panel display makers, chemical refineries, power generators for wind turbines, and equipment and machinery makers who need these minerals for numerous optical, medical, and military devices. Overall demand for rare earths is expected to rise in line with global GDP growth from 135 kilotonnes per annum in 2008 to 200 kilotonnes in 2015. China is responsible for about 97 percent of the global production of rare earths but has cut its export quota by half from 60 kilotonnes per annum in 2007 to only 30 kilotonnes in 2010. Rare earths may be abundant in nature, but getting new mining projects into production can take up to a decade. Only three or four non-Chinese projects are likely to come onstream before 2015. Even if all these projects come to fruition within that timescale, the market will still rely on China to expand supplies. Supply shortages have led to a sharp spike in prices—expanding the value of this market from about $1 billion in 2009 to an estimated $11 billion in 2011.

The United States, Japan, and Germany have reacted to worries by making significant investment in supply. Today, the recycling rate of rare earth is very low (e.g., only 1 percent in Germany), but this can be improved. For example, Japan is treating recycling as a key strategy for bridging the gap between demand for rare earths and their supply and has earmarked ¥42 billion (roughly $550 million) for the development of rare earth recycling. Veolia Environmental Services is planning to extract precious metals such as palladium from road dust in London.[1] New discoveries are being expedited. Japanese researchers have found very large deposits of rare earths under the ocean, but it may take a decade to start extraction. As prices rise, there is likely to be more investment in finding substitutes and in productivity opportunities. Although shortages will persist in the short to medium term, the availability of rare earths should become a less pressing concern over the longer term as new projects come onstream.

1 "Waste management: Veolia to extract platinum and palladium from street sweepings." *scrap-ex News*, September 28, 2011.

3. STRONG LINKAGES BETWEEN RESOURCES AND GLOBAL MARKETS WILL COMPOUND THE IMPACT OF RESOURCE CONSTRAINTS

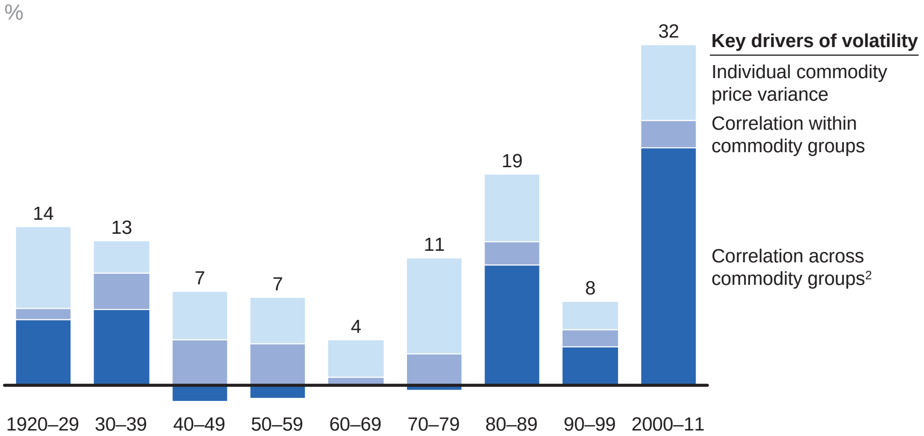
The prices and the volatility of different resources have displayed an increasingly close correlation over the past three decades. That correlation between commodity baskets in MGI's commodities index is now higher than at any point over the past century (Exhibit 14). This means that exogenous shocks in one part of the resource system can transmit rapidly to other parts of the system.

Exhibit 14

Tighter correlation across commodities has been key in driving volatility higher than at any time over the past century

Annual standard deviation (relative to mean) of MGI Commodity Price Index and key drivers[1]

%



1 Drivers of commodity index volatility determined by covariance analysis at commodity index and commodity subindex level based on annual changes in prices. See the methodology appendix for further details.
2 Energy, metals, agricultural raw materials, and food.

SOURCE: Grilli and Yang; Pfaffenzeller; World Bank; IMF; OECD; FAO; UN Comtrade; McKinsey analysis

Correlated demand across resources is a partial cause of the increased linkages that we observe. However, three important additional factors are driving new links between resources.

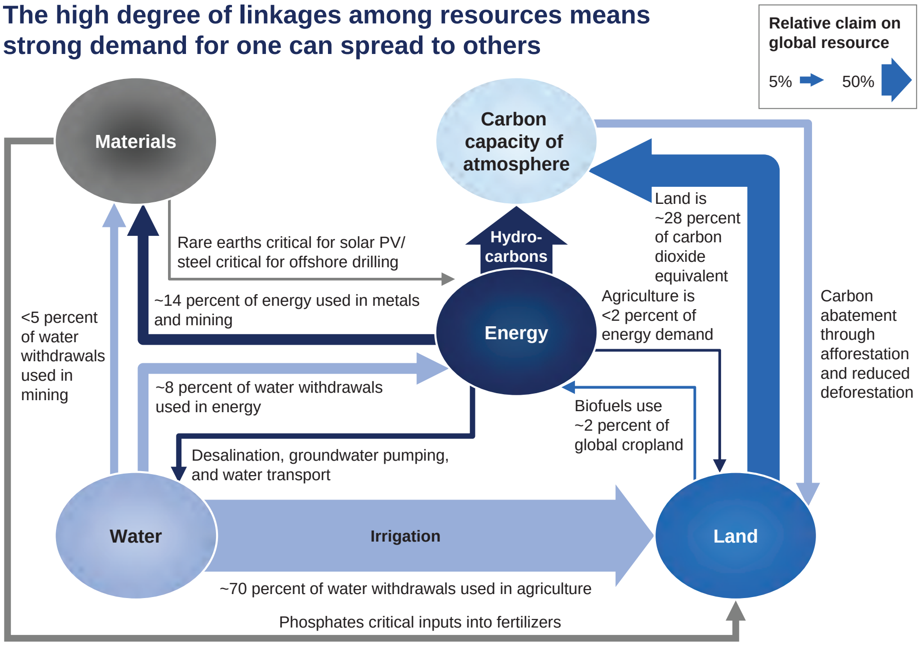
Resources represent a substantial proportion of inputs to other resources. There are strong linkages in the volume of demand for different resources (Exhibit 15). For example, agriculture accounts for close to 70 percent of the use of water worldwide and around 2 percent of global energy demand. These shares can be significantly higher in some cases. India, for instance, uses up to 20 percent of its electricity for irrigation, much of it subsidized as a result of diesel subsidies on generators used for the extraction of groundwater. In California, the water sector consumes 19 percent of the state's electricity and 30 percent of its natural gas.[74] Energy accounts for about 8 percent of global water withdrawal, and biofuels represent around 2 percent of (mostly prime) cropland. Mineral resources such as rare earth metals and iron ore are critical inputs for energy technologies from solar PV to offshore oil, as well as for agricultural fertilizers.

74 *Roadmap to a resource efficient Europe*, European Commission staff working paper, September 20, 2011.

Energy is a particularly important part of the cost of producing resources as a whole because it constitutes a substantial share of the cost of other resources. Energy accounts for 15 to 30 percent of the cost of crop production,[75] 25 to 40 percent of the cost of steel, roughly 70 percent of the cost of groundwater, and 50 to 75 percent of the cost of freshwater produced through desalination. These linkages would be even stronger if resources were sold at market prices. Most parts of the world do not price agricultural water, for example. If water attracted an average global market price of 10 cents per cubic meter, water would account for an estimated 20 to 40 percent of the cost of major cereals and meat. Rice, which is water-intensive, is a special case in which water can account for up to 75 percent of the total cost. Water is also a key input in mining and the generation of thermal power, accounting for 8 to 13 percent of the cost. More importantly, the availability—or lack of availability—of water is becoming a bottleneck for mining and power operations. Shortages have led to shutdowns or lower production in several instances in China, South Africa, India, Chile, and elsewhere.

Exhibit 15

The high degree of linkages among resources means strong demand for one can spread to others



SOURCE: McKinsey analysis

Over time, improving productivity has somewhat reduced the volume intensity of most of these linkages. The exceptions are the energy intensity of water production and the water intensity of the production of liquid transport fuel. In the United States, for instance, the energy intensity of steel has declined by 66 percent since 1950 as production has shifted to more efficient means. Similarly, global growth in yields over the past 50 years has outpaced the expansion of land under irrigation, and this has reduced the global drop-per-crop by 30 percent.

However, except in the case of lower natural gas prices that support lower fertilizer prices in some regions, recent price increases have more than offset such improvements in intensity and resulted in stronger linkages between any

75 Randy Schnepf, *Energy use in agriculture: Background and issues*, Congressional Research Service, 2004.

one commodity price and the cost of producing other resources. We find that future changes in prices and production processes could continue to compound these linkages. For example, if carbon had a price of $30 per tonne, linkages would be tighter as products produced or transported with carbon-intensive energy would have a higher share of energy in total costs. The energy intensity of water has been rising as the groundwater table has lowered and the share of desalination and wastewater and mega-projects for the surface transfer of water has increased. Unconventional energy sources are expected to require more inputs such as steel. Industry data show that unconventional methods such as horizontal drilling use more than four times as much steel as traditional vertical drilling.[76] Uganda illustrates how water constraints can affect both agricultural yields and energy production. Water shortages, partly related to demand from power generation, resulted in escalating energy prices and more demand for wood fuels to substitute for the more expensive electricity. This led to an increase in deforestation and soil degradation that, in turn, threatened food supply (see Box 5, "The negative multiplier: The case of Uganda").

Box 5. The negative multiplier: The case of Uganda

In Uganda, reduced water resources caused by climate change have set off a damaging chain reaction.[1] After the extreme and prolonged drought of 2004 and 2005, Lake Victoria's water level dropped by one meter in 2006. This reflected not only evaporation and low rainfall but also the fact that so much water had been removed from the lake to fuel the generation of electric power at the Owen Falls dam. With less water available for Owen Falls, Uganda was forced to ration power for both industrial and domestic use. This has had a negative impact on the entire economy. To meet electricity demand, the government started using expensive thermal power. Electricity tariffs per unit of domestic consumption nearly doubled from 216 shillings to 426 shillings ($0.13 to $0.25). Higher electricity prices have increased pressure on forest resources. Around 95 percent of Ugandan households use wood fuel to meet at least some of their energy needs, and exorbitant power tariffs only heightened the population's dependence on tree and forest products for fuel. Even urban households that had tended to use electricity for cooking have reverted to wood fuel. Demand for wood fuel has outstripped supply, and the prices of charcoal and wood fuel have rocketed. The heavy cutting of forests, coupled with unsustainable slash-and-burn practices, has contributed to the degradation of land and soil, leading to poor yields on food crops and threatening Uganda's food security.

1 Fred Kafeero, "The impact of water shortage on forest resources—The case of Uganda," *Unasylva* 58(229): 38, 2007.

- **Technological advances and the growing scarcity of resources increasingly result in substitution between resources.** Such substitution results in closer links between the prices of resources. The most prevalent example of this is biofuels, where higher energy prices can encourage the use of land for energy production. In the past, the prices of maize and oil had a negative correlation. However, since the fall of 2007, there has been a very

76 Colin P. Fenton and Jonah Waxman, "Fundamentals or fads? Pipes, not punting, explain commodity prices and volatility," J. P. Morgan Global Commodities Research, *Commodity markets outlook and strategy*, August 2011.

strong positive correlation between the two. A driver of this significant change is likely to be the fact that the ethanol industry has become the marginal user of corn.[77] This creates a link between the break-even prices of ethanol and realized corn prices.[78] There are other instances. Higher oil prices have driven up the prices of synthetic products such as rubber and nylon fibers. These products have, in turn, put upward pressure on the prices of their natural counterparts in natural rubber and cotton.[79] Similarly, energy costs drive approximately 50 to 75 percent of the cost of desalination.

- **Global markets are increasingly linked.** Historically, the links between international markets have been less close than they are today and the correlation between prices between different parts of the world less tight. Today, much closer links mean that changes in the price of a particular resource in one part of the world ripple out quickly to corresponding price increases elsewhere.[80] For example, local market factors have historically set gas prices. But as the global market for liquefied natural gas develops alongside an expanding cross-border pipeline network, arbitrage opportunities and changes in the contracting structure of the market could lead to greater price convergence. Similarly, if China were to become a larger net importer of coal (or any other major resource category), it would lead not only to cross-border price arbitrage but also to changes in market conduct and price-setting mechanisms.

4. THE IMPACT OF STRONGLY RISING DEMAND FOR RESOURCES ON THE ENVIRONMENT COULD RESTRICT SUPPLY

Damage to the environment, itself driven by growing demand for resources, could constrain growth in the supply of resources. This impact of the environment on supply is another reason that the current resource challenge could be harder to address than resource-related shocks of the past.

Recent research highlighted nine interlinked "planetary boundaries"—thresholds that, if crossed by human beings, present significant risk to the resilience of the world's social and economic structures, especially for the most vulnerable

77 Bruce Babcock, "How low will corn prices go?" *Iowa Ag Review*: 14(4), 2008.

78 This does not mean that prices in corn would not have increased in the absence of biofuels. Other market pressures such as weather and increased demand for meat also have put upward pressure on prices. However, when biofuels are the marginal user of corn, increases in ethanol prices can increase the price that this marginal user will pay for corn. For more information see Bruce Babcock, *The impact of US biofuel policies on agricultural price levels and volatility,* International Center for Trade and Sustainable Development, 2011.

79 Josef Schmidhuber, *Impact of an increased biomass use on agricultural markets, prices and food security: A longer-term perspective*, paper presented at the International Symposium of Notre Europe, Paris, November 2006.

80 For example, in Indonesia, the World Bank found that over a period of about one year, a 1 percent increase in world prices leads, on average, to a 1 percent increase in domestic prices. See Enrique Aldaz-Carroll, *Boom, bust, and up again? Evolution, drivers, and impact of commodity prices: Implications for Indonesia*, World Bank Working Paper No. 58831, December 2010.

communities, and could potentially destabilize the wider ecosystem.[81] Three of these thresholds are greenhouse gas emissions that induce climate change, rates of biodiversity loss, and interference with the global phosphorus and nitrogen cycles.

- **Greenhouse gas emissions.** Our base case projects that greenhouse gas emissions could reach 66 gigatonnes of carbon dioxide equivalent by 2030. This could lead to an increase in global average temperatures by more than five degrees Celsius by the end of the century.[82] There is a great deal of uncertainty about both the potential impact of these carbon emissions on temperature increases and the impact of these temperature increases on economic and environmental outcomes. However, there is evidence that, even within the next 20 years, some of the most vulnerable regions of the world could begin to feel the effects of a changing climate. A recent study by the Economics of Climate Adaptation Working Group suggests that some regions are at risk of losing 1 to 12 percent of their annual GDP by 2030 as a result of existing climate patterns and that this impact could more than double in some cases under "high-change" climate scenarios.[83] Possible effects range from increasingly severe droughts that reduce agricultural productivity, have a damaging effect on health, and compromise power generation capacity, through to rising wind speeds and sea levels increasing the risk of hurricanes. In India's Maharashtra state, for instance, climate change could cause an increased frequency and severity of drought that could undermine agricultural productivity at a cost of as much as $570 million annually by 2030. In the United States, higher wind speeds and sea level increases could cost the southern Florida counties of Miami-Dade, Broward, and Palm Beach $33 billion a year by 2030. In Tanzania, drought could increase incidence of diseases such as cholera and dysentery and increase levels of malnutrition. And because Tanzania relies on hydropower for 50 percent of its energy capacity, power generation could be put at risk and cost the economy as much as $1.3 billion, or 1.7 percent of its GDP.

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81 The nine planetary boundaries are the stratospheric ozone layer; biodiversity; chemical dispersion; climate change; ocean acidification; freshwater consumption and the global hydrological cycle; land system change; nitrogen and phosphorous inputs to the biosphere and oceans; and atmospheric aerosol loading. For more detail, see Johan Rockström, et al., "Planetary boundaries: Exploring the safe operating space for humanity," *Ecology and Society* 14(2): 32, 2009.

82 *The emissions gap report: Are the Copenhagen Accord measures sufficient to limit global warming to 2 degrees Celsius or 1.5 degrees Celsius? A preliminary assessment*, UN Environment Program, November 2010. The actual temperature rises from increased greenhouse gas emissions are uncertain. The five-degree increase represents a likely outcome.

83 *Shaping climate-resilient development: A framework for decision-making*, Economics of Climate Adaptation Working Group, 2009. High-change scenarios are based on the outer range of the 2030 climate change considered possible by existing studies and experts.

- **Loss of biodiversity.** Biodiversity includes the genetic variation within species, the variety of species in an area, and the range of habitat types within a landscape. Because the value of such diversity is hard to price, markets don't reflect its true benefits. A TEEB study estimates that 11 percent of the world's remaining natural areas could be lost by 2050, with agricultural conversion being a major cause. The impact of this loss would not be limited to losing carbon storage and some species in the world's ecosystem. Biodiversity provides significant benefits that are difficult to quantify. One example is health care. The pharmaceutical industry makes heavy use of biodiversity. Of all the anti-cancer drugs available today, 42 percent are natural and 34 percent are semi-natural. In addition, three-quarters of the global population depends on natural traditional remedies.[84] In total, TEEB values the impact of lost biodiversity at €50 billion ($69 billion) annually between 2000 and 2005. We note that roughly $10 billion a year is spent globally on biodiversity conservation.[85]

- **Interference with the global phosphorus and nitrogen cycles.** Increased nitrogen and phosphorus consumption has potentially negative effects on the environment and human health.[86] The increased use of fertilizer in agriculture has been a primary driver of the increased use of phosphorus and nitrogen around the world. In practice, crops actually absorb less than 50 percent of the nitrogen that is applied, and a significant portion runs off into water and evaporates to air. The European Nitrogen Assessment identifies five key societal areas threatened by nitrogen fertilizers: water quality, air quality, greenhouse balance, ecosystems and biodiversity, and soil quality.[87] Water pollution by nitrogen causes eutrophication and acidification in freshwaters. Phosphorous is also a major source of eutrophication of freshwater ecosystems (see Box 6, "Future challenges in phosphorous"). High nitrate concentrations in drinking water could pose a significant danger for human health. Air pollution by nitrogen oxides and ammonia not only increases the level of chemicals that can cause respiratory problems and cancers for humans but can also damage crops and vegetation. Increasing concentrations of nitrous oxide have potentially considerable implications for global warming. One tonne of nitrous oxide in the air has the same effect as roughly 300 tonnes of carbon dioxide over a 100-year time frame. Furthermore, atmospheric nitrogen deposition may encourage certain plants to outcompete sensitive species, leading to biodiversity issues. Finally, nitrogen can induce soil acidification—potentially reducing the growth of forests—and a loss of soil biodiversity.

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84 Daniel J. Newman and Gordon M. Cragg, "Natural products as sources of new drugs over the last 25 years," *Journal of Natural Products* 70(3): 461–77, March 2007.

85 D. W. Pearce, "Do we really care about biodiversity?" *Environmental and Resource Economics* 37(1): 313–33, May 2007.

86 Johan Rockström, et al., "Planetary boundaries: Exploring the safe operating space for humanity," *Ecology and Society* 14(2): 32, 2009.

87 Mark A. Sutton, et al., eds., *The European nitrogen assessment: Sources, effects and policy perspectives* (Cambridge, UK: Cambridge University Press, 2011).

Box 6. Future challenges in phosphorous

Phosphorous is an important global element for agricultural production. In the case of plants, phosphorous plays multiple roles in plant health, including photosynthesis, the construction of DNA and RNA (structures of DNA and RNA are linked together by phosphorous bonds), and as a key component of adenosine triphosphate (ATP), the energy-carrying molecule. Phosphorous deficiency in plants leads to reduced leaf size and root growth, the lower utilization of carbohydrates, and, ultimately, lower yields. Phosphorous is also essential to humans. It makes up roughly 1 percent of average body weight and is a key component in bone health. Importantly, unlike many other elements, phosphorous has no known substitutes.[1]

Current global reserves of phosphate (the naturally occurring form of phosphorous mined for fertilizer production) would last more than 400 years at current levels of production. However, there are three issues relevant to the availability of this resource. First, historical underinvestment in phosphate extraction capacity coupled with the long lead times typical in expanding production means that there is likely to be shortfall in the production of phosphate over the next few years. Second, approximately 80 percent of global phosphate reserves are located in and around Morocco. Outside that country, current reserves will last only about 100 years at current rates of consumption and less than 50 years if consumption increases at 2 percent per annum (in line with historic growth rates from 2000 to 2010).[2] If additional reserves are not found within a relatively short period, Morocco would have a dominant position in the global phosphate market. Third, there is some debate about "peak phosphorous." If indeed phosphate reserves have peaked, this would suggest that the annual global output of phosphate could eventually begin to decline well before total reserves are exhausted. Regardless of a potential decline, it is clear that the use of phosphate is growing more quickly than the ability to replenish recoverable reserves.

Given these challenges, it is important to improve the productivity of phosphorus use. Improving the efficiency of fertilizer use, reducing food waste, and recycling phosphorous from waste and wastewater streams are three of the leading ways to improve the productivity of phosphorous. Due to excess fertilization, phosphorous in fertilizers that is not taken up by plants can flow into local water systems. This runoff causes eutrophication, or blooms, in the number of phytoplankton in a body of water, leading to depletion of water oxygen levels, and that in turn reduces fish and other marine life populations. Improved timing and quantities of fertilizer application can reduce this waste. Waste of food from the farm to fork similarly wastes phosphorous (see the discussion on food waste in Chapter 4 for more detail). Finally, opportunities exist to recycle phosphorous in both waste and wastewater streams. The United Kingdom, Canada, and Japan already have such recovery plants in operation.[3]

1 "Functions of phosphorus in plants," *Better Crops* 83(1): 6–7, 1999.

2 Jeremy Grantham, "Resource limitations 2: Separating the dangerous from the merely serious," *GMO Quarterly Letter*, July 2011.

3 *Phosphates, the only recyclable detergent ingredient*, European Center for the Study of Polyphosphates, July 2007.

5. MORE THAN ONE BILLION CONSUMERS DON'T HAVE ACCESS TO BASIC ENERGY, FOOD, AND WATER NEEDS

A large share of the global population still lacks access to basic needs such as energy, food, and water. An estimated 1.3 billion people lack access to electricity, and 2.7 billion people still rely on traditional biomass for cooking food. Global awareness of energy access has been growing thanks to reports by international agencies such as the IEA and the Secretary-General's Advisory Group on Energy and Climate Change. The FAO and the United Nations World Food Program have estimated that the number of undernourished people in 2010 was 925 million (98 million down from 1.023 billion in 2009).[88] Water shortages also have a dramatic effect on basic welfare. Roughly 884 million people lack access to safe water, and 2.5 billion people lack access to improved sanitation.[89] Nearly 3.6 million people die each year from water-related disease.[90] Concern is growing that such a large share of the global population lacks access to basic needs such as energy, water, and food. We discuss the challenge associated with providing universal access to energy in further detail in Chapter 5.

These five trends could pose risks to economic growth, welfare, geopolitical concerns, and public finances.

The conjunction of rising demand, difficulties in expanding supply, increasingly tight links between resources, the potential for environmental damage to constrain demand, and catering to the needs of one billion consumers who don't have access to modern energy services today poses a risk to economic growth, welfare, resource security, and public finances. Economic and political tensions between countries could increase.

- **Economic growth.** Rising commodity prices increase the input cost of manufacturers and reduce the discretionary consumption of households in commodity-importing countries. The price inflation linked to these higher commodity prices could also trigger a rise in interest rates as central banks seek to maintain official inflation targets. The risk then is that tighter monetary policy could further dampen short-run growth in these countries. Globally, higher expenditure in commodity-exporting countries is unlikely to fully offset the impact of these cuts in aggregate demand in net resource-importing countries, and this could have a negative impact on short-run global economic growth. For example, recent McKinsey macroeconomic analysis has estimated that if the price of crude oil were to rise to $125 or $150 a barrel and stay there for years rather than months, global growth could fall by 0.6 to 0.9 percentage points in the first year.[91] High prices are one issue; their volatility is another. Higher volatility in resource prices can potentially dampen long-run economic growth by increasing uncertainty that may discourage businesses from investing or prompt them to delay investment, and increase the costs of hedging against resource-related risks. Some past economic research has found that volatility has a stronger impact on the relationship between the oil

88 *The state of food insecurity in the world: Addressing food insecurity in protracted crises*, Food and Agriculture Organization of the United Nations, 2010.

89 *Progress on drinking water and sanitation: Special focus on sanitation*, World Health Organization and the United Nations Children's Fund, 2008.

90 *Safer water, better health: Costs, benefits and sustainability of interventions to protect and promote health*, World Health Organization, 2008.

91 Jonathan Ablett, Lowell Bryan, and Sven Smit, "Anticipating economic headwinds," *McKinsey Quarterly*, November 2011.

price and industrial output than does the price itself.[92] One research report found that the volatility of commodity prices can have a negative impact on resource-exporting countries, resulting in a slower accumulation of physical capital.[93] Concerns about resource security (see upcoming text) may also lead to export restrictions, creating trade-related risks.

The impact on countries, and on sectors, will vary significantly depending on their relative endowments of resources and the stage of their economic development. A 2005 report found that a volatility measure constructed using daily crude oil futures prices had a significant negative effect on future GDP growth in the United States from 1984 to 2004.[94] In 2010, China consumed 9.1 million barrels of oil per day and generated $3.7 trillion in GDP in 2005 dollars (or 2.4 million barrels of oil per day per trillion dollars). At this rate, China's economy is actually more oil-intensive than the US economy was from 1984 to 2004. In those years, US intensity fell from 2.4 million barrels of oil per day per trillion dollars to 1.7 million barrels. Such evidence justifies concerns about China's exposure to volatility in oil prices.

- **Welfare and civil unrest.** While rising resource prices may benefit large-scale farmers, higher prices generally hit the poor disproportionately hard. Lower-income households spend a larger share of their income on energy and food. For example, the rural poor in India spend around 61 percent of their expenditure on food and 12 percent on energy.[95] Even for the new middle class, the share of income dedicated to food and energy is substantial. At $10 per day in PPP terms, 35 percent of expenditure goes toward food and at least 10 percent toward energy.[96] An increase in food and energy costs of just 20 percent implies a 16 percent reduction in remaining income for other goods and services. The World Bank has estimated that recent increases in food prices have driven 44 million people into poverty—defined as earning less than $1.25 a day. Many academic studies have linked sudden food price hikes to civil unrest. An International Monetary Fund (IMF) study covering 120 countries from 1970 to 2007 shows that increased food prices in poor countries led to increased incidence of anti-government demonstrations, riots, and civil conflict. In contrast, the impact of increases in food prices in wealthier nations was negligible, not least because prices for more processed foods are only partially linked to the underlying cost of resources.[97] In 2007 and 2008, price increases triggered food protests and riots in 48 countries, and food price increases have also been the spark for some of the civil unrest seen in 2011.

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92 J. Peter Federer, "Oil price volatility and the macro economy," *Journal of Macroeconomics* 18(1): 1–26, 1996.

93 Tiago V. de V. Cavalcanti, Kamiar Mohaddes, and Mehdi Raissi, *Commodity price volatility and the sources of growth*, University of Cambridge Working Paper No. 1112, January 2011.

94 Hui Guo and Kevin L. Kliesen, "Oil price volatility and U.S. macroeconomic activity," *Federal Reserve Bank of St. Louis Review*, November/December 2005, 87(6): 669–83.

95 India is used as a proxy. For more information, see *Household consumer expenditure in India, 2006–07*, National Sample Survey Organization, Government of India, 2008.

96 *Key indicators of household consumer expenditure in India, 2009–10,* National Sample Survey Organization, Government of India, 2011.

97 Rabah Arezki and Markus Brückner, *Food prices and political instability*, International Monetary Fund Working Paper No. 11/62, March 2011.

- **Concerns about resource security.** Many countries rely heavily on imported resources. They are likely to have rising concerns about the security of supply of these resources. For instance, about 80 percent of Asia-Pacific and European oil demand could be met from imports by 2030, according to Chatham House.[98] From October 2010 to April 2011, China, India, Vietnam, and other countries imposed at least 30 new export curbs on mineral resources, up from 25 during the previous 12 months, according to the WTO. The fact that a large share of reserves of key resources is in relatively high-risk countries—whether from an infrastructural or political standpoint—only compounds worries about the security of resource supply. It is a measure of these concerns that governments are playing an increasingly active role in securing access to resources. For example, cross-border purchases of land account for around 15 percent of remaining arable land worldwide. A number of the critical minerals for renewable energy technologies, notably rare earth metals, are also facing concerns over the security of supply.[99] The risk is that resource nationalism becomes self-fueling, and that concerns about the security of supply translate into increased protectionism, less integrated resource markets, and therefore increased uncertainty over price volatility and supply.

- **Public finances.** Rising demand for resources—and their prices—could place additional pressure on state finances, particularly in developing countries. Governments are currently subsidizing the consumption of resources by up to $1.1 trillion, depending on the resource (Exhibit 16).[100] At least eight countries (Egypt, Iran, Iraq, Kuwait, Saudi Arabia, Turkmenistan, the United Arab Emirates, and Uzbekistan) commit 5 percent or more of their GDP to energy subsidies. In Iran, for instance, energy subsidies totaled $101 billion in 2008—one-third of the country's annual central budget. Contrast this with global subsidies for renewable energy, which Bloomberg New Energy Finance estimates at $43 billion to $46 billion.[101]

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98 John V. Mitchell, *More for Asia: Rebalancing world oil and gas*, Chatham House, December 2010.

99 For a discussion of potential geopolitical concerns around key mineral inputs for renewable energy technologies, see Bernice Lee, "Managing the interlocking resources challenges in a globalized world," *Review of Policy Research* 28(5): 509–15, September 2011. See Box 4 for a discussion of rare earth metals.

100 This excludes the cost of unpriced externalities such as carbon and the impact on ecosystems. Based on 2005 emissions of 45.9 gigatonnes of carbon dioxide equivalent and a carbon price ranging from $20 to $30, this implies an annual "subsidy" of $900 to $1,400. The Economics of Ecosystems and Biodiversity's 2010 report estimates the annual cost associated with biodiversity loss and ecosystem degradation at $2 trillion to $4.5 trillion in 2008, while Trucost estimates it to be $6.6 trillion.

101 This total includes the cost of feed-in-tariffs, renewable energy credits or certificates, tax credits, cash grants, and other direct subsidies. For further information see *Subsidies for renewables, biofuels dwarfed by supports for fossil fuels*, Bloomberg New Energy Finance, press release, July 29, 2010.

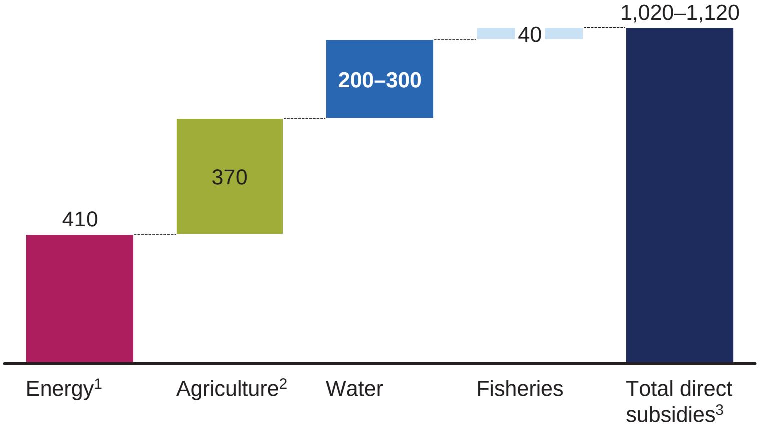
Exhibit 16

Direct subsidies of up to $1.1 trillion per year have supported resource prices

ESTIMATE

Annual subsidies for key resources

$ billion



1 Includes fossil-fuel consumption in power production; excludes subsidies on alternative energy.
2 Estimated as OECD plus Brazil, China, Russia, South Africa, and Ukraine; total support estimates less market price supports.
3 Excludes unpriced externalities such as carbon emissions and ecosystem impact.

SOURCE: OECD; IEA; UNEP; Global Water Institute; McKinsey analysis

□ □ □

The resource challenge could be severe because of five factors occurring at the same time. Demand for resources is likely to grow strongly due to an increase of three billion middle-class consumers in the global economy. This injection of demand comes at a time when expanding supply appears to be getting more complex and costly. Compounding this challenging demand and supply picture is the fact that resources are increasingly closely linked, posing the risk of increased volatility and the rapid transmission of shocks from one resource to others around the world. On top of this, the potential for environmental damage due to untrammeled demand for resources could create harmful spillover effects on the global economy and on the welfare of citizens. Last, more than one billion consumers today do not have access to basic energy, food, and water needs—catering to them could add another layer of complexity to the resource challenge.

Experience has shown that new waves of innovation develop and that shifts in society's behavior occur precisely during periods when resource prices put consumers, businesses, and the global economy under stress. But what might be done now to engineer the change needed to meet rising demand for resources without further increasing environmental risk? In the next three chapters, we will explore options in three illustrative scenarios—supply expansion, productivity response, and climate response.

3. The supply challenge

If investment in supply remained at historical levels and productivity growth improved only in line with our base case, there would be a notional gap between supply and demand in 2030 of 15 to 80 percent across the four key resources we discuss. In this chapter we offer our first illustrative scenario—a supply expansion case in which supply rises above our base case sufficiently to meet projected demand for resources with productivity growing in line with our base case. We analyze the required supply increases to meeting 2030 projected demand and the challenges this could face. Our main findings include:

- Meeting projected resource demand would require historically unprecedented increases in supply. Water and land could present the largest challenges on the supply side. We estimate that the annual pace for supply additions over the next 20 years would have to be almost triple the rate at which it expanded over the past two decades.
- There are significant opportunities to expand supply in an efficient and cost-effective way—think of the recent breakthroughs in unconventional gas. But the fact remains that rapid growth in supply can involve significant capital, infrastructure, and geopolitical risks and can have a negative impact on the environment.

Meeting future demand would require historically unprecedented increases in supply

It would be possible simply to invest only as much as necessary to meet rising demand for resources and compensate for the accelerating depletion of current supply. However, doing so—without a step change in resource productivity—would mean an unprecedented increase in supply additions in absolute terms.

We stress that, although we call this scenario a supply expansion case, it does include some productivity improvements that reflect current policy approaches, expected advances in business technology such as higher fuel economy, and the trajectory of economic development. We do not, however, include any incremental productivity opportunities beyond these (see Box 7, "Productivity improvements in our base case"). We do not allow for dynamic feedback loops in which prices would be likely to rise in response to higher demand, helping to pay for the increased investment but also potentially having a dampening effect on demand growth.

Box 7. Productivity improvements in our base case

Our base-case assumptions allow for productivity improvements that are consistent with current policy approaches and projected economic development. For example, in agriculture, we expect yields per hectare to improve at 1 percent per annum. This is consistent with FAO projections but lower than historical yield growth over the past five decades of 1.7 percent. In water, we assume that agricultural water productivity—crop-per-drop—will increase at 0.8 percent per annum. This is in line with the historical trend in water withdrawal required for agricultural production.[1] We assume that the productivity of the use of water by industry—water withdrawals relative to the economic output of these sectors measured by gross dollar value added—improves at around 0.5 percent per annum. We have also built into our base case a certain amount of productivity improvement in energy. In transport, for example, we assume that the fuel economy of the average new passenger vehicle will increase from 33 miles per gallon today to 48 miles per gallon in 2030, reflecting current policy and technological improvements.

Beyond these productivity improvements, rapid changes will occur in the economic structure of many economies as they increasingly develop less resource-intensive service sectors. To arrive at a sense of the size of this impact, consider how much higher resource demand would be if resource intensity (i.e., inputs relative to economic output) were frozen at 2010 levels and the global economy grew at the rates we assume. In the case of energy, 2030 demand would be 50 percent higher than our base-case demand. Under the same set of assumptions, 2000 energy demand would have been roughly 60 percent higher if energy intensity was at the same level as in 1980.

1 This is not the same as growth in agricultural yields because of changes in land under irrigation and the water required to cultivate a unit of land.

Water and land are the resources where the need for additional supply is likely to be the greatest. We estimate that supply would need to be 140 percent and up to 250 percent higher, respectively, over the next 20 years than it has been over the past 20 (Exhibit 17).

The supply of water needs to expand to meet increasing demand and to ensure accessible, sustainable, and reliable provision.[102] We forecast that water supply over the next 20 years would need to be almost 140 percent higher than the past 20 years. The two main drivers of this are historic underinvestment in supply and accelerated growth in water withdrawals. Water withdrawals are likely to increase by more than 40 percent between now and 2030. Increased agricultural output would account for 65 percent of incremental demand (we expect water withdrawals for the purposes of agriculture to increase by 30 percent due to expanded and more intensive irrigation), growth in water-intensive industries an additional 25 percent, and municipal demand the remaining 10 percent. In

102 By reliable, we assume that existing supply can be provided with 90 percent reliability, an estimate that we base on historical hydrology and infrastructure investment scheduled through 2010, net of environmental requirements. For more information see *Charting our water future: Economic frameworks to inform decision-making,* 2030 Water Resources Group, 2009.

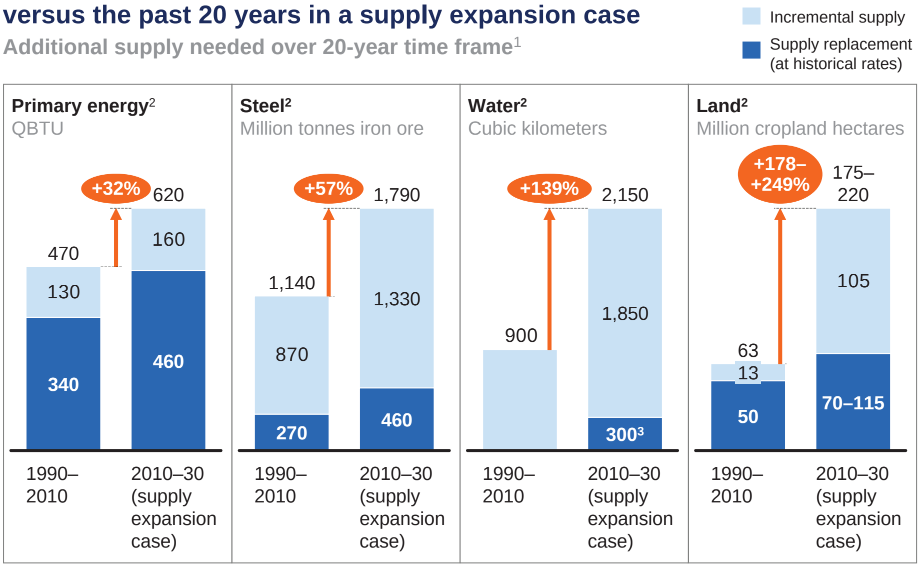
addition, water supply would need to increase by a further 300 cubic kilometers, or 7 percent of global withdrawals in 2010, to ensure accessible, sustainable, reliable supply.

In land, if we assume base-case yield improvements, the supply of cropland over the next 20 years may need to increase by as much as 250 percent relative to the past 20 years. This is due to demand for food and feed, a declining rate of growth in yields, and the use of biofuels increasing incremental land demand by 105 million hectares over the next 20 years. At the same time, land degradation, climate change, and the loss of arable land due to the expansion of the world's cities could remove 70 to 115 million hectares of cropland from production over the next 20 years.

Exhibit 17

Additional supply would have to accelerate by up to 250 percent versus the past 20 years in a supply expansion case

Additional supply needed over 20-year time frame[1]



1 Calculated as incremental supply plus replacement rate; does not tie to total demand.
2 See the methodology appendix for details of our assumptions for all four resource groups.
3 Water supply will need to increase by a further 300 cubic kilometers to meet accessible, sustainable, reliable supply.
SOURCE: McKinsey analysis

In the case of oil, a large share of the new production that is necessary between 2010 and 2030 is due to the depletion of existing wells. Peter Voser, chief executive officer of Shell, recently stated that the equivalent of "four Saudi Arabias or ten North Seas over the next ten years" needs to be added just to replace declining production and to keep oil output flat.[103]

Our base-case assumption for gas is that demand will increase by 30 percent over the next 20 years, in line with the 2010 IEA's "current policies" scenario.[104] Total primary energy demand for natural gas is projected to grow from 112 trillion cubic feet in 2010 to 141 trillion cubic feet, remaining roughly stable at 22 percent of total energy demand. Within power, we assume that gas maintains a similar share of 21 percent with a 50 percent increase in total production capacity over the next 20 years. Given recent developments in shale gas, we believe that these assumptions are conservative. We assume in our supply expansion base case a price of $10 per MBTU in the United States and $14 per MBTU in Europe in 2030.

103 "Rush is on to develop smarter power," *Financial Times* Special Report, September 29, 2011.

104 *World energy outlook 2010*, International Energy Agency, November 2010.

We expect renewable energy capacity including hydropower to increase by nearly 85 percent between now and 2030. However, renewable energy's share of total power generation is expected to increase by only three percentage points from 20 percent today to 23 percent in 2030 due to an expected 45 percent increase in overall power capacity and the higher intermittency of renewable energy sources compared with other forms of energy.[105] Within renewables, we expect wind to increase its share of power generation the quickest, from 1.5 percent today to around 5 percent in 2030; installed capacity is likely to increase by almost 400 percent. We see solar power increasing its share of power generation from 0.1 percent today to 1 percent in 2030, a 12-fold increase in generation and an eightfold increase in total capacity. However, we anticipate that the share of hydropower in power generation will fall from 17 percent today to 14 percent in 2030, despite its absolute generation growing by 30 percent.

Expanding supply sufficiently to meet projected resource demand faces many challenges

Expanding supply at the rapid rate that is necessary faces many challenges. For example, investment would need to increase significantly in absolute terms from past levels, at a time when access to capital may prove increasingly challenging. Past MGI research has examined past and future trends in saving, investment, and capital costs around the world.[106] This research found that, while a three-decade decline in global investment helped drive real interest rates down to their pre-crisis lows, an impending worldwide investment boom may drive rates higher over the next two decades. In coming years, we may have to say farewell to cheap capital.

Meeting future demand for energy, agricultural products, water, and steel without higher productivity growth would require investment of $3 trillion per annum compared with $2 trillion per annum historically. Additional investment will also be necessary to help populations adapt to the effects of climate change. Such investment could include addressing the risk of flooding and desertification. The estimates of the annual costs of such efforts vary widely from less than $50 billion a year to more than $150 billion.[107] However, the investment required in a supply expansion case is a smaller percentage of global GDP than we have seen historically and is achievable, despite the potential for capital to become increasingly expensive, if we assume higher resource prices and sector profitability (i.e., within a typical tax regime).

Beyond the additional investment required, significant logistical difficulties are likely in expanding supply. Take land as an example. The World Bank and the International Institute for Applied Systems Analysis estimate that there are still 450 million hectares of "available"—uncultivated, unforested, and productive—land. But accessing that land is unlikely to be straightforward. Most of the remaining available land is in countries that are not considered politically stable; where there is a high chance of conflict between human settlement, pastoralists,

105 An intermittent energy source is any source of energy that is not continuously available because of some factor outside direct control (e.g., the amount of wind available to turn wind turbines).

106 *Farewell to cheap capital? The implications of long-term shifts in global investment and saving*, McKinsey Global Institute, December 2010 (www.mckinsey.com/mgi).

107 Ibid.

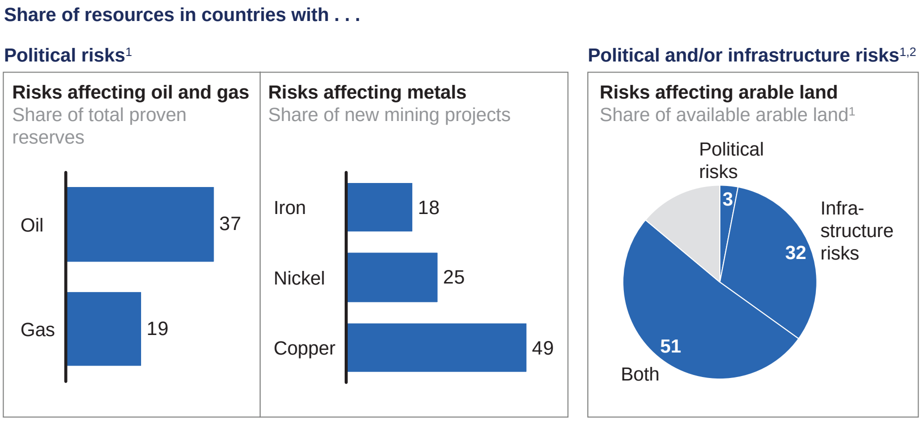
and crop production (including biofuels); and where tensions over land titles and indigenous land rights could arise. Moreover, a great deal of the remaining available land is highly dispersed and at a considerable distance from the market. This implies that significant investment in infrastructure will be necessary to make that land viable. In practice, it appears likely that much of the additional land requirements would be met through further deforestation (especially if food prices remain high), leading to substantial carbon dioxide emissions, a loss of biodiversity, and the potential destabilization of ecosystems. Similar barriers exist in the case of other resources. For instance, almost half of new copper projects are in countries with a high degree of political risk (Exhibit 18).

There is also a significant risk that supply-chain bottlenecks could increase the cost of expanding supply—and delay the availability of additional supply. US quarterly data from 1952 to 2011 suggest that a rise of more than 5 percent in farm product prices in any one year has a strong correlation with the cost of farm machinery two to three years later. On average, a 10 percent increase in farm product prices leads to a 3.6 percent increase in machinery prices two to three years down the line.[108] In addition, the long lead time between decisions to increase supply and the actual start of production—in the minerals sector, it can take up to 20 years from conceptual planning to the development of a mine—can result in a mismatch between demand and supply, and volatility in prices.

Exhibit 18

Supply expansion could be difficult given that a significant portion of reserves are in countries with political or infrastructure risks

%



1 We use the Economist Intelligence Unit's Political Instability Index. We classify countries scoring more than 5.0 on "underlying vulnerability" as "low political stability." We base infrastructural development on World Bank road density data; we classify developing countries with road density lower than 50 kilometers per 100 square kilometers of land area as "low."
2 Numbers may be higher because 8 percent of the available arable land data lack specific country classification.
SOURCE: Economist Intelligence Unit; World Bank; IIASA; BP; McKinsey analysis

However, innovation could create new, previously unimagined opportunities for low-cost supply—innovations that can be a disruptive force in meeting resource needs in the future. For instance, recent innovations related to the extraction of shale gas have enabled a 50 percent increase in reserves relative to conventional sources of gas (see Box 8, "The shale gas opportunity"). A highly priced resource can be a powerful catalyst toward innovation. But an increased focus on innovation can also help to improve the potential for breakthrough technologies to occur, as we discuss in Chapter 6.

108 US Bureau of Labor Statistics.

Box 8. The shale gas opportunity

The recent boom in unconventional gas production in North America has shed light on the potential for unconventional gas to play a more significant role in the primary energy mix of the future. In the mid-1990s, Mitchell Energy began to apply two techniques that led to the development of the economic extraction of shale gas: hydraulic fracturing, or fracking, to free the gas from the shale rock, and horizontal drilling to allow an increased well exposure from a few hundred feet to thousands of feet. As these innovations began to scale up in 2005, shale gas grew from just 2 percent of US natural gas supply in 2000 to 16 percent in 2009.[1] Gas prices in the United States fell substantially, with winter gas prices halving from $8 per thousand cubic feet in 2008 to just $4 in 2010.

Shale gas could account for a substantial increase in global natural gas reserves. Current estimates imply that recoverable reserves of shale gas could be 50 percent higher than in the case of conventional gas. Including shale gas more than doubles conventional reserves in Asia, North America, Latin America, and Africa.[2] If we also take into account tight gas and coal-bed methane, we find that unconventional reserves could increase by more than 100 percent over conventional gas reserves.

However, there is still uncertainty about the full potential impact of unconventional sources of gas. More exploration could turn up additional shale gas reserves. Reserves of as much as 200 trillion cubic feet were recently discovered in Lancashire in the United Kingdom.[3] At the same time, however, the actual reserves on some existing sites have been revised down. In the United States, for instance, the estimated recoverable reserves at the Marcellus Shale site was cut by 80 percent from 410 trillion cubic feet to 82 trillion cubic feet.[4]

And environmental concerns have cast some doubt about how quickly this new source of gas will be scaled up. Many countries, including France, India, and South Africa, have imposed moratoriums on further development of shale gas until the implications are better understood. Certain US states, too, have imposed moratoriums. These concerns need to be addressed for further growth of shale gas. A recent report by the US Department of Energy suggests that further research could help better understand environmental outcomes, regulation, and monitoring of emissions and water management and that adoption of industry best practices are necessary to ensure responsible development of this resource.[5]

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1 Shale gas was drilled for many years before the huge expansion of the industry after 2005, but only in very small amounts in easily accessible rock formations. The production share comes from *Annual energy outlook 2011*, US Energy Information Administration, April 2011.

2 "Are we entering a golden age of gas?" *World energy outlook*, International Energy Agency Special Report, 2011.

3 "Shale gas firm finds 'vast' gas resources in Lancashire," BBC News, September 21, 2011.

4 "US to slash Marcellus Shale gas estimate 80%," Bloomberg, August 23, 2011.

5 *Shale gas production subcommittee 90-day report*, US Department of Energy, Secretary of Energy Advisory Board, August 2011.

(The shale gas opportunity)

Environmental worries about shale gas focus on the management of three key areas: air quality, water quality, and land use. The production of shale gas can result in emissions of methane, a greenhouse gas that has roughly 25 times the impact of carbon dioxide on a 100-year time frame and 70 times its impact on a 20-year time frame. There are also concerns about the potential for shale gas to contaminate local drinking water. Hydraulic fracturing uses 100,000 barrels of water per well, with 30 to 70 percent of the water not being recaptured and remaining within the reservoir.[1] When water is returned, known as flowback, it must also be properly treated or disposed of. Concerns about the impact on land use center on wells and their accompanying infrastructure that can occupy up to almost three hectares per well but have highly variable productivity. Horizontal drilling has been shown to be three times as productive per acre as vertical drilling.[2]

According to the IEA's "golden age of gas" scenario, gas could increase to 25 percent of the total primary energy supply by 2030, compared with the 22 percent that we assume in our supply expansion case.[3] Two main factors would drive this expansion in the use of shale gas—price and policy. Gas prices could fall by roughly 30 percent in the United States (from $10 per MBTU to $7) compared with IEA current projections, and we foresee a similar fall in other regions. Policy assumptions include a more ambitious approach toward the use of gas in China, including investing in the pipeline infrastructure, particularly in coastal cities, to increase access. The IEA also assumes that the global fleet of vehicles powered by natural gas will increase from 30 million today to 70 million by 2035 and that additional nuclear capacity is reduced by 10 percent.

As long as environmental concerns are dealt with satisfactorily, further expansion in shale gas could have significant economic benefits for economies involved in its production through potentially lower energy prices and the feedstock benefits that would accrue to other industries. In the United States, for example, local businesses could benefit in three ways. First, high transportation costs mean that local businesses that supply equipment for the extraction of shale gas can create new jobs in the local area. Second, landowners who benefit from selling land rights will pay taxes and increase spending on local goods and services. These two factors alone could result in the creation of an estimated 260,000 new jobs.[4] Finally, the largest economic gain is likely to come from a potential reduction in energy prices that would benefit consumers as well as businesses that are either energy-intensive or use natural gas as a feedstock. Lower natural gas prices can also lead to lower electricity prices where gas is the marginal

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1 *Modern shale gas development in the United States: A primer*, US Department of Energy, 2009.

2 *Environmental considerations of modern shale gas development*, Society of Petroleum Engineers, 2009.

3 "Are we entering a golden age of gas?" *World energy outlook*, International Energy Agency, 2011.

4 Timothy J. Considine, et al., "The economic opportunities of shale energy development," *Energy policy and the environment report*, Manhattan Institute, May 2011.

(The shale gas opportunity)

supply for electricity production in many countries. Prices of US natural gas are expected to remain low as this energy source is “stranded” in the United States with no current liquefaction facilities to export to other markets. One industry that will likely benefit from cheap shale gas is ethylene production, an intermediate used to produce many plastics for which gas is an important input. Lower gas prices could also reduce fertilizer prices. Lower feedstock prices have led many companies to announce new plants in regions producing shale gas.[1]

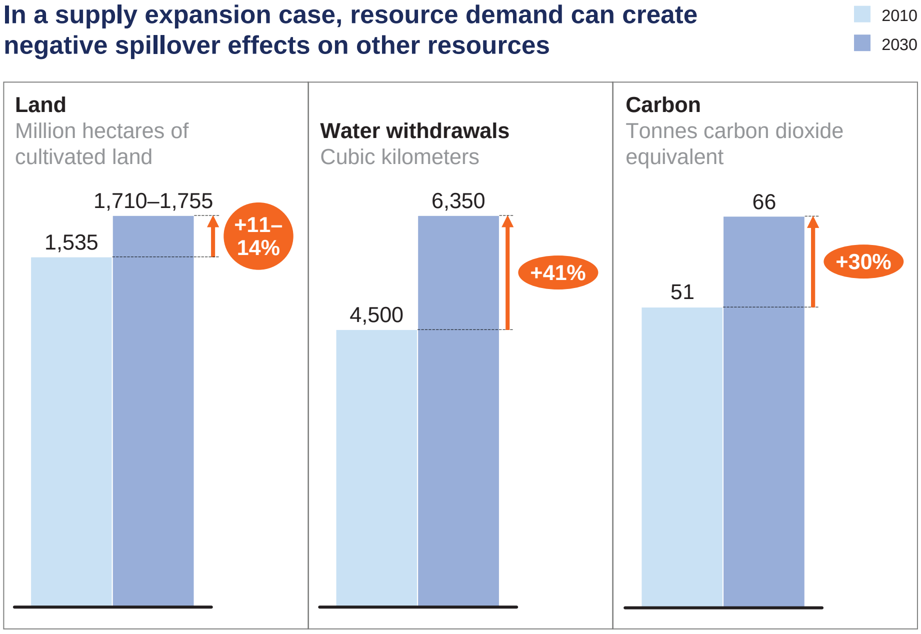
1 “US shale gas bonanza: New wells to draw on,” *Financial Times*, October 5, 2011.

In the absence of significant innovation across many resources, the rapid expansion of supply that is necessary is likely to involve large costs, have a negative social and environmental impact, and exacerbate geopolitical tensions. The countries that would be most at risk would be those whose economies are resource-intensive and have to import those resources—economies that are in the industrialization phase of their development. For example, China and India would shift from being marginal net cereal exporters to importing about 5 and 15 percent of their cereal needs, respectively, in our supply expansion case. This case could also lead to almost 1,850 cubic kilometers of additional water withdrawal by 2030, 40 percent higher than today’s levels; 140 million to 175 million hectares of further deforestation, assuming that 80 percent of the expansion of cropland is into forested areas; and additional carbon emissions of 15 gigatonnes of carbon dioxide equivalent, 90 percent higher than the emissions that would deliver a 450-ppm pathway (Exhibit 19).[109] It is worth noting that the numbers in the supply expansion case all assume relatively limited feedback from potential changes in the stability and performance of the ecosystem into the real economy. It is not difficult to describe a scenario in which higher food prices result in further deforestation in the Amazon, leading in turn to significant changes in rainfall patterns in Brazil’s main agricultural regions, and thereafter to even higher food prices and volatility.

109 Note that 2030 emissions in the supply expansion case are slightly lower than those in the McKinsey Greenhouse Gas Abatement Cost Curve v2.1 at 66 gigatonnes of carbon dioxide equivalent versus 67 gigatonnes. This is due to adjustments in industry’s demand for electricity.

Exhibit 19

In a supply expansion case, resource demand can create negative spillover effects on other resources



SOURCE: McKinsey analysis

However, for resource-rich countries, if used wisely, this demand for resources could create the potential to transform their economies. Much of remaining mineral resources appears to be in developing countries where there has been minimal exploration to date. Because exploration has been so limited, the known subsoil assets in the least developed countries in Africa, Asia, and South America total only $29,000 per square kilometer (relative to $114,000 per square kilometer in the developed world).[110] Further exploration in these regions is likely to yield significant discoveries of resource wealth. While history is littered with examples of a "resource curse" in which endowments of resources have retarded rather than enhanced growth, there are some recent examples, including Botswana, that have demonstrated the transformational impact that resource wealth could have on growth.

□ □ □

Expanding supply could in principle meet resource demand, but supply would need to increase at historically unmatched rates, creating a range of geopolitical and environmental risks. In the next chapter, we will explore options available to improve the productivity of resources in parallel with this supply expansion.

110 Paul Collier, *Plundered planet: Why we must—and how we can—manage nature for global prosperity,* 2010.

4. The productivity challenge

The potential for serious environmental and geopolitical consequences as a result of trying to meet the resource challenge solely through expanding supply is a compelling argument for twinning that effort with action to accelerate resource productivity. In this chapter, we explore our second illustrative case—a productivity response case in which expansion in productivity is coupled with growth in supply. To help prioritize the resource productivity initiatives we have identified, we have developed an integrated resource productivity cost curve consisting of 130 potential measures, grouped into 15 priority groups. We discuss opportunities to improve the productivity of resources that make up our new integrated cost curve as well as the barriers to their capture. We also discuss how to measure and track the progress of different countries in tapping the potential that is available.

The curve is a work in progress, and we intend to expand and refine it in future research. We present median estimates of the benefits and costs of different levers but acknowledge that there is a significant range in the case of both benefits (depending mainly on the basis of price estimates) and costs (depending mainly on accuracy of implementation and technology cost estimates).

Our main findings include:

- Productivity opportunities are available in the four resources we discuss that could address up to approximately 30 percent of total 2030 demand.

- Capturing the total resource productivity opportunity—including the more difficult levers—could save $2.9 trillion in 2030, at current market prices.

- Of these opportunities, 70 percent have an internal rate of return of more than 10 percent at current prices.

- The value of the opportunity would increase to $3.7 trillion assuming a $30 per tonne price for carbon as well as the removal of energy, agriculture, and water subsidies, and the removal of energy taxes.

- From this “societal” perspective, 90 percent of the opportunities have an internal rate of return of more than 4 percent.

- The top 15 opportunity areas in the integrated resource productivity cost curve account for about 75 percent of the total resource productivity prize.

Resource productivity opportunities could address nearly 30 percent of 2030 resource demand

Our second illustrative scenario is a productivity response case. This includes 130 measures that either increase the efficiency of the transformation of resources into productive inputs (e.g., yield per hectare) or increase the economic value achievable from a given volume of resources (e.g., reduced food waste, improved building efficiency). We exclude behavioral changes that involve a loss of welfare (e.g., smaller apartments, changing diets, and the removal of energy subsidies) from our definition of productivity (see Box 9, "Defining resource productivity opportunities").

Box 9. Defining resource productivity opportunities

Our analysis of productivity opportunities includes any supply or demand lever that improves the availability of resources by 2030. On the supply side, we identify opportunities that would maximize the transformation of resources into productive inputs by 2030. These include improved yield per hectare, increased thermal conversion efficiency, reduced water losses in transit, more recycling, and enhanced oil recovery. We exclude opportunities that do not increase the transformation of resources into productive inputs even if these lower the cost of production (e.g., building more cost-efficient mines and dams). We also exclude opportunities for end-use substitution (e.g., using more concrete instead of steel) because it is difficult to assess the relative cost and benefits of such measures. Nor do we include the expansion of supply (e.g., renewable energy sources, such as wind and solar, and new mines).

On the demand side, we include opportunities to maximize the economic value achievable from a given volume of resources by 2030. These include improved building efficiency, reduced food waste, and more efficient domestic water appliances. We estimate the impact of behavioral changes that involve a loss of welfare (e.g., smaller apartments, changing diets, and the removal of energy subsidies) for the sake of comparison. However, we do not include these shifts as opportunities from a productivity perspective.

Some of the behavioral changes that we exclude could have a significant impact on resource demand. While not exhaustive, some examples, with total resource benefits in 2030, include: [1]

- **Shift from meat to fish ($120 billion to $160 billion).** Shifting just 20 percent of global calorie consumption in 2010 to fish from meat would save about 60 to 80 million hectares of cropland.[2] This is equivalent to two to three times the landmass of the United Kingdom and around 30 to 45 percent of new cropland required over the next 20 years (see Box 18, "Shifting diets from meat to fish").

1 Behavioral opportunities are calculated after implementation of all other levers.

2 Size varies depending on the efficiency of feed conversion; production is assumed to come from aquaculture.

(Defining resource productivity opportunities)

- **Reduced consumer food waste ($90 billion):** Reducing food waste at the point of consumption in developed countries by 30 percent could save roughly 40 million hectares of cropland. In North America and Oceania, for example, one-third of fruits and vegetables purchased by consumers end up being thrown away compared to sub-Saharan Africa, where only 5 percent is wasted.[1] Consumer food waste is also more water and energy intensive than post harvest waste due to energy used in transport, packing, processing, distribution, and preparation at home. On average, consumer food waste uses 8 times more energy than post-harvest waste. In this sizing, we are being deliberately conservative, only capturing farm-gate food prices, water, energy, and carbon savings. Value to the consumer could be multiples of this estimate.

- **Reduced heating and air-conditioning use ($110 billion).** Moving the temperature at which heaters and air conditioners are used by two degrees could reduce heating, ventilation, and air conditioner use by 12 percent. The operative temperature, or the ideal level of temperature in a building to maximize comfort, varies by season but also by country. In Japan, for example, people are more tolerant of cooler indoor climates during the winter and warmer indoor climates during the summer relative to the United States.[2]

- **Behavioral changes in road transport ($120 billion).** Changes in passenger and commercial road travel could reduce fuel demand by roughly 10 percent in 2030. Smaller cars, more efficient driving, and avoiding trips would reduce fuel consumption for light-duty vehicles. In addition, improved scheduling and vehicle utilization in commercial fleets can reduce fuel costs for commercial use. One study found that capping truck speeds on highways could improve fuel efficiency by 7 to 10 percent in the United States.[3]

- **Reduced air travel ($50 billion).** Reducing air travel by 20 percent could be achieved through the use of alternative modes of transport or through the increased use of video conferencing technology.

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1 Food and Agriculture Organization, *Global food losses and food waste*, 2011.

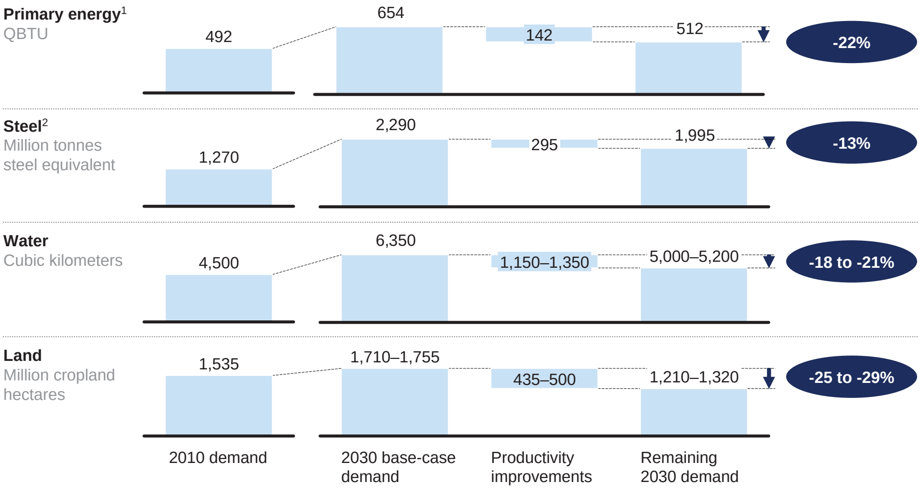
2 Hyojin Kim, et al., *Thermal adaptation to air-conditioned spaces*, proceedings of the International Conference on Sustainable Building in Asia, Seoul, South Korea, June 27–29, 2007.

3 Knut Alicke and Tobias Meyer, “Building a supply chain that can withstand high oil prices,” *McKinsey Quarterly*, November 2011.

The 130 productivity opportunities could address 13 to 29 percent of 2030 resource demand, depending on the resource (Exhibit 20). Their successful implementation could more than offset the expected base-case increase in land demand over the next 20 years and address more than 80 percent of expected demand growth for energy, 60 percent of expected demand growth for water, and more than one-quarter of expected demand growth for steel. This potential is over and above the productivity improvements that we assume in our base case. These efficiency improvements do not allow for dynamic effects from changes in market prices and could be at least partly offset by behavioral changes—so-called rebound effects—that policy would need to mitigate in order to capture the full benefits on offer.

Exhibit 20

In a productivity response case, opportunities could meet 13 to 29 percent of resource demand



1 Productivity improvements include supply-side measures, such as enhanced oil recovery, that lower effective remaining demand.
2 Supply-side levers such as improving recovery rates and the conversion rate in mining and coke do not save steel and are not reflected in this exhibit. We have included effective steel savings from higher scrap recycling.

SOURCE: McKinsey analysis

Delivering on resource productivity would take the strain off the need to expand supply but would not eliminate it. In the case of energy, productivity improvements could cut incremental demand to only 20 QBTU. However, 400 QBTU of new supply would still be needed due to declining sources of existing supply, where output could fall by approximately 6 percent per annum for oil and natural gas and 3 percent per annum for coal.[111] To put this in perspective, just 1 QBTU is enough energy to power all of the cars, trucks, buildings, homes, infrastructure, and industry of New York State for more than three months.

Despite these potentially high returns, our productivity response case requires even more capital than the supply expansion scenario. The capital required to implement the productivity opportunities would be approximately $900 billion a year. However, the capital required for additional supply would fall from $3 trillion in a supply expansion case to $2.3 trillion. Overall, this implies that the capital costs could be $100 billion per annum higher—$1.2 trillion a year above historical expenditure—in a productivity response scenario.

111 We base these estimates on Wood Mackenzie production data and McKinsey experts.

More capital investment would be required to implement a productivity response case in full. This is because of the high capital intensity of many productivity levers, including retrofitting buildings to make them more energy-efficient and shifting road freight to rail and barge. The total investment necessary for the global energy system would increase from $1.4 trillion to $1.7 trillion—there would be considerable shifts in the composition of this investment. For example, energy-related productivity levers, such as building efficiency and EVs, would require total annual investment of $730 billion. However, the cost of supply including, for example, upstream oil and gas extraction, and power generation and transmission, would decrease from $1.4 trillion to $1 trillion per annum due to lower demand for all forms of energy. This compares with current global investment in energy, land, water, and steel of around $2 trillion per annum.

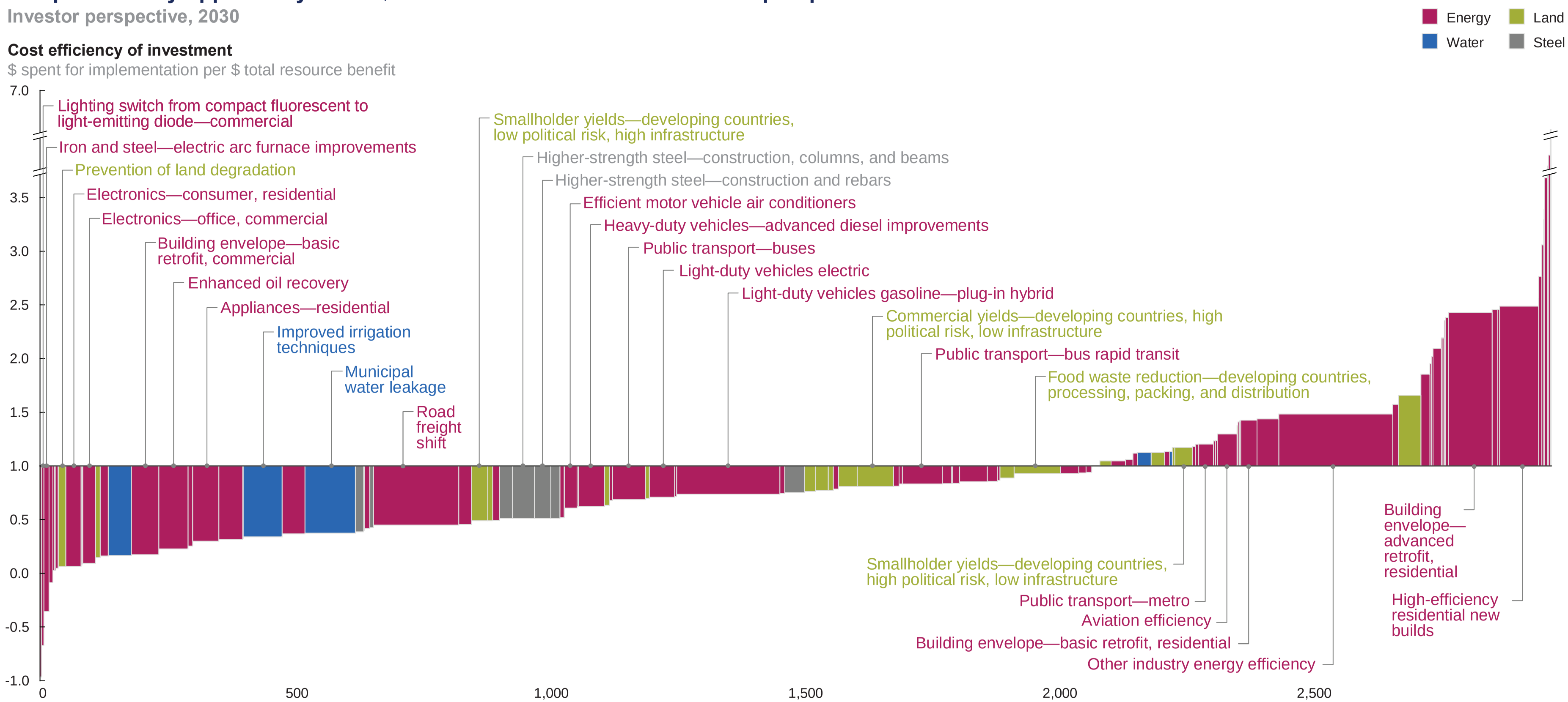
Despite the increase in capital investment, the potential benefits of pursuing resource productivity in addition to supply expansion are significant. Our integrated resource productivity cost curve aims to understand the magnitude of these benefits and help policy makers and businesses to prioritize their response to the opportunity available (see Exhibit 21 and Box 10, “The integrated resource cost curve”).

Exhibit 21

The productivity opportunity totals $2.9 trillion in 2030 from an investor perspective

Investor perspective, 2030

Cost efficiency of investment
$ spent for implementation per $ total resource benefit



Total annual resource benefit[1]
2030 savings, $ billion

1 Based on current prices for energy, steel, and water at a discount rate of 10 percent per annum. All values are expressed in 2010 prices.
SOURCE: McKinsey analysis

Box 10. The integrated resource cost curve

The integrated resource productivity cost curve shows the resource benefits and costs associated with each opportunity (Exhibit 22). If we were to expand the range of resources covered in the curve, the number of levers and potential resource benefits would also increase.

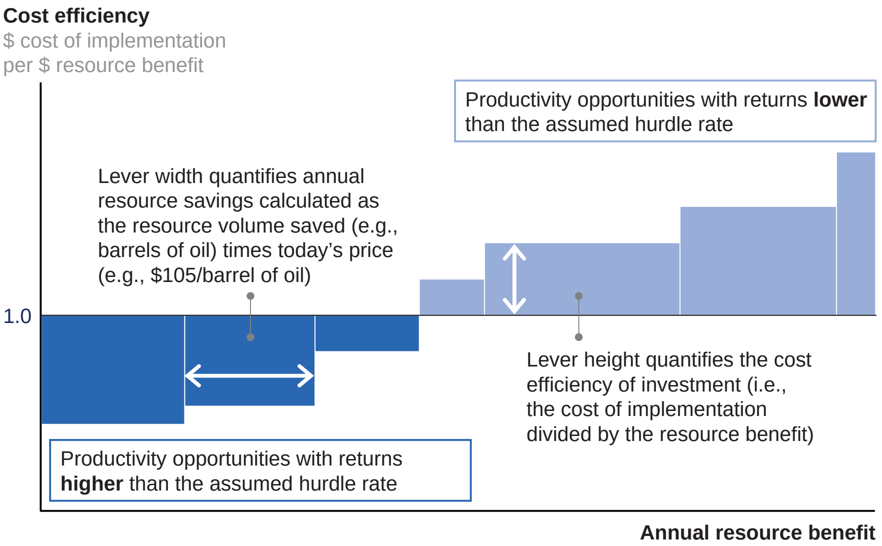
The curve has two versions. The first takes the perspective of a private-sector investor. It includes a real discount rate of 10 percent and uses only current market prices (in dollar terms) to reflect the potential benefits of resource efficiency. The second version takes a societal perspective (Exhibit 23). This version assumes a discount rate of 4 percent (a rough proxy for global government discount rates), includes benefits that are unpriced today such as reducing carbon emissions, and adjusts for water, agriculture, and energy subsidies (as well as taxes). In addition to the resource benefits, we take into account cost efficiency—i.e., the ratio of implementation costs compared with the total benefits of an opportunity.

We have designed the curve to offer an integrated view of global resource economics, containing productivity improvements across multiple resources on a global basis. While we believe our analysis to be directionally correct and able to provide new actionable insights for decision makers, the curve is very much a work in progress. Think of this version as a 17th-century map of the world. We plan to extend our research in several areas. One of these is our assumptions on discount rates. In this version of the curve, we assume global discount rates (in each of the two versions of the curve we have constructed thus far). This means that some opportunities such as smallholder agriculture look relatively attractive compared with others that would likely have lower discount rates. We also want to look at regional prices. At present, we assume global prices for resources apart from in the case of energy where we have a regional and technology breakdown. In the future, we want to incorporate additional externalities and more detail on subsidies. In these versions of the curve, we include only carbon pricing and an adjustment to water subsidies. In the future, we could, for instance, allow for the impact on biosystems, health, and benefits from reduced adaptation costs.

(The integrated resource cost curve)

Exhibit 22

We have developed an integrated resource cost curve to compare productivity levers across resources

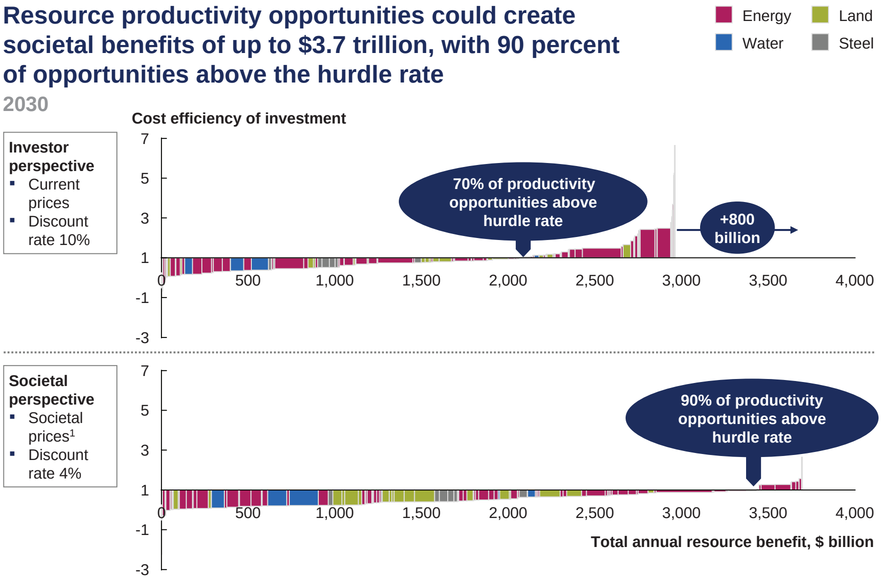


SOURCE: McKinsey analysis

Exhibit 23

Resource productivity opportunities could create societal benefits of up to $3.7 trillion, with 90 percent of opportunities above the hurdle rate

2030



1 Based on current prices for energy, steel, and food, less energy taxes, plus subsidies, and a shadow cost for carbon (at $30 per tonne of carbon dioxide equivalent).

SOURCE: McKinsey analysis

From a private-sector investor perspective, based on current prices, capturing the total resource productivity opportunity—even the more difficult levers—could save $2.9 trillion in 2030. Even at today's market prices (i.e., assuming no real price increase over the next 20 years), 70 percent of the productivity opportunities could deliver real returns in excess of 10 percent (Exhibit 23).[112]

The value of the opportunity would increase to $3.7 trillion if we were to adopt a "societal" perspective, taking into account a $30 per tonne price for carbon as well as assuming the removal of agriculture, energy, and water subsidies, and the removal of energy taxes (see Box 11, "The role of subsidies").[113] If this were to happen, we find that 90 percent would offer returns of more than 4 percent.[114]

Box 11. The role of subsidies

Past MGI research has found that removing energy subsidies would reduce energy demand by a significant 14 QBTU. To put that into context and illustrate the importance of this policy change, this impact on energy demand would be on a par with measures to boost transport efficiency and a shift to electric and hybrid vehicles and is just ahead of urban densification as a lever for reducing energy demand. Moreover, other sources estimate an even higher potential impact from removing subsidies related to fossil fuels. The IEA's 2009 report estimates a potential reduction of 29 QBTU by 2020 from the removal of all subsidies that lower end-user prices for fossil fuels and electricity generated from fossil fuels.[1] The IEA also notes that this does not include the removal of production-side subsidies in advanced economies (e.g., tax expenditure, support for R&D of fossil-fuel technologies, and the transfer of risk via concessional loans or guarantees) that are hard to estimate but also distort the level of demand for fossil fuels. The IEA notes that there is variation in the level of the subsidization of different fossil fuels. On average, consumers in subsidized economies pay 81 percent of the competitive market reference price for oil products and only 49 percent of the reference price for natural gas.

We consider the impact of reducing fuel subsidies by 80 percent, removing gas subsidies in the Russian residential sector, and changing economic incentives in industries that today receive preferential treatment.[2]

1 *The scope of fossil-fuel subsidies in 2009 and a roadmap for phasing out fossil-fuel subsidies*, International Energy Agency, Organisation for Economic Co-operation and Development, and World Bank, November 2010.

2 For a complete discussion, see *Curbing global energy demand growth: The energy productivity opportunity*, McKinsey Global Institute, May 2007 (www.mckinsey.com/mgi). Estimates are based on bottom-up projections to 2020, extrapolated to 2030 using estimates of demand growth of relevant sectors and geographies.

112 Weighted by the size of resource benefits.

113 As a rough proxy, we assume a price of $30 per tonne of carbon dioxide equivalent.

114 We use 2010 resource prices where available and adjust for subsidies and carbon externalities. We do not capture other additional benefits (e.g., reduced air pollution) due to difficulty of sizing. In a world where resource prices are higher, the opportunity becomes even more attractive. If, for example, market prices for food, energy, and materials increased by 20 percent, the productivity opportunity would grow to $4 trillion. See the methodology appendix for more detail.

(The role of subsidies)

- **Transport fuel subsidies (5 QBTU of energy demand saved).** The IEA estimates fossil fuel subsidies at roughly $410 billion in 2010, the great majority of which are in non-OECD countries and nearly 50 percent of which are spent on oil. Countries that subsidize transportation fuels encourage driving and have vehicle fleets with lower fuel economy. As a result, these countries consume up to twice the fuel per vehicle as do countries with similar income levels. The overall cost of such programs is substantial. For example, Iran spent 16 percent of its GDP in 2007 on energy subsidies. In Mexico, the estimated cost of such subsidies reached 2 percent of GDP in 2008. MGI estimates that reducing fuel subsidies by 80 percent globally (largely in the Middle East, Venezuela, and Mexico) would reduce global demand for road transportation fuel by 5 percent. In 2030, that could reduce energy demand by more than 5 QBTU—the equivalent of shaving 2.9 million barrels per day off overall oil demand.

- **Energy and electricity subsidies in Russia and developing Asia (3 QBTU).** In the Russian residential sector, non-marginal pricing—or the zero marginal cost—of gas for heating removes incentives for insulation and has led to wasteful practices such as regulating room temperature by opening and closing windows during the winter. We estimate that removing the current subsidy on Russian gas would save 2 QBTU of energy in 2030. Removing kerosene subsidies in China and India and electricity subsidies in Russia and India would also help reduce consumption by an additional 1 QBTU.

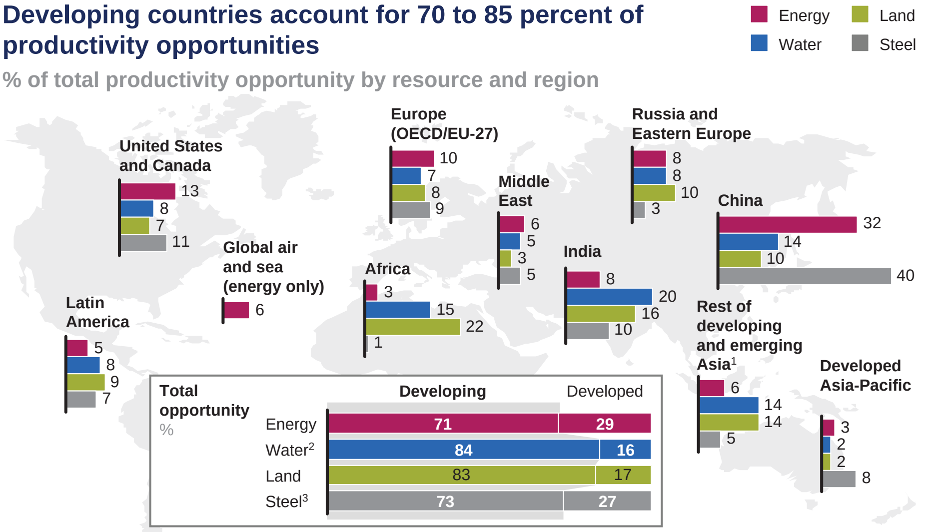
- **Preferential treatment in industry (6 QBTU).** In industry, the major opportunities lie in removing energy subsidies and policies that give preferential treatment to particular industries (e.g., power subsidies for favored industrial operations in Russia) and introducing corporate governance practices that create incentives to capture opportunities to boost energy productivity that offer positive returns (such as improving the economics of refining conversion in Mexico). Together these measures present an opportunity of about 6 QBTU in 2030.

The geographic distribution of productivity opportunities depends on the resource. In the case of energy, improving the efficiency of buildings is one opportunity where developing and developed economies each have significant potential. But nearly three-quarters of the overall energy opportunity lies in developing countries. It is in these economies that the lion's share of growth in power generation and vehicle fleets will take place between now and 2030. In the case of land, the largest opportunity is in Africa (Exhibit 24).

Exhibit 24

Developing countries account for 70 to 85 percent of productivity opportunities

% of total productivity opportunity by resource and region



1 Rest of developing Asia includes Central Asia (e.g., Uzbekistan), South Asia (e.g., Bangladesh), Southeast Asia (e.g., Laos), and North Korea.
2 Includes water savings from water-specific levers as well as water savings from improved agricultural productivity.
3 For steel, the chart represents all the demand-side levers and the scrap recycling lever but excludes supply- and conversion-side levers.
NOTE: Numbers may not sum due to rounding.
SOURCE: McKinsey analysis

The reasons for the geographic location of opportunities vary according to the resource. The majority of new infrastructure investment relevant to energy and steel will be in developing regions. About 90 percent of the opportunities in improving the efficiency of power plants are in developing markets because the potential largely lies in new builds given that there are difficulties in retrofitting existing plants for higher efficiency. In transport, 60 percent of the opportunity is in developing markets because it is in these regions that the penetration of passenger cars could potentially rise from 55 percent today to 75 percent in 2030. In land and water, the biggest opportunities are in improving agricultural and irrigation practices. About 80 percent of the potential to improve yields is in developing economies as farms in developed countries already have relatively high levels of productivity.

Although the opportunity for action is skewed toward developing countries, there is still a considerable, potentially transformational agenda for the developed countries. Capturing the opportunity in retrofitting buildings, for example, would require retrofitting 70 percent of the existing building stock, the majority of which is in developed countries. In addition to capturing opportunities at home, developed countries will need to play a key role in continuing to push the technological frontier in resource-related areas and supporting the diffusion of that knowledge to developing countries. Japan, the United States, and Germany, for example, lead in the development of patents of emerging energy technologies such as solar PV, wind, and geothermal and marine energy.[115] Between 1988 and 2007, developed countries filed more than 2,000 new patents in China for solar PV alone.[116] While markets with appropriate intellectual property rights are powerful mechanisms for diffusing new technologies, peer-to-peer networks (such as the C40, a group of major cities globally committed to implementing

115 Nick Johnstone, et al., *Climate policy and technological innovation and transfer: An overview of trends and recent empirical results*, Organisation for Economic Co-operation and Development, July 2010.

116 Ibid.

sustainable climate-change-related actions) are also playing a growing role in accelerating the international diffusion of technologies, managerial practices, financing models, and institutional design. It is important to stress that this analysis does not include behavioral changes that could lead to a welfare loss (e.g., living in smaller houses, reducing meat consumption, using more public transport) where opportunities are likely to be heavily concentrated in developed countries.

If there was decisive action to accelerate growth in resource productivity and capture a significant share of the available benefits, the price of resources could decline.[117] This could, of course, make the economics of investing in higher resource productivity less attractive to the private sector. However, the benefits to society would be highly significant. A 10 percent reduction in resource prices alone could save $1 trillion to $1.5 trillion globally on the cost of consuming resources in 2030, even after adjusting for potential productivity improvements.

For large resource-importing countries, such a positive impact argues for pursuing resource price-sensitive opportunities even on the right-hand side of the integrated cost curve—in other words, the more expensive levers. The argument is particularly strong in cases where taking action to capture the available potential would push resource-efficient technologies up the learning curve. This would be the case, for example with advanced building retrofits that currently offer an internal rate of return of lower than 4 percent (from a societal perspective).

There are potentially both short-term and long-term economic benefits associated with these resource productivity opportunities. In the short term, the investment could provide a stimulus to the global economy. Economists estimate that each $1 billion in investment spending in the United States can create 10,000 to 28,000 jobs.[118] Estimates have suggested that "green" stimulus packages outside the United States have created 10,000 to 22,000 jobs.[119] In our productivity response case, the capital required to implement the productivity opportunities would be approximately $900 billion a year. Assuming that this is incremental investment, it could create 9 million to 25 million jobs as long as certain assumptions are

117 There are, of course, large uncertainties associated with future price trajectories. There are generally steep upwardly sloping supply curves across most resources, and large opportunities to reduce resource demand from these productivity opportunities. Given this, it is likely that there could be a significant decline in prices compared with a case in which the global economy merely invests in supply at historical levels and achieves productivity growth in line with our base-case projections. It is less clear that prices would be lower than in our supply expansion case. For example, an excess of supply coming onstream could also lead to lower prices.

118 This range is based on estimates by the United States Federal Highway Administration of the employment impact of capital expenditure on highways. See *Employment impacts of highway infrastructure investment*, Federal Highway Administration, 2007. Other studies on the US economy have found broadly similar estimates. See, for example, James Heintz, Robert Pollin, and Heidi Garrett-Peltier, *How infrastructure investments support the US economy: Employment, productivity, and growth*, Political Economy Research Institute and Alliance for American Manufacturing, January 2009. This report found that $1 billion of infrastructure investment generates around 18,000 jobs. This is likely to be a conservative number when extrapolated to global investment, given the higher labor to capital ratios in other countries.

119 According to government estimates, South Korea's "green new deal" is projected to create 960,000 jobs from 2009 to 2012, equivalent to roughly 22,000 jobs per $1 billion of investment. France's green stimulus package is expected to create 80,000 to 110,000 net jobs in 2009 to 2010 period, equivalent to roughly 11,000 to 16,000 jobs per $1 billion. See *Towards green growth: Green growth strategy synthesis report*, Organisation for Economic Co-operation and Development, May 2011.

met. The number of net new jobs would depend on the relative labor intensity of resource productivity investments. They would also depend on an assumption that there is no crowding out of other investment—i.e., that there is no increase in the real interest rate as a result of investments in resource productivity. We believe that our assumptions are reasonable in the short term given the current amount of unused capacity in the global economy.[120] Over the longer term, the potential for these resource productivity opportunities to moderate the volatility of prices and to spur a new wave of long-term innovation could bring additional economic benefits.[121] By reducing expenditure on imported resources and improving the cost competitiveness of businesses, these productivity opportunities could also strengthen trade balances in many advanced net resource-importing economies.

By pursuing opportunities to boost productivity as well as expanding supply, concerns about energy security—oil—would ease. We estimate that oil demand would be 20 percent lower than it would otherwise have been (83 million barrels per day versus 103 million barrels). In the productivity response case, oil would account for 79 percent of fuel demand for road transport in 2030 compared with 96 percent today. Oil demand could drop by an additional seven million barrels per day, from 83 million barrels to 76 million, if its production and the use of biofuels were to be ramped up aggressively, and if there was a shift in the power-sector mix that nearly eliminated oil-fired power by 2030. This would reduce oil's share of the energy used by road transport to 63 percent, with the remaining energy provided by biofuels (23 percent), electricity (13 percent), and other fuels (1 percent).

Carbon emissions could decline from 66 gigatonnes per annum in a supply expansion case to 48 gigatonnes per annum, getting more than halfway to a 450-ppm pathway (35 gigatonnes per annum).[122] Higher yields on smallholder and large-scale farms, in addition to other productivity opportunities such as reducing waste, would mean a net reduction in the land needed for cultivation (215 million to 325 million hectares less than today's use of cropland). This would have broad benefits for biodiversity and mean significantly lower water consumption because of the improved productivity of rain-fed land and higher crop-per-drop where irrigation is in use.

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120 An important priority for future global research in this area is building on the existing suite of macroeconomic models so that we can fully capture the effects of price volatility on consumption, investment, and growth. This must include developing realistic supply-side models that accurately reflect the dynamics of industry cost curves.

121 Some academics have discussed the possibility that resource productivity opportunities could create a new Kondratiev cycle, a long-term growth cycle (typically lasting 30 to 50 years) that can be attributed to major technological innovations, such as the invention of steam power, railroads, and software information technology. For further details, see Ernst Von Weizsäcker, et al., *Factor five: Transforming the global economy through 80% improvements in resource productivity* (London: Earthscan, 2009).

122 The sizing of carbon abatement is based on McKinsey Greenhouse Gas Abatement Cost Curve. We base savings on carbon dioxide equivalent due to the capture of energy productivity opportunities on average carbon dioxide equivalent emissions by fuel type. We assume an abatement opportunity in land of 300 to 400 tonnes of carbon dioxide equivalent per hectare of avoided deforestation, using the assumption that each hectare of additional cropland leads to 0.8 hectare of forest loss—0.5 hectare from primary forest (65 percent tropical forest, 25 percent tropical moist deciduous forest, and 10 percent dry forest) and 0.3 hectare from secondary forest. Increasing yields for smallholder farms is assumed to require additional nitrogen fertilizer of 25 kilograms per tonne of yield increase, partially offset by the average global fertilizer use per hectare from avoided land expansion. Carbon abatement opportunities from steel are based on an average 1.3 tonnes of carbon dioxide equivalent emissions per tonne of steel.

The integrated resource productivity cost curve can be used to understand the impact of different scenarios. In reality, capital is likely to be tight, incentives often weak, and information imperfect, and companies and governments alike will need to prioritize, taking into account not only cost but also the difficulties they are likely to face. So, although we have modeled the total benefits that capturing all available productivity opportunities would deliver, it is useful to understand what the implications would be if only a portion of the available productivity opportunities were implemented.

Governments and companies may prioritize productivity opportunities with the highest returns. If only those opportunities that offer societal returns (that adjust for subsidies, energy taxes, and include the pricing of carbon emissions) of more than 4 percent were captured, measures such as shifting toward EVs and advanced retrofits of residential building may be excluded. In this case, the capital costs of meeting 2030 demand for resources would be about $300 billion per annum lower and come into line with the supply expansion case. The substantial savings come about because of the exclusion of levers with high capital costs, as well as the lower electricity demand from charging fewer electric vehicles and making fewer shifts to electric arc furnace-direct reduced iron (EAF-DRI) steel mills—which have higher electricity needs than blast furnace and basic oxygen furnace (BOF) plants. The capital needed would be approximately $3 trillion a year compared with about $2 trillion per annum today. This would mean, however, that oil demand would be 8 percent or seven million barrels per day higher than if all productivity opportunities were captured and that oil would account for around 87 percent of road transport fuel demand in 2030 compared with 79 percent if all productivity levers were pulled. If we included incremental biofuels, the oil share could be 73 percent compared with 63 percent. Carbon emissions would decline only to 49 gigatonnes per annum in 2030.

Alternatively, we could model a different case in which the most difficult opportunities, such as increasing smallholder yields in politically unstable countries, are not implemented.[123] In this scenario, the capital cost of the productivity response case would decrease by $130 billion, but emissions would decline only to 55 gigatonnes per annum in 2030 compared with 66 gigatonnes in the supply expansion case. Here, too, there could be an increase in oil demand of around seven million barrels per day relative to a scenario in which all productivity opportunities were implemented.

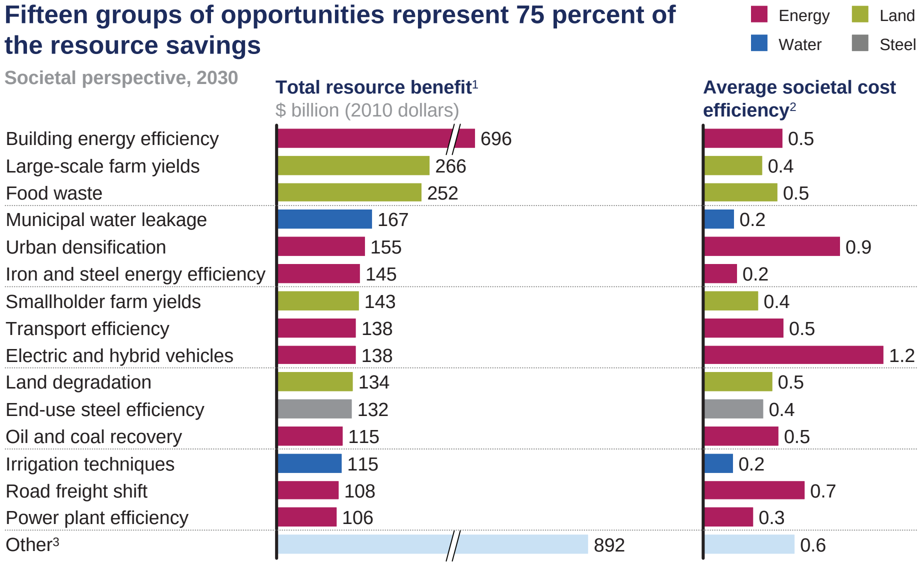
The integrated resource productivity cost curve has 15 key areas of opportunity—each of which faces barriers

The resource productivity agenda is challenging not only because of the capital cost involved but also because it is highly fragmented. Decision makers in the public and private sectors need to find a way of prioritizing where to put their limited stocks of capital and institutional leadership and where to focus their political will. The top 15 areas of opportunity in our integrated cost curve together account for roughly 75 percent of the total benefits available from boosting resource productivity in 2030 (Exhibit 25).

123 See the methodology appendix for further detail.

Exhibit 25

Fifteen groups of opportunities represent 75 percent of the resource savings



1 Based on current prices for energy, steel, and food plus unsubsidized water prices and a shadow cost for carbon.
2 Annualized cost of implementation divided by annual total resource benefit.
3 Includes other opportunities such as feed efficiency, industrial water efficiency, air transport, municipal water, steel recycling, wastewater reuse, and other industrial energy efficiency.

SOURCE: McKinsey analysis

We estimate the size of each opportunity not on its technical potential but on what each productivity lever could realistically achieve over the next 20 years. We reach a judgment on this using evidence from case studies and by benchmarking the performance across countries in pulling the various types of productivity levers we have identified.

In the case of smallholder yields, for example, we assume that yields can double from their current levels. This would still leave these yields at only about 40 percent of those on large-scale farms today, let alone large-scale farm yields in 2030. In short, we have made relatively conservative assumptions on what smallholders can achieve on yields. In the case of energy, we have incorporated aggressive—but, we believe, achievable—assumptions about the implementation of opportunities for higher building efficiency. We assume that by 2030, 60 percent of existing buildings are retrofitted to a "basic," cost-efficient standard, and that disruption is low. We further assume that an additional 10 percent of buildings are retrofitted to higher standards, including replacing windows and installing more aggressive insulation, and that this would involve more cost and disruption.

It is important to stress several aspects about the relative sizing and cost efficiency of these opportunities. First, these are opportunities over and above productivity improvements that we include in our base case. In transport efficiency, for example, we capture roughly three-quarters of the potential productivity improvements identified in the efficiency of light-duty vehicles over the next 20 years in our base case. Second, the size and cost efficiency of opportunities are highly dependent on the future evolution of resource prices. Given the uncertainty in future prices, we base our estimates on current prices. However, plausible scenarios for future prices could lead to significant differences in sizing and cost estimates. Third, these estimates are based on a societal view (removing energy taxes, as well as energy, agriculture, and water subsidies, and including a price of carbon of $30 per tonne). Taking a private-sector perspective, the relative size and cost efficiency of opportunities would change significantly. For example, EVs and hybrid vehicles would rise from the ninth-largest productivity opportunity to become the second-largest opportunity (behind building energy efficiency) due to the additional savings from taxes on oil. The returns from this opportunity would exceed 10 percent. In contrast, food waste would fall from the third-largest opportunity to the seventh-largest due to the fact that agriculture and water subsidies are ignored, and there is no pricing of carbon emissions—all of which lowers the associated returns of this productivity opportunity.

Shale gas and renewable energy are excluded from the analysis of productivity opportunities as we treat these as sources of new supply rather than as opportunities to improve the extraction, conversion, or end use of energy resources. Whilst there is considerable uncertainty about the potential resource benefits of shale gas and renewable energy (due to learning-curve rates, assumptions about what energy sources would be displaced, externalities involved in production, and so on), a rough sizing of these opportunities suggest they could be among the top five opportunities (see Box 12, "Where do unconventional gas and renewables come into our productivity cost curve?").

Box 12. Where do unconventional gas and renewables come into our productivity cost curve?

Unconventional gas and renewable energy innovations, while important components of meeting future energy demand, are not included in the curve because we consider them as sources of expanding supply rather than levers to improve productivity. Even so, it is interesting to see how they would compare with the productivity opportunities we have identified. There is clearly a large degree of uncertainty on the potential resource benefits and cost efficiency of shale gas and renewable energy, which will depend on factors such as the rate of learning-curve improvements, environmental concerns associated with production, and what assumptions we make on which energy sources they might displace. However, to arrive at a rough approximation of the potential resource benefits associated with shale gas and renewable energy (focusing just on wind, solar and geothermal), we have made some simplifying assumptions.

For unconventional gas, we use the IEA's "golden age of gas" scenario to provide estimates of the potential resource benefits from the expansion of unconventional gas. Assume that gas prices could be between $2.60 and $2.90 lower per MBTU in 2030 due to advances in lower-cost gas production such as shale gas. Under a scenario in which gas reaches 169 trillion cubic feet or 181 QBTU, the global savings would be approximately $500 billion per annum. The IEA also estimates a carbon benefit of 0.16 gigatonnes, which represents a $5 billion benefit to society if carbon is priced at $30 per tonne. In total, this gives a total benefit of $505 billion in 2030. That would make shale gas the second-biggest opportunity of our top 15. If the expansion of shale gas were to enable natural gas prices to fall even further—to be in line with today's prices (e.g., $4.00 in the United States) in real terms at around 2030—the benefit would increase to $1 trillion per annum relative to the IEA's price projections in its "new policies" scenario.[1]

1 *World energy outlook 2010*, International Energy Agency, November 2010.

(Where do unconventional gas and renewables come into our productivity cost curve?)

Renewable energy sources have multiple benefits to society as they scale up. First, renewable energy plays a major role in reducing carbon emissions. Second, renewables diversify energy sources and offer a potentially more stable energy price, providing a hedge against volatile fossil fuel prices.[1] Finally, renewable energy is a cleaner source of energy that can help lower the health costs associated with fossil fuel extraction and use.[2] Additional research is needed to quantify all of these benefits. For our calculation of the size of the benefit, we take a fairly narrow assessment that focuses on the carbon abatement benefits associated with wind and solar and the potential benefits in the form of lower energy costs if there is a breakthrough in these technologies. A scale up in wind, solar, and geothermal could reduce global emissions by 4.5 gigatonnes per annum by 2030 above our base-case projections. At $30 per tonne, the societal benefit of this would be $135 billion per annum in 2030, which would be the tenth-largest opportunity of our top 15. Beyond the carbon benefits, if and when these renewable energy sources were to reach grid parity, there would be additional benefits because they would provide a cheaper form of electricity.[3]

However, the cost of scaling up renewable technologies is highly uncertain. We estimate the cost to be between $210 and $305 billion per annum over the next 20 years.[4] Conservative estimates suggest that many renewables will not reach grid parity until after 2030. However, if costs fell substantially through breakthroughs in innovation, the benefits of lower costs in power could begin to accrue for some technologies as early as 2015.[5] Breakthroughs could lower the levelized cost of electricity (LCOE) in 2030 to as low as $35 per megawatt hour for onshore wind and even $29 per megawatt hour in solar compared with $66 per megawatt hour for coal. In 2030, the average LCOE for solar, wind, and other renewables would then fall to $56 per megawatt hour, implying additional savings of $75 billion per annum. Understanding the broader benefits of renewable energy and other emerging sources of supply will be an area of our future research.

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1 See, for example, Mark Bolinger, Ryan Wiser, and William Golove, "Quantifying the value that wind power provides as a hedge against volatile natural gas prices," *Proceedings of windpower 2002*, June 2002.

2 See, for example, Michael Greenstone and Adam Looney, *A strategy for America's energy future: Illuminating energy's full costs*, The Hamilton Project, Brookings Institution, May 2011.

3 The point at which an alternative energy source falls to at least the same cost as existing grid power sources.

4 Includes costs for hydro, wind, solar, dedicated biomass, geothermal, marine and coal-to-gas shifts as well as costs for additional transmission and distribution infrastructure.

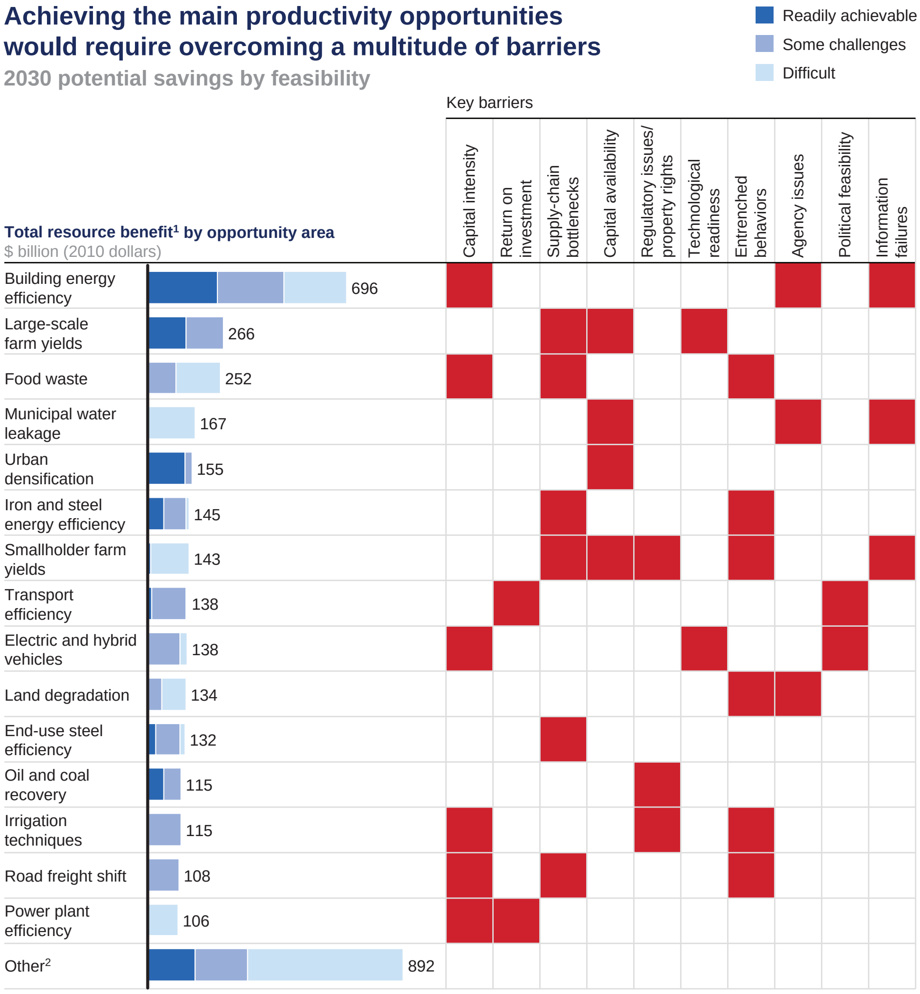
5 *The impact of clean energy innovation: Examining the impact of clean energy innovation on the United States energy system and economy*, Google.org, July 2011.

In each of the 15 priority areas, we have estimated how much of the opportunity is "readily achievable" or faces "some challenges." We estimate that approximately 20 percent of the productivity opportunities in our integrated cost curve are readily achievable, 40 percent of the opportunities face some barriers, and the remaining 40 percent would be difficult to achieve (Exhibit 26).[124]

Exhibit 26

Achieving the main productivity opportunities would require overcoming a multitude of barriers

2030 potential savings by feasibility



1 Based on current prices for energy, steel, and food plus unsubsidized water prices and a shadow cost for carbon.
2 Includes feed efficiency, industrial water, air transport, municipal water, steel recycling, wastewater reuse, and other industrial energy efficiency.

SOURCE: McKinsey analysis

There is little doubt that capturing all the available productivity opportunities in the 15 priority areas would be highly challenging, especially given that current prices often do not fully reflect resource scarcity or environmental costs. As we have noted, it is hard to envisage governments and businesses pulling all the levers that we have identified. But it is still important to understand which opportunities are likely to be most straightforward to capture and where the biggest difficulties

124 We assessed resource productivity opportunities against ten key barriers. "Readily achievable" opportunities did not have a significant barrier. Opportunities listed as having "some challenges" had one significant barrier. "Difficult" opportunities had two or more significant barriers. For more details on the methodology for assessing feasibility of implementation, see the methodology appendix. This research has completed an assessment of the barriers to higher resource productivity. We have not yet quantified the barriers to supply expansion.

lie. Only through a pragmatic assessment of the task ahead is it possible to prioritize where to start and map out a realistic path to higher resource productivity. In this spirit, we have developed a framework that we hope will help companies and policy makers to understand the barriers they face in trying to tap all the productivity opportunities that are available. The obstacles include:

- **Incentive barriers.** Conditions that make decision makers less likely to pursue an opportunity, such as return on investment and associated capital intensity.
- **Decision-making barriers.** Conditions that may discourage actors from pursuing opportunities within their own interests. This group includes the misalignment of incentives between actors (e.g., agency issues where landlords are not incentivized to make profitable energy-efficiency investments as it is tenants who enjoy the benefits of such outlays); a lack of information about the opportunities that are available; and political feasibility—for example, potential opposition to change from a group of influential stakeholders who may feel adverse effects from that shift.
- **Implementation barriers.** Factors that may prevent the implementation of an opportunity even if there is an incentive for that implementation. These include supply-chain bottlenecks, weaknesses in technology and mechanisms to diffuse best practice (especially in the case of small and medium-sized enterprises and smallholders), the availability of capital, regulatory issues, technological readiness, and entrenched behavior.

We looked at the experience of countries that have been successful in overcoming certain barriers in the hope that this could point the way toward more effective approaches that others might emulate. We now briefly describe each of the 15 areas where resource productivity can improve, along with metrics relevant to each that allow us to measure progress in capturing the potential. We also discuss the barriers in each of the 15 groups and potential means of addressing them.

1. BUILDING ENERGY EFFICIENCY

Improving energy efficiency in residential and commercial buildings could deliver approximately 19 percent of the total benefits that could accrue from boosting resource productivity. We calculate that 35 percent of the potential in this group is readily achievable and a further 33 percent has some challenges.[125] The potential in buildings accounts for 30 percent of the total opportunity for increasing energy productivity. If captured in full, raising the energy efficiency of buildings would reduce energy demand by 31 QBTU—20 percent more than the global use of energy by shipping and air transport combined. Our base case already includes substantial improvements in the average per unit energy consumption of the buildings sector. We project that residential buildings will improve their efficiency by roughly 14 percent in the base case, from 140 kilowatt hours per square meter per year in 2010 to 120 kilowatt hours per square meter in 2030, with the potential to improve a further 20 percent to 91 kilowatt hours per square meter. We see commercial buildings increasing their energy efficiency by roughly 12 percent in the base case, from 310 kilowatt hours per square meter to 275 kilowatt hours per square meter, with the potential to improve a further 20 percent to

125 We define “readily achievable” as cases in which the productivity opportunity does not face significant difficulties on any of ten assessment criteria. See the methodology appendix for further detail.

213 kilowatt hours per square meter. There are two major opportunities to achieve these improvements:

- **Improved building heating and cooling performance through retrofitting existing buildings and improved energy efficiency in new buildings (12 percent of total resource productivity benefits).** Improving the performance of heating and cooling, together with installing efficient water heaters, accounts for more than 20 percent of the total opportunity to reduce energy consumption in the cost curve. Two-thirds of this potential comes from retrofitting buildings, with the other third coming from high-efficiency new buildings. One of the most important areas is that of heating, ventilation, and air-conditioning. In the United States, for example, 40 percent of residential energy consumption relates to space heating and cooling, compared with just 10 percent that is used for lighting. Additionally, unlike lighting energy use that is projected to decline by 1.6 percent per annum, space cooling is projected to grow by 0.5 percent per annum from 2009 to 2030.[126]

  — **Retrofitting existing buildings with improved building envelopes, heating and cooling systems, and water heaters (8 percent of total resource productivity benefits).** Retrofitting the existing building stock accounts for 8 percent of total resource productivity benefits, and half the total potential that we project is available from reducing the consumption of energy. The importance of retrofits is highest in the developed world, where the established infrastructure is aging in many cases. To illustrate, more than 68 percent of the apartments in France and more than 60 percent of single-family homes there were built before 1975. In the United States, 45 percent of apartments were constructed before 1970. One exception to this kind of pattern is Japan, where 98 percent of the multifamily housing was built after 1960.[127] About 70 percent of this retrofitting opportunity comes from improving building envelopes through better insulation. We assume that approximately 60 percent of existing buildings are retrofitted to a "basic" standard. By this we mean undertaking cost-efficient activities that cause low levels of disruption, such as increasing the airtightness of buildings through sealing baseboards and other areas of air leakage, weather-stripping doors and windows, and further insulating attic and wall cavities. We further assume that an additional 10 percent of buildings are retrofitted to higher standards. This would involve installing new, high-efficiency windows and doors; increasing insulation on outer walls, roofs, and basement ceilings; and applying basic passive solar principles such as using sunlight to aid in natural heating and natural ventilation. We also assume that energy-efficient heating, ventilation, and air-conditioning systems purchased as existing stock reach the end of their useful life and that additional processes are put in place to improve the maintenance of such systems, accounting for an additional 15 percent of the opportunity. The remaining 15 percent of the benefits in this subgroup would come from improving the efficiency of water heaters. We assume that water heaters are replaced with more energy-efficient models such as solar water heaters or tankless models.

126 *Annual energy outlook*, US Energy Information Administration, 2011.

127 *Energy efficiency in buildings: Business realities and opportunities*, World Business Council for Sustainable Development, September 2008.

— **Improved energy efficiency of new buildings (4 percent).** Improved efficiency in new buildings represents 4 percent of the total resource productivity opportunity. If we assume that construction adheres to passive house standards, we estimate that energy-efficient new buildings could require only 20 to 30 percent of the average consumption of energy of existing buildings in developed countries today.[128] The potential to reduce energy consumption in new buildings is larger than retrofitting existing ones because new builds offer other options for reducing energy, including the orientation of buildings and their design. We assume that 65 percent of buildings constructed from 2010 to 2030 worldwide accord with high-efficiency standards. In 2030, that would account for 30 percent of total floor space. We assume some regional differences in implementation rates. We assume, for example, that the United States builds 80 percent of new buildings according to high-efficiency codes by 2020 and 90 percent by 2030, but that India builds only two-thirds to these standards by 2020 and a little over 80 percent by 2030. China, in contrast to India, makes efficient construction a high priority, with 80 percent compliance by 2020 and 98 percent compliance in 2030.

- **Switching to efficient lighting, appliances, and electronics (6 percent).** Lighting accounts for 19 percent of global electricity consumption.[129] In commercial buildings, more than 35 percent of a building's electricity use goes toward lighting, more than any other single end user. An incremental 4 to 5 percent goes toward removing waste heat generated by those lights.[130] Opportunities include upgrading lighting to light-emitting diodes (LEDs), retrofitting commercial lighting controls, and replacing inefficient white goods and home and office electronics. These opportunities all have positive returns. In some cases, they save on up-front expenditure even before accounting for energy savings because investments of this kind have longer lifetimes than less efficient alternatives.

— **Lighting.** We estimate the total potential to reduce energy in this subgroup at 2 QBTU, of which three-quarters would come through the adoption of lighting control systems in commercial buildings. Such systems help to reduce energy consumption by using dimmable lighting ballasts with photosensors. These optimize light according to available daylight and the number of occupants in a room. Using current technologies, lighting control systems can reduce electricity use by 50 percent in a new building and 29 percent in a retrofit. In new buildings, we assume 50 percent adoption of these measures, while we assume 30 percent capture in the case of retrofits. The remaining potential would come from the accelerated

128 Germany's passive house (Passivhaus) standards are stringent energy consumption standards using high-quality insulation and efficient heating and cooling equipment. Energy consumption is assumed to be 20 kilowatt hours per square meter in warm developing countries, 30 kilowatt hours per square meter in cold developing countries, and 35 kilowatt hours per square meter in developed countries. We base this estimate on an average energy consumption of 118 kilowatt hours per square meter a year in the United States in 2010 (90 kilowatt hours per square meter in 2030), compared with an estimated potential reduction to 31 kilowatt hours per square meter per year under passive house standards. China's energy consumption is significantly lower at 57 kilowatt hours per square meter currently, and there is an estimated potential to reduce that to 20 kilowatt hours per square meter per year.

129 Alice McKeown and Nathan Swire, *Vital signs update: Strong growth in compact fluorescent bulbs reduces electricity demand*, Worldwatch Institute, October 2008.

130 Energy Star, *Building upgrade manual*, US Environmental Protection Agency, 2006.

adoption of new lighting technologies, predominately LEDs and Super T8 and T5 fluorescent bulbs.

— **Appliances and electronics.** There is potential to reduce energy consumption by 4 QBTU. More than half of that could come through the increased adoption of more energy-efficient appliances in residential buildings. On average, certified efficiency appliances use 35 percent less energy than standard appliances. We assume that high-efficiency alternatives substitute existing appliances when they need replacing.

A recent survey of global executives and owners of buildings (who are therefore responsible for the management of energy as well as investment in commercial and public-sector buildings) found that they were increasingly interested in energy efficiency. This rising worldwide engagement in the issue has come about through various government incentives, concerns about the public image of those surveyed, and the savings on energy costs that higher efficiency delivers.[131] But this survey also identified five key barriers to investing in energy efficiency: (1) a lack of awareness of opportunities for energy savings; (2) a lack of technical expertise for the design and completion of projects; (3) a lack of certainty that promised savings will be achieved; (4) the inability of projects to meet the organization's financial payback criteria; and (5) a lack of available capital for investment in projects. Limited awareness and gaps in technical expertise appeared to be particularly high barriers in India and China.

Industry interviews also highlighted the lack of incentives to support building efficiency within maintenance departments. Maintenance managers are often rewarded according to whether they meet their budgets, not on total cost savings to the business. As a result of this siloed approach, these managers may opt against relatively low-cost measures, such as purchasing lubricant for air-conditioning units, because they don't have the incentive to consider the benefits to the business in terms of lower energy costs and avoided disruptions from equipment that breaks down.

Do the energy-efficiency opportunities in the buildings sector have attractive returns? In some cases, there are potentially very large returns from readily available opportunities. Simply cleaning air-conditioning coils (even with soap and water in some cases) could reduce electricity consumption by more than 5 percent. More broadly, we find that while some basic retrofits have attractive internal rates of return of more than 10 percent, many other building-efficiency programs often have returns below 10 percent. These include more advanced retrofits and making new builds energy-efficient to a passive house standard. The sizable capital that needs to be spent up front is doubtless a barrier to the full realization of this lever, and it is very likely that public policy intervention is required.

Enacting building codes that require energy efficiency in new construction is one approach that some municipalities have taken. Such codes have proved to be effective in some countries, but there is doubt whether developing countries will adopt them widely. In the case of retrofits, mandates like these appear even less politically feasible. Such incentives as tax rebates have not resulted in retrofitting on a large scale. Experience of public policy in this area thus far suggests that

131 *2011 energy efficiency indicator: Global survey results*, Institute for Building Efficiency, June 2011.

achieving efficiency improvements in buildings will require new regulatory or legal models.

Direct government support may be particularly necessary in the case of low-income housing. The Weatherization Assistance Program in the United States targets 40 million low-income homes and has weatherproofed more than 6.3 million homes to date. The program has achieved returns of $1.67 in energy-related benefits for every $1 invested. Some cities have taken a direct approach, particularly in public housing. Boston, for example, retrofitted one-third of its public housing stock and achieved a 30 percent reduction in utility costs. For existing homes belonging to those on higher incomes—where government support is clearly not as relevant—a range of targeted indirect measures could play a useful role. Labeling and voluntary standards could raise awareness and help with the transfer of the value of a property. Only 2 percent of existing homes in the United States have energy-efficiency ratings, but more than 25 percent of new homes built in 2010 had an Energy Star rating.[132]

A greater role for specialized energy services companies and utilities to provide funds for up-front investment and deploy their expertise in identifying and capturing energy-efficiency savings may also be necessary. Innovative financing can help to overcome capital constraints and rapid payback requirements by tying loan payments to the property or to the utility meter, instead of to the homeowner, and by ensuring that investments always have a positive cash flow to the homeowner (in other words, the monthly savings are greater than the loan payment). Rebates and incentives for the installation of efficiency measures such as fitting new windows and better insulation have proved to deliver increasing efficiency. Residential-scale energy service companies are already emerging with the aim of providing end-to-end turnkey efficiency services for owners of homes and small businesses. They are seeking to attract customers by offering guaranteed savings on their utility bills.

2. LARGE-SCALE FARM YIELDS

Boosting yields on large-scale farms, which we define as farms with more than two hectares of land, could deliver 7 percent of the total benefits available from raising resource productivity. We calculate that 50 percent of action in this area is readily achievable and the remaining 50 percent has some challenges. Large-scale farms account for an estimated 70 percent of global land under cultivation. Increasing their yields could account for 65 percent of the potential improvement in the yields on cropland as a whole over the next 20 years. Because of the dominance of large-scale farms in agriculture, a 40 percent improvement in their yields over the next 20 years—double our base-case projection—would account for a large part of the overall opportunity. This is despite the fact that the potential to improve yields is much larger on smallholder farms.

When measuring crop yields, it is important to factor in relative conditions for crops. A key source for such information is the International Institute for Applied Systems Analysis's global agro-ecological zones, which take into account relative soil and weather conditions. However, there is no separate measurement of the performance of large-scale and smallholder farms. Because of this data gap, we

132 The national energy performance rating is a type of external benchmark that helps energy managers assess how efficiently their buildings use energy, relative to similar buildings nationwide.

have estimated the relative performance of these two types of farm using expert interviews. There is clearly a compelling need to capture this information in the future.

Limited mechanisms for the diffusion of technology are a major barrier to preventing large-scale farms in developing and developed countries from adopting the best technology. A notable exception is the Brazilian Agricultural Research Corporation, known as Embrapa, which has pioneered more than 9,000 technology projects to develop Brazilian agriculture, including designing a tropical strain of the soybean and other crops that can thrive in Brazil's climate and other innovations of relevance for Brazil's unique circumstances.[133]

Investing in farming practices—such as machinery to support precision farming—is capital-intensive. So, too, is investing in the basic infrastructure for getting goods from farms to market. Large-scale farms in developing countries do not always find it easy to access finance at a low enough cost to enable them to invest in more advanced farming equipment. In such cases, it may be necessary to bring forward reforms to strengthen local financial systems. Action on this front could be pursued simultaneously with targeted capital-support schemes such as those operating in Nigeria. In Nigeria, the central bank created a fund supported by the government that helped farmers to meet their need for capital. Large-scale farms also have to be able to operate on an effective scale, and barriers to their expansion need to come down.

Further intensification of farming could potentially have effects on the environment. When we sized the potential to boost growth in yields, we included increases from improved mechanization, genetic variety, and farming practices. So we assume that the use of fertilizer is only higher on smallholder farms that achieve yield increases (our seventh opportunity area). Without the effective management of soil, reduced soil fertility could result. In addition, any increased use of fertilizers—rather than their more efficient use—could increase emissions of carbon dioxide and nitrogen dioxide, and increase runoff of potassium, potash, and nitrogen. It will be important, therefore, to improve crop production per tonne of fertilizer while also improving yields.

3. FOOD WASTE

Reducing food waste in the value chain could deliver 7 percent of the total benefits from increasing resource productivity. However, we find that none of the potential in this area is readily achievable, and 39 percent of the potential faces some challenges. Between 20 and 30 percent of food is wasted somewhere along the value chain, even before allowing for food waste at the point of consumption.[134] In developed countries, the vast majority of waste occurs in processing, packaging, and distribution. In developing countries, poor storage facilities and insufficient infrastructure mean that a significant share of food is

133 Elcio Perpétuo Guimarães, et al., eds., *Agropastoral systems for the tropical savannas of Latin America*, International Center for Tropical Agriculture (CIAT) and Brazilian Agricultural Research Corporation (Embrapa), 2004.

134 We do not consider food wastage at the point of consumption (e.g., food that either spoils in homes or is thrown away by consumers after it reaches the plate) as this is considered a behavioral lever. However, there is large potential to reduce consumer food waste. For example, in North America and Oceania, one-third of fruits and vegetables purchased by consumers is thrown away (Food and Agriculture Organization, *Global food losses and food waste*, 2011).

wasted after harvest. Because postharvest waste in developing countries is twice as large as waste in developed economies, the opportunity in developing economies is relatively big. Developing regions could also invest in additional opportunities in processing, packaging, and distribution. By doing so, these regions could reap considerable rewards on food security because they tend to be home to more net food importers than exporters. As in the building sector, new IT applications may make it possible to track inefficiencies across the supply chain, enabling much better resource monitoring and management.

Reducing food waste will also have significant benefits in cutting the amount of water used in agriculture by avoiding irrigation and reducing energy consumption. Because of the energy consumed throughout the length of the supply chain, reducing food waste at the later stages of that chain can save three times the energy of cutting waste at the postharvest stage (although reducing postharvest and supply-chain waste would have more benefits for food security). Being able to monitor the percentage of food waste in each value chain would be useful for supporting a drive to reduce it. Even in individual countries, there is a paucity of systematically collected data on food waste. The FAO has recently attempted to assess food waste by region, food type, and value chain.[135] This work is a very good start, but it is clear that collectively more needs to be done to track the flow of food waste around the world. The appropriate metric to track performance on capturing this opportunity will differ according to the type of food, the stage of economic development of a particular country, and even each part of the food supply chain. This suggests a wide range of implications for how to go about reducing waste.

Action on this front would require significant investment. The improved storage and transportation necessary to reduce waste are both capital-intensive. Implementing a cold supply chain in developing countries would be expensive. More than 60 percent of the opportunity is in reducing perishable waste throughout the supply chain, and to achieve this will require the development of modern cold storage systems. A system of this kind with a capacity of 30,000 tonnes would have an annualized cost in China of more than $100 million. The public sector clearly needs to get involved, investing in infrastructure, particularly roads.

Even once the necessary investment is in place, case studies have shown that farmers must change their behavior to capture the opportunity in full. For example, one major issue in adoption of using metal silos in some African countries has been the fact that most farmers wanted to keep the grain stored in the safety of their own homes, in case of theft. An effective way to resolve some of these barriers could be mechanisms that help to coordinate smallholders by achieving scale for the purchase of capital-intensive equipment and storage. The private sector can become involved in such arrangements by encouraging investment and providing expertise.

4. MUNICIPAL WATER LEAKAGE

In some areas of the world, a significant amount of water is lost because of leaking pipes. We estimate that there is potential to reduce the amount of leakage that could deliver 5 percent of the total resource benefits available. The size of this opportunity is larger than for irrigation, despite the fact that agriculture represents

135 Food and Agriculture Organization, *Global food losses and food waste*, 2011.

roughly 70 percent of current water withdrawals. The reason is that municipal water is valued at about 15 times as much as bulk water used in agriculture. However, we find that none of this potential is readily achievable, notwithstanding advances in remote monitoring of water leakages.

The rate of leakage varies widely, even among developed economies. While Germany has a leakage rate of just 5 percent, the United Kingdom's rate is 25 percent. The opportunity to plug leaks is particularly large in developing countries. In India, we estimate that action on this front could reduce municipal water demand by 26 percent. Overall, we find that 100 billion to 120 billion cubic meters of water can be saved in 2030 by reducing leaks in the supply of bulk water in commercial, residential, and public premises. There are difficulties in monitoring progress on this opportunity. Data on leakage are not easily available at the country level, especially in developing economies. Two organizations, Global Water Intelligence and the International Benchmarking Network for Water and Sanitation, provide country-level data for non-revenue water, but there is a lack of complete time-series data for many countries. Some OECD countries also publish leakage data at a national level.

This is another capital-intensive lever, but the economics are favorable. For example, we estimate that action to reduce leakage in China could have a 22 percent rate of return, based on the subsidized price of municipal water of $0.50 per cubic meter.[136]

The biggest constraint on the rehabilitation of these networks and the replacement of pipes is a lack of awareness among utilities about the benefits of reducing leaks. In some cases, there is not enough pressure on utilities to perform profitably, and these companies therefore make limited efforts to secure the funding needed to detect and repair leaks. Unconditional financial support from government or subsidies within municipal accounts lead to a lack of incentives for service providers to improve their metering, billing, and collection practices. The World Bank's Water and Sanitation Program found that more than 40 percent of water produced in Indian cities does not earn revenue because of leaks or the fact that water is not invoiced to customers.[137] Municipal operators are also averse to making timely and sufficient capital investment, which means that infrastructure becomes obsolete. Overly defined specifications in the tender process can also lead to inferior performance. Our key recommendations on this lever include conducting regular water audits, reviewing network operating practices, developing information systems, and training and incentivizing staff.

5. URBAN DENSIFICATION

Denser urban development could deliver 4 percent of the total potential benefits in our integrated cost curve. We calculate that 84 percent of this opportunity is readily achievable and the remaining 16 percent has some challenges. Densely planned cities will be important forces that enable a shift away from traveling in private cars and toward public transit over the next 20 years. Jeffrey Zupan of the New York Planning Association has suggested that public transport becomes

136 *Charting our water future: Economic frameworks to inform decision-making*, 2030 Water Resources Group, 2009.

137 Pronita Chakrabarti Agrawal, *Designing an effective leakage reduction and management program*, World Bank, April 2008.

viable at a threshold of around seven dwellings per acre.[138] We include in our analysis a shift of nearly 23 percent of passenger kilometers from light-duty vehicles to public transit buses and bus rapid transit—a shift that delivers more than 80 percent of the savings in this priority area—and a shift of nearly 3 percent of passenger vehicle kilometers to metros. The total reduction of 25 percent of light-duty-vehicle-based travel is based on the IEA's Blue Shifts scenario.[139]

Cities—and their national governments, depending on the constitutional structure—need to invest in the infrastructure required to support this shift. Mayors and regional governments have the most direct control over this lever because they tend to have power over public transit and zoning laws. Nearly 75 percent of mayors have direct control of all or part of the city transit system. Organizations such as the C40 cities forum strive to unite city leaders in settings where they can share best practices on these types of levers, including determining the most effective form of public transport. City authorities need to take into account the relative costs of shifting toward different forms of public transport. Consider, for instance, that building metro capacity is 20 times as capital-intensive per passenger-kilometer as extending the use of buses. Bus rapid transit can be tremendously effective in moving passengers efficiently, as observed in Seoul and Bogotá.

Dense urban development is not just a question of enabling the greater use of public transport. It is also vitally important how cities plan their housing. The way in which new urban residential infrastructure is developed will have a substantial impact on the vehicle miles traveled, and therefore on global oil demand. The Environmental Protection Agency (EPA) in the United States has shown that a household in a dense urban setting consumes only one-third as much transport energy as a household in a "conventional" suburban development.[140] The EPA defines transit-oriented development as "housing that is located in a walkable neighborhood near public transit, employment centers, schools, and other amenities," the benefits of which allow residents to "drive less and thereby reduces transportation costs." Such development also saves time. A recent study from the Texas Transportation Institute found that Americans spend an average of an extra 34 hours a year in their cars because of traffic congestion.[141]

Cities—and governments—should take note of the arguments in favor of denser urban living. We expect the turnover in the urban housing stock to be substantial in both developed and developing economies, and new housing needs to be built in a way that maximizes the productivity and energy efficiency of urban centers. Between 2010 and 2030, the United States and Europe are expected to build 80 million new dwellings. Over the same 20-year period, we anticipate that the urban population of China and India will increase by 50 to 60 percent—that's up to 600 million additional individuals going to live in cities. Much thought needs to go into how to plan urban development to cater to the housing and transport needs of these new urbanites. Getting it wrong would mean missing a once-in-a-generation opportunity to lock in higher efficiency and productivity.

138 David Owen, *Green metropolis: Why living smaller, living closer, and driving less are the keys to sustainability* (New York: Riverhead Books, 2009).

139 *Transport, energy, and CO_2: Moving toward sustainability*, International Energy Agency, 2009.

140 *Location efficiency and housing type: Boiling it down to BTUs*, US Environment Protection Agency, March 2011.

141 *2011 urban mobility report*, Texas Transportation Institute, September 2011.

6. IRON AND STEEL ENERGY EFFICIENCY

Boosting the energy efficiency of the steel industry could account for 4 percent of the total resource benefits we have identified. We calculate that 40 percent of this opportunity is readily achievable and a further 52 percent has some challenges.

Today, the steel industry accounts for 6 percent of global final energy consumption, but the rate at which energy efficiency has been improving has declined. We expect this rate of improvement to be flat or even fall further if no concerted action is taken to boost the productivity of steel production. From 1960 to 1980, annual energy-efficiency improvements ranged from 2 to 4 percent per annum. From 1980 to 2005, this rate of improvement declined to 0.5 to 1 percent a year. Our base case assumes that energy efficiency will increase by 0.7 percent per annum from 2010 to 2030. We see this modest rate being driven primarily by a shift from blast furnaces and BOF to EAF. Technical improvements naturally taking place in the industry will also play a role, but these are likely to yield lower marginal results than historical rates.

There are many opportunities for the industry to accelerate efficiency beyond this 0.7 percent per annum pace. In total, we estimate that the global rate of improvement in energy efficiency of the steel industry could increase to 1.4 percent per annum. China's attitude toward energy efficiency in steel will be particularly important, given how dominant China is in global production.

Recapturing waste heat presents 10 percent of the opportunity in this sector. Cogeneration captures waste heat from power generation and uses it for heating applications at various phases of the steelmaking process. For each tonne of steel produced, cogeneration can offset five to ten kilowatt hours of direct energy (e.g., the direct use of gas and coal in the plant) and 95 kilowatt hours of electricity. Our base case envisages that only 10 percent of this opportunity is tapped, but we assume 75 percent capture in our productivity response scenario. Some cogeneration opportunities are readily achievable, but even capturing this potential will require less sophisticated producers, largely in developing countries, to overcome information failures and obtain access to the critical engineering resources they need. Another opportunity to boost efficiency in steel production is coke dry quenching, which uses water sprinkling to recover heat that would otherwise be diffused into the atmosphere. This technique can capture up to 75 kilowatt hours of electricity per tonne of steel capacity.

About 44 percent of the total opportunity could come from several energy-efficiency levers that could be pulled in the different phases of the steel production process. These include coke and sinter making (e.g., sinter plant heat recovery, the use of waste fuel, and coal moisture control), which can reduce direct energy use by 50 percent. Rolling (e.g., hot charging, recuperative burners, and controlled oxygen levels) can reduce the direct energy use in BOF steelmaking by 88 percent and electricity consumption by 5 percent. Other opportunities exist that are specific to the type of steelmaking process. In BOF steelmaking, for example, pulverized coal injection, top pressure recovery turbines, and blast furnace control systems can reduce direct energy use by 10 percent and electricity by 35 percent. Improved process control, oxy fuel burners, and scrap preheating in EAF steelmaking can cut electricity consumption by 76 percent.

However, efforts to accelerate the energy-efficiency gains in iron and steel beyond 0.7 percent face high hurdle rates for returns on investment. Investors may be deterred by the volatility in energy and output prices and by uncertainty over whether specific plants will remain open. Financing is therefore often pro-cyclical, increasing when prices are high and slowing when prices are low and there is greater risk of plant closure.

A substantial further opportunity—accounting for 30 percent of the total in this priority area—is in shifting iron and steel plants from blast furnaces and BOF to EAF-DRI (direct reduced iron). The hurdle here is access to low-cost natural gas, and this makes such upgrades a hard sell in Europe and Brazil (where gas prices are high) and in China (which has access to cheap coal). It is notable that the single EAF-DRI factory built in Brazil has been idled because of the high cost. The increased supply of shale gas in China and Europe after 2020 may change the equation.

7. SMALLHOLDER FARM YIELDS

Improving yields on smallholder farms, defined as farms with less than two hectares of land, accounts for 30 percent of the opportunity to increase the yields of cropland over the next 20 years. Action on this front could deliver 4 percent of the total resource benefits on offer. We calculate that only 8 percent of the opportunity is readily achievable and that the remainder of the opportunity is likely to be highly difficult to capture.

We find that there is net potential to double current yields—more than on large-scale farms. However, the total impact of doubling yields on smallholder farms is smaller than raising yields by less on large-scale farms. This is because smallholder farms account for only 30 percent of total cropland, and the current level of smallholder yields is 50 percent of the level of large-scale farms.

Boosting yields on smallholder farms would require a significant change in farming practices, and we see this effort being readily achievable only in developed countries. It is not easy for smallholders, who often operate on subsistence incomes and are sometimes very risk averse, to adopt new practices. In some cases, smallholders lack the information they need about the benefits of advanced inputs and farming practices. They may also lack access to market because of shortcoming in the available infrastructure and information. This can raise the cost of farming inputs such as fertilizers and higher-quality seeds and, at the same time, lower the prices at which smallholders can sell their produce.

There is no single solution to finding the right model for supporting a drive to raise yields on smallholder farms. Various organizations and countries are experimenting with different approaches to try to find the right balance between benefits of scale and continued small-scale ownership models. Efforts today include contract farming in Kenya, agro-dealer networks in Nigeria, and smallholder aggregation mechanisms led by the private sector in Morocco.[142] It is vital that the impact of these initiatives is understood in order to ascertain whether they might be workable and scalable elsewhere.

142 This includes contract farming where agricultural production is carried out according to an agreement between a buyer and farmers that establishes conditions for the production and marketing of a farm product or products.

Ensuring that the entire agriculture value chain works is necessary so that improvements in one area of the system, such as increased yields, are not constrained by a lack of connections to market or export infrastructure. In Ethiopia, for example, improvement in seed inputs, supported by good weather, led to a significant increase in maize production in 2002. However, farmers couldn't benefit from the surplus because the country had high domestic transport costs and low purchasing power and the export infrastructure was constrained. Because the economics for the extra maize to reach markets didn't make sense, maize prices more than halved. The lesson is that agricultural transformation requires substantial investment in infrastructure and connections to market as well as improved inputs and farming practices. Having learned from past failures, Ethiopia's latest acceleration of agriculture development is based on an integrated portfolio of projects in five priority areas: enhancing frontline productivity; improving the structure of the industry to develop strong public and private actors in priority value chains; scaling up the development of sustainable irrigation; adopting a sustainable approach to preserving and expanding cultivated land; and putting in place an effective enabling environment including access to finance, the development of necessary infrastructure, the innovative use of communication and technology, and building human capacity in the public sector.[143]

As on large-scale farms, increased farming intensity could have environmental ramifications without effective management of soil quality and fertilizer application. Unlike in the case of large-scale farms, we assume that smallholders will have to increase their use of fertilizer to raise yields. Based on an average 25 kilograms of nitrogen fertilizer per tonne of yield increase, we assume that capturing this opportunity could require approximately 11 million tonnes of nitrogen fertilizer. However, we find that the eight million tonnes of fertilizer saved from avoided land expansion can go a long way toward offsetting this. In aggregate, the additional three million tonnes of fertilizer could increase greenhouse gas emissions by around 0.5 gigatonnes and global energy consumption by about 1 QBTU. However, these increased yields could reduce pressure on additional deforestation. By avoiding 90 million hectares in land expansion, this could deliver a net benefit in reducing greenhouse gas emissions by 1.4 gigatonnes to 1.8 gigatonnes of carbon dioxide equivalent per annum.[144] On top of any resource and environmental benefits, there is a welfare imperative associated with increased smallholder yields. Some 1.5 billion people are dependent on smallholder farm production. They are still operating at a low-income, subsistence level and are vulnerable to ongoing environmental risk.[145] Helping these farmers to raise yields is important for resource productivity, environmental stewardship, and improved distributional objectives.

8. TRANSPORT EFFICIENCY

Improved transport efficiency could deliver 4 percent of the total potential benefits in our integrated cost curve. We calculate that 11 percent of this opportunity is readily achievable and a further 87 percent has some challenges.

143 *Accelerating Ethiopian agriculture development for growth, food security, and equity,* Bill and Melinda Gates Foundation, July 2010.

144 Assumes 300 to 400 tonnes of carbon dioxide equivalent per hectare of avoided deforestation.

145 Julian Quan, *Science review: SR25, a future for small-scale farming*, Foresight Project on Global Food and Farming Futures, 2011.

Although there are significant opportunities to electrify the passenger transport fleet over the next 20 years, ICEs could still account for more than three-quarters of the vehicle fleet by 2030. This share will be particularly high in the case of medium- and heavy-duty vehicles used for industrial purposes and the transportation of goods. Improving the fuel efficiency of these vehicles is therefore critical.

There have been some improvements in transport fuel efficiency over the past 40 years. Inspired by the 1970s oil crisis, the United States put in place CAFE standards that increased the fuel efficiency of new light-duty vehicles (i.e., passenger cars and light trucks) from 15 liters per 100 kilometers in 1975 to 9 liters per 100 kilometers in 1985.[146] The 1985 levels met the basic CAFE requirements but, incredibly, the average fuel economy of new sales remained essentially flat for the next 20 years. Today, there is major scope to further improve efficiency. Original car manufacturers in the major car markets of the United States, Europe, China, and Japan, for instance, appear ready to commit to very substantial improvements in fuel economy standards over the next decade. If they follow through on these intentions, the fuel economy of the average new light-duty vehicle could improve from 7 liters per 100 kilometers today to just below 5 liters per 100 kilometers in 2030.

Given these projected base-case improvements, the incremental potential for fuel efficiency in light-duty vehicles is somewhat limited. We estimate that by 2030, automakers could reduce fuel consumption by an additional 0.6 liters per 100 kilometers to a final consumption of 4.3 liters per 100 kilometers, or nearly 40 percent below today's levels. Light-duty vehicles could therefore travel the same distance as a car from 1975 with only one-quarter of the fuel.

Medium-duty trucks have the potential to improve their fuel efficiency by 11 percent and heavy-duty trucks by 13 percent. However, unlike in the case of light-duty vehicles where we expect nearly 80 percent of the potential to be captured by current policy paths, we estimate that only 15 percent of the potential for medium- and heavy-duty trucks is captured in the base case. We estimate that the fuel economy of medium-duty trucks could improve from 23 liters per 100 kilometers today to 20 liters per 100 kilometers by 2030, and that the fuel economy of heavy-duty trucks could increase from 37 liters per 100 kilometers today to less than 32 liters per 100 kilometers.

Capturing the full efficiency potential of ICEs would require considerable sophistication and investment, and original equipment manufacturers may find the full pursuit unattractive, particularly given that larger cars tend to have higher margins. For example, small sedans have operating margins of around 2 percent, while medium SUVs have operating margins of 6 to 8 percent, and luxury sedans' operating margins are 7.5 to 10 percent.[147] Just before oil prices soared in 2008, John MacDuffie, head of the International Motor Vehicle Program, noted that US automakers were slow to move away from SUVs and pickup trucks "because they needed the profits from those products … it would have been hard to shift

146 Corporate Average Fuel Economy (CAFE) are regulations in the United States, enacted in 1975 and intended to improve the average fuel economy of cars and light-duty trucks (trucks, vans, and SUVs) sold in the United States in the wake of the 1973 Arab oil embargo.

147 This is according to McKinsey's Automotive & Assembly Practice.

resources to build more hybrids."[148] Government fuel-efficiency standards will be important to drive further improvements. A transportation version of Japan's Top Runner program in which manufacturers are requested to improve the energy efficiency of their products to the top level of the benchmark within a specified period could be a useful model for others.

9. ELECTRIC AND HYBRID VEHICLES

The increased penetration of pure EVs and plug-in hybrid electric vehicles (PHEVs) could deliver 4 percent of the total resource benefits that we have identified.[149] None of this potential is readily achievable, but 81 percent has some challenges.

A PHEV contains a small ICE that runs only when the batteries are depleted and allows the vehicle to extend its range with the main electric motor providing the great majority of mechanical energy. Assuming an average life of 15 years, the total passenger vehicle fleet will turn over completely by 2030, leaving ample opportunity for a huge increase in EV and PHEV penetration. We project that aggressive policies (specifically, a cap on passenger vehicle emissions of 40 grams of carbon dioxide per kilometer by 2050, which is not feasible with improvements to ICEs alone) could mean that electric and hybrid vehicles comprise 62 percent of new light-duty vehicle sales in 2030 (51 percent PHEVs and 11 percent EVs). Such a shift would cut oil demand by 6.7 million barrels of oil per day, or about 8 percent of current demand. Net energy demand would fall by slightly less than this because energy demand would shift from oil to the electrical grid.

Most important, investing in EVs over the next 20 years would drive learning curves so that after 2030 there could be a paradigm shift in the transport system. Such investment could even support the smart penetration of renewables such as offshore wind into the grid through providing a distributed storage capacity for off-peak power generation. In 2030, "pure" ICEs could make up an estimated 32 percent of new car sales; by 2040, that could fall to only 5 percent. By 2050, a scenario where emissions are capped at 40 grams of carbon dioxide per kilometer could mean that new vehicle sales could include nearly 40 percent pure EVs, 40 to 45 percent PHEVs (using their small internal combustion engine less than 25 percent of the time), and almost 20 percent hydrogen fuel-cell vehicles. Transport would no longer be dependent on oil, leading to lower exposure to the risk of higher and more volatile oil prices as production and reserves become more concentrated.

There are significant transport cost advantages for EVs compared with ICEs. Our analysis shows that driving an ICE is up to four times more costly per distance traveled than an EV (Exhibit 27). It is important to stress that a significant portion of this cost advantage comes from lower taxes on electricity compared with fuel. Taxes on transport costs for ICEs are roughly four times higher than for EVs. The greater use of EVs would therefore shift value from governments to consumers and, potentially, to utility companies. Over time, governments in consuming countries with high gasoline taxes are likely to rebalance their tax systems,

148 *Behind the curve: Have U.S. automakers built the wrong cars at the wrong time—again?* Knowledge@Wharton, July 9, 2008.

149 Includes EVs, PHEVs, full hybrids, and the increased penetration of cars using compressed natural gas (CNG).

especially if they have supported infrastructure investment or public-private partnerships in EVs. However, even excluding taxes, EVs still retain a sizable transport cost advantage over ICEs.

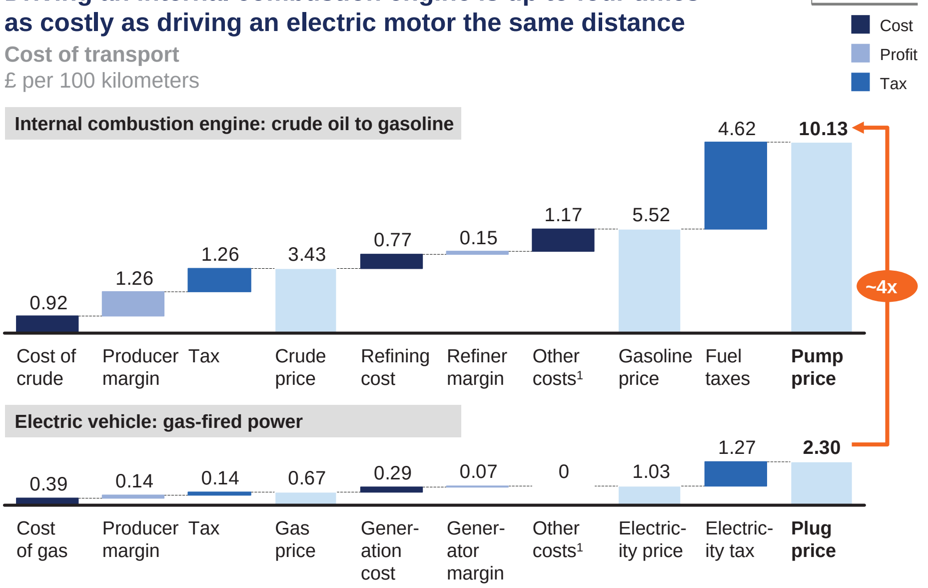
Exhibit 27

Driving an internal combustion engine is up to four times as costly as driving an electric motor the same distance

Cost of transport

£ per 100 kilometers

UK EXAMPLE



1 Includes distribution and retailing costs.
NOTE: Numbers may not sum due to rounding.
SOURCE: McKinsey analysis

Despite that advantage, EVs and PHEVs remain more expensive than ICEs today primarily because of the cost of batteries. The future cost competitiveness of EVs and PHEVs will depend on technological learning rates in batteries and electrified engines versus ICE engines.[150] The pace at which battery prices could decline is uncertain. In our base case, we assume that battery prices, one of the key drivers of the price difference between EVs and PHEVs compared with ICEs, fall from approximately $500 per kilowatt hour today down to $300 per kilowatt hour in 2020 and down to $250 per kilowatt hour in 2030. Under these assumptions, a battery electric vehicle could be roughly $3,500 more expensive than a comparable ICE. Falling battery prices could imply that lower-range EVs could eventually offer lower total costs of ownership than PHEVs given the lower cost of transport for battery-powered propulsion. Because of potentially slower reductions in the cost of conventional parts, at a battery price of $300 per kilowatt hour, the incremental price of a PHEV to an ICE would be roughly the same as an EV.

More dramatic improvements in the cost of a battery can be imagined. If we assume that significant breakthroughs occur in battery technology, battery costs could fall as low as $100 per kilowatt hour by 2030.[151] Under this scenario, assuming that the battery size would also increase by two-thirds to extend the range of the automobile, the cost of a battery-powered EV could be only $1,800

150 Similarly, the penetration of CNG and hydrogen vehicles will depend on the technology evolution of these vehicles compared with other types of vehicles. In addition, beyond heavy-duty vehicles, where limited supply infrastructure is needed, increasing the penetration of CNG in other vehicle types would require significant investment in infrastructure.

151 *The impact of clean energy innovation: Examining the impact of clean energy innovation on the United States energy system and economy*, Google.org, July 2011.

more expensive than an ICE. As a result, it is likely that adoption of EVs could increase to as high as 30 percent of new sales.[152]

The wider adoption of EVs and PHEVs undoubtedly requires government subsidies to make their economics attractive to consumers today. Offering such subsidies is not likely to be easy given the state of government finances in most developed countries at present. In the long run, however, as these vehicles become more widely adopted, they will become more cost-competitive. Another impediment today is the fact that the necessary range of batteries is not long enough for the segment of end users who drive the farthest, and there is a lack of recharging infrastructure to support their use.

Higher penetration of EVs could have multiple benefits for consumers. At these lower prices, total cost of ownership for an EV would be lower than that of an ICE. Cheaper grid storage would also be available through a large network of batteries, allowing for much higher penetrations of solar and wind than would be possible at lower levels of penetration. This would prevent significant spikes in energy prices during times of peak demand for areas that have high penetration of renewable energy. Finally, owners of ICEs would also benefit. As EV penetration increases, electricity would begin to compete with oil in the transport sector, lowering oil prices to consumers.

The carbon impact of EVs depends heavily on the emissions of the grid. In a very dirty grid with high conversion losses, the expanded use of EVs could actually increase emissions by 10 percent. However, on average, shifts in the power mix toward lower-carbon technologies mean that the carbon impact should be quite positive—cutting emissions by 30 to 55 percent in the case of PHEVs and up to 85 percent for EVs. The expanded use of EVs could have the additional benefit of improving the economics of increasing the penetration of renewables by providing distributed storage capacity for downloading off-peak power and making it available (through smart grids) at times of peak demand.

10. LAND DEGRADATION

Reducing the degradation of land and restoring land that is already degraded could deliver 4 percent of the total resource benefits we have identified. The net rates at which land degradation is occurring can be reduced either by preventing ongoing degradation through more conservational farming practices such as no-till agriculture or restoring degraded land through such practices as terracing and the replacement of topsoil. We find that none of the overall potential is readily achievable and 36 percent has some challenges.

Because there has already been a significant amount of degradation with varying severity of yield loss, rehabilitating the productivity of this cropland would offer substantial benefits to agricultural productivity around the world. The Global Land Degradation Assessment (GLADA) and the Global Assessment of Human-Induced Soil Degradation (GLASOD) gather historical data on soil degradation and monitor current trends. However, there is no annual reporting of these estimates today. Nor are there unified standards to define degradation. Specific data about cropland degradation are scarce. All of this limits the ability to monitor progress toward reducing land degradation.

152 *The impact of clean energy innovation: Examining the impact of clean energy innovation on the United States energy system and economy*, Google.org, July 2011..

Rehabilitating degraded land is capital-intensive, particularly in the case of severely degraded land. In some cases, the cropland is in areas where there is no clear ownership (this occurs in Africa, for instance) and is occupied by a household that lacks access to the finance needed to put the problem right. Moreover, the return on such investment tends to be relatively low, and in many cases some kind of public support may be necessary for restoration.

Preventing the degradation of land would require farmers to adopt crucial practices such as no-till or low-till agriculture. The implementation of land certification programs (which has proven highly challenging in many developing countries, primarily due to a lack of community engagement) and extension services (i.e., providing training to farmers on new techniques) will be important components of any drive to address land degradation.

To date, we have seen governments leading most initiatives to reduce degradation. One example is the soil erosion control program put in place by China in eight regions.[153] Another is the Egyptian government's Fuka-Matrouh program, launched in 1993 in collaboration with the Mediterranean Action Plan of the United Nations Environment Program to rehabilitate the northwest Delta area.[154] Central to these programs is assessing soil degradation to identify the most effective restoration approaches and supporting conservation through extension services and financial support. Although governments have tended to drive such initiatives, the private sector could participate at the implementation stage. We are also beginning to see the deployment of new technological packages for the refertilization of soil, which has benefits for terrestrial carbon and water retention. Such technology could have a game-changing impact on the economics of land restoration. Many agribusiness players are interested in the potential of growing high-value crops, including biofuel crops, on restored land.

11. END-USE STEEL EFFICIENCY

Another 4 percent of the total resource benefits available could come from increasing efficiency among the main end users of steel—the construction, machinery, and automotive sectors, which today account for 80 percent of global demand. We calculate that 21 percent of the potential in this group is readily achievable and a further 64 percent has some challenges. We find that there is an opportunity to reduce steel annual demand by 165 million tonnes in these sectors by 2030 through optimizing the design and increasing the penetration of higher-strength steel.

- **Higher-strength steel in construction.** The construction sector accounts for nearly half of global steel consumption. Rebars (short for "reinforcing bar") and heavy sections (columns and beams) are the main steel products used in this sector. Using higher-strength steel in construction can save 105 million tonnes of steel (45 million tonnes in rebars and 60 million tonnes in heavy sections) in 2030, a savings of 9 percent compared with using regular steel on the basis of a penetration of higher-strength steel of 30 to 35 percent. Researchers at Cambridge's WellMet 2050 project have found that developing countries such as China use lower-strength steel (335 MPa) rebars, while Europe tends to use

153 *Asia-Pacific environment outlook*, Environment Assessment Program for Asia and the Pacific, United Nations Environment Program, 1997.

154 *Land degradation assessment and prevention: Selected case studies from the ESCWA region*, Economic and Social Commission for Western Asia (ESCWA), United Nations, 2007.

400 to 500 MPa rebars.[155] Companies such as Qube Design Associates have developed optimized rebars that can reduce their weight by 30 percent. If all developed countries moved to a 500 MPa rebar strength and if 50 percent of the use of rebars in developing countries moved to 450 MPa, this would save around 45 million tonnes of steel in 2030. ArcelorMittal, the world's largest steel company, has estimated that substituting higher-strength steel achieves a weight reduction of about 32 percent in steel columns and 19 percent in steel beams.[156] Buildings such as the Shanghai World Financial Center and Emirates Towers in Dubai have already adopted higher-strength steel. Apart from saving on steel, this technology reduces carbon dioxide emissions during construction by an estimated 30 percent.

- **Design optimization and higher-strength steel in automotives.** The automotive industry has been trying to move toward producing lighter cars to improve fuel efficiency, and higher-strength steel and advanced higher-strength steel are already increasingly popular in the sector. Substantial research has demonstrated a potential to reduce the weight in automobiles by a further 20 to 25 percent through a combination of design optimization and using higher-strength steel. Even with currently proven technology, realizing the potential weight savings could save 35 million tonnes of regular steel in 2030.

- **Increased use of higher-strength steel in the machinery sector.** This sector is likely to account for 20 to 25 percent of global steel demand in 2030. Machinery's potential to reduce weight is theoretically similar to that of the automotive sector, but it thus far lags behind the auto industry because concerns about fuel efficiency are relevant for only a few types of mobile machines such as cranes. However, if we draw on historical trends in weight reduction in the automotive sector, we estimate that the machinery sector could save 25 million tonnes of steel in 2030.

Although the economics of adopting higher-strength steel are favorable, there is some doubt about whether materials such as niobium and manganese will be available in sufficient quantities to use them in alloys. In addition, there is a lack of awareness about the usefulness of this product among the many fragmented buyers of construction steel in emerging markets. Government standards could play an important role in mandating the use of higher-strength steel in different applications to ensure that more players capture the profitable opportunity that this technology offers.

12. OIL AND COAL RECOVERY

Improving recovery rates from coal mines and oil fields could deliver 3 percent of the total benefit we have identified. We estimate that half of this opportunity is readily achievable and that the remainder has some challenges.

Small coal mine operations—and many oil fields—leave a significant portion of the fossil fuel in the ground. Increased mechanization could enhance recovery

155 Julian M. Allwood, et al., *Going on a metal diet: Using less liquid metal to deliver the same services in order to save energy and carbon*, WellMet 2050, University of Cambridge, 2011. A pascal (Pa) is the SI (International System of Units) unit of pressure; 1 megapascal (MPa) = 1 million Pa.

156 *High strength steel for low-carbon construction: Today's challenge*, ArcelorMittal at www.arcelormittal.com.

rates by 50 percent in small coal mines in developing countries. We define small as producing less than 500 kilotonnes a year; these coal mines account for about half of today's world production. The Chinese government is making significant efforts to improve the safety of small mines through the consolidation or forced shutdowns of at least 30 percent of existing capacity. This effort should have a positive effect on recovery rates. Our estimate includes only the incremental mechanization of remaining small mines, which we see yielding an additional 477 million tonnes of thermal coal, or 9 percent of today's production.

For oil, adopting practices that lengthen the productive lifetime of wells, for example by pumping carbon dioxide into the well throughout the drilling process, could significantly increase recovery rates. Norway has high oil recovery rates of 46 percent, while the rates in some Middle Eastern countries are today less than 25 percent by some estimates. Using enhanced oil recovery techniques to extend the life of wells could add an incremental 1.5 million barrels per day in 2030, or 2 percent of today's production.

While improving oil and coal recovery can provide attractive long-term returns, in the short term, it can actually increase costs. Capital costs are relatively low, but operating costs can increase substantially. In coal mines in China, cheap labor means that improving mechanization actually increases the operating costs of extraction by 50 to 60 percent. China has managed to overcome these hurdles by applying regulatory pressure on small coal mines from an alternative angle—safety measures. When China raised safety standards, recovery improved. Large mechanized operations have much higher recovery rates and better safety records than small, unmechanized mines. From 2008 to 2010, Beijing set out to improve the performance of more than 4,000 small coal mines and consolidated or upgraded 40 percent of them.

An additional barrier is that there is no widespread regulatory framework to manage the level of recovery in coal mines and oil wells. Norway's government has been working hard in collaboration with the oil industry to overcome these barriers to improving recovery rates. Norwegian production peaked at 3.4 million barrels per day in 2003 and has declined every year since then to 2.3 million barrels per day in 2010 despite steadily improving recovery rates from 34 percent in 1991 to 46 percent in 2010. Today, the government is reviewing a set of 44 proposals that together it believes could boost recovery by 14 percentage points to 60 percent. The measures being considered include government-industry partnerships to pilot new enhanced oil recovery technologies and changing tax rules to make the value of increased production more attractive. This effort could mean that existing fields produce an additional 16 billion barrels from today to the end of their lifetimes, extending the output of some existing wells beyond 2050.

13. IRRIGATION TECHNIQUES

Micro-irrigation systems that use sprinklers, and even more so drip irrigation, can replace flood irrigation, increasing yields and saving on water at the same time. This is the second-largest opportunity to reduce the global consumption of water after improving crop yields. We find that improving irrigation techniques can deliver 3 percent of the total resource benefits on offer but that only 5 percent of this opportunity is readily achievable. The remainder has some challenges.

The use of sprinklers can improve yields by 5 to 20 percent and reduce the water required by 15 percent. Drip irrigation is even more effective, improving yields by

15 to 30 percent while reducing the water required by 20 to 60 percent. Together, these levers have the potential to save 250 billion to 300 billion cubic meters of water in 2030—savings on net water withdrawal. Drip irrigation has the potential to save a large amount of water withdrawal on any given farm, but these savings are lower if we consider return flows. For example, the use of drip irrigation in sugarcane farming in India can reduce gross withdrawal by 40 percent but net withdrawal by only 18 percent. In coastal regions, these irrigation techniques can also prevent land degradation caused by salinization, by slowing depletion of local aquifers.

Adoption of these practices varies significantly across different geographies.. Israel, for instance, has adopted the drip approach in more than three-quarters of the entire irrigated area in the country. By contrast, in India—an equally water-short country—this method covers less than 5 percent of its cultivated land. We should note that micro-irrigation techniques are not typically used for rice but are popular with crops other than cereals and that their use can be expanded. Historical data on the use of sprinkler and drip irrigation as a percentage of the total irrigated area by country are available from the FAO and the International Commission on Irrigation and Drainage. However, the data are not up to date.

Despite the favorable economics of using sprinkler and drip irrigation, there are still three major barriers. First, drip irrigation equipment is capital-intensive and, as we have discussed, many smallholders and marginal farmers do not find it easy to access credit. Second, many smallholders lack information about the benefits of these irrigation techniques, and this encourages inertia. Third, in most parts of the world, water does not have a market price. If it did, the economic returns for investing in improved irrigation would be even more favorable.

Israel's heavy use of drip irrigation has increased the country's agricultural output 12-fold over the past 50 years, even while its water consumption has remained constant. The key source of Israel's success has been agricultural R&D and a quota system that discourages overconsumption. Israel has also integrated drip irrigation with the application of fertilizers in a method known as fertigation. In this technique, farmers apply water and fertilizers directly and precisely to the plant roots according to the amount needed.

14. ROAD FREIGHT SHIFT

The transportation of goods today requires more than 20 million barrels of oil per day, and this is expected to increase to 31 million barrels of oil per day in 2030. Freight transport (including air) currently accounts for more than one-third of oil consumption in the transport sector. Shifting some of this freight transport from road to more efficient sources of transport such as rail and shipping could deliver 3 percent of the total resource benefits that we identify. However, none of this potential is readily achievable, in our view.

Shipping and rail transport is significantly more energy-efficient than road transport. Transport via waterways currently requires around 20 liters per 1,000 revenue tonne-kilometers.[157] Rail transport needs about 6.8 liters per 1,000 tonne-kilometers and trucking around 50 liters.[158] Switching 20 percent

157 Utilized (sold) capacity for cargo is expressed in metric tonnes, multiplied by the distance flown.

158 Based on McKinsey analysis and expert interviews.

of kilometers from truck-based freight to rail and 5 percent to barge could reduce oil demand by 2.3 million barrels per annum in 2030 and account for 20 percent of the total energy transport efficiency opportunity (roughly 4 QBTU in 2030). China, India, and Europe together account for two-thirds of the opportunity, as existing, or rapidly expanding, rail networks provide the greatest potential for shifts away from trucking. The impact on oil will vary by region, depending on the type of energy used in rail. In China and India, nearly all trains run on diesel compared with only around 50 percent in OECD Europe.[159]

Despite the generally attractive returns from shifting from road to rail and shipping, three major barriers prevent change. First, many regions currently lack viable rail and shipping options, and building them (or expanding them to deal with volume requirements) requires significant up-front capital investment. Second, even where the necessary infrastructure does exist, inertia and entrenched behavior will be difficult to overcome. Many business supply chains today are based solely on road freight transport, and there may be significant sunk costs involved in changing to alternative freight transport channels. Third, there is a need to manage potentially increased complexity in supply chains and difficult trade-offs. Optimizing the energy efficiency of a supply chain's transportation process is a challenging task made harder by inevitable tensions between the supply-chain group and functions such as sales, service, and product development. Tricky trade-offs also are likely, for example, between service levels and the lower speed of energy-efficient transport.

Part of the answer will be creating nimbler supply chains by, for example, using slower, more energy-efficient modes such as ocean freight for the base load and reserving faster, less energy-efficient modes such as road freight for peak demand. Change will also require greater cross-functional collaboration on supply-chain issues within companies.

15. POWER PLANT EFFICIENCY

Nearly 5,300 terawatt hours of coal and 2,300 terawatt hours of additional gas generation will come online from 2010 to 2030—a substantial opportunity to boost the energy efficiency of power plants. Making power plants more efficient can deliver 3 percent of the total resource benefits that we identify, but none of this potential is readily achievable.

We expect nearly one-third of coal plants will still be using subcritical technology in 2030, and half of gas plants will use basic gas turbines rather than combined-cycle gas turbines. If we assume that half of these plants upgrade to more efficient technologies, including ultra-supercritical coal and combined-cycle gas turbines, savings on the use of primary fuels could reach 140 million tonnes of coal in 2030 (3 percent of current production) and 1.5 trillion cubic feet of gas (1 to 2 percent of current production). There is room to improve conversion rates from natural gas and coal by five to ten percentage points. In China, where more than 80 percent of existing plants are subcritical, conversion rates stand at 34 percent today compared with Canada's average of 41 percent, achieved through the extensive adoption of advanced power plant technologies. From 2005 to 2010, China added 50 gigawatts of coal capacity per year. From 2010 to 2030, we estimate that it will add 550 gigawatts of incremental coal capacity (or nearly 30 gigawatts per year), equivalent to the current coal capacity of the United

159 *World energy outlook 2010*, International Energy Agency, November 2010.

States, Canada, Western Europe, and Japan combined. Clearly, locking in more efficient plants in China would have a significant impact on global demand.

An additional opportunity, which we do not include in our analysis, is using combined heat and power for district heating. This is a system for distributing heat generated from a cogeneration plant for residential and commercial heating such as space and water heating. A traditional power plant converts only about 40 percent of the total energy input to electricity, while 60 percent escapes in the form of heat. A combined heat and power plant captures up to 75 percent of the heat energy (that would otherwise just escape), converts 50 percent of energy inputs into heat, and then distributes that to consumers in a district heating network. In Denmark, district heating covers more than 60 percent of space heating and water heating requirements. In 2007, combined heat and power plants produced more than 80 percent of the heat used in this district heating system.[160]

It is significantly more expensive to make capital investment to try to raise the efficiency of an existing plant than to build a new one with higher energy efficiency. The up-front capital cost of a more efficient plant can be 50 to 65 percent higher than a basic plant. Moreover, investing in such efficiency programs is difficult given uncertainty about future prices—low coal and gas prices give this investment a low rate of return. In the past, governments at both the federal and the state levels have used a combination of carrots and sticks to overcome these barriers. The carrots have included financial incentives to reduce the financial burden on utilities through direct support or indirect changes to rate bases. The sticks have included stricter emissions standards (applied not just to carbon but also to mercury, acid gases, and particulate matter, for instance) to force higher efficiency.

Direct support, involving cash or tax incentives or co-investment in technology, has the most immediate results. The United States has used direct cash incentives, sponsoring a major part of the required investment. The US Energy Policy Act of 2005 led to the funding of several major "clean coal" enhancements, including Duke Energy's Edwardsport integrated gasification combined-cycle plant, which received more than $460 million in federal, state, and local incentives.[161] A less direct financial incentive involves allowing regulated utilities to recoup their investment in newer technologies through adjustments in the rates they charge to customers (i.e., through their rate-base filing). Support for nuclear power in the United States started building about 50 years ago largely due to adjustments in the rate base.

Alternatively, sticks in the form of stricter emission controls can also lead to the phasing out of inefficient plants in favor of more efficient ones that incorporate newer technologies. New rules from the US EPA could drive exactly this kind of shift.[162]

160 *Danish energy statistics*, Danish Energy Agency, 2007.

161 Integrated gasification combined-cycle technology turns coal into gas.

162 Beyond the 15 opportunities we have described, there are a number of additional productivity opportunities across energy, land, water, and steel including improved energy efficiency in the production of petroleum and gas, industrial water efficiency, improved efficiency in feed, the acceleration of second-generation biofuels, and steel scrap recycling.

A resource productivity scorecard: How well are countries doing in capturing the opportunities?

A number of organizations have produced a range of top-down indicators of resource productivity at the country level. These indicators include, for example, energy use to GDP and water use to GDP. As part of its green-growth strategy, the OECD has undertaken the most ambitious of recent attempts to formulate a set of resource productivity metrics. The organization has developed a set of 21 indicators that cover both resource productivity outcomes (e.g., energy use in GDP) and policy outcomes (e.g., energy prices and taxes).

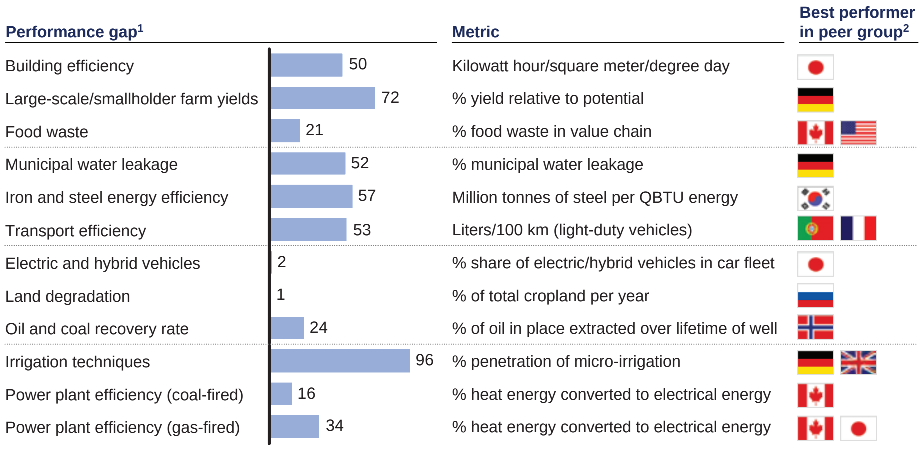
To build on the work on top-down indicators of resource productivity that organizations such as the OECD have pioneered, we have developed a range of metrics that relate to each of the 15 productivity opportunities. We believe that using both top-down indicators and the specific metrics that we have developed in combination offers a more comprehensive approach to tracking progress. Together, they can also smooth out the impact of differences in the sector mix of different countries (linked to stage of economic development) on resource productivity.

Our new integrated resource productivity cost curve is a work in progress, as we have said. So, too, is our work on establishing the best metrics against which to judge the performance of countries in capturing the opportunities available to boost productivity. Our analysis is in its early stages, but we have, nevertheless, begun to build a scorecard (Exhibit 28).[163]

Exhibit 28

Available data suggest that large performance gaps exist between countries on these productivity opportunities

Performance gap between best and worst performers in relevant peer group, %



1 Performance gap is the percentage difference between best and poorest performers in the relevant peer group. In cases where the metric itself is a percent, we take the difference; otherwise, we take the percent change versus the top performer.
2 Peer group varies between metrics based on the availability of data and comparability. For building efficiency, only OECD countries are used. For other metrics, 19 countries were compared where data exist. Urban densification, end-use steel efficiency, and road freight shift were excluded due to lack of data.

SOURCE: IEA; FAO; World Steel Association; McKinsey analysis

On those metrics where cross-country data are available, there is evidence that performance varies widely. For example, within peer groups, we find that there is a performance gap—a percentage difference between the best and worst

163 See the methodology appendix for a detailed discussion of the metrics.

performer in that group.[164] This gap is 50 percent in the case of building energy efficiency, more than 50 percent in municipal water leakage, and 96 percent in the penetration of micro-irrigation techniques. But it is interesting that no one country outperforms all others across the full range of the opportunities we have identified. This suggests that there is real value in countries learning from each other how to capture the potential most effectively—and scope for them to make significant improvements in their resource productivity.

Beyond these metrics, additional consideration should be given to capturing resource productivity opportunities in a sustainable way. For example, increasing yields should be undertaken within the broader context of the food system. Recent work by The Prince's Charities' International Sustainability Unit highlights four goals for the food system: economic productivity, environmental impact, social impact, and resilience (i.e., the capacity to avoid, repel, or adapt to risks and shocks). In this context, additional measures such as tonne of crop production per tonne of fertilizer as well as crop-per-drop are equally important metrics to ensure that agriculture is intensified in a sustainable way.[165]

Achieving progress on some productivity measures could take time. It is therefore important to be able to assess whether countries are on the right track. For this reason, we have developed an initial set of "milestone" indicators that can serve as useful guides for whether countries have put in place the critical building blocks to improve performance.[166] These include the adoption of building-efficiency codes, the introduction of fuel economy standards, investment in urban bus and rail networks, degree of land certification, and share of businesses and households with a functioning water meter. Unfortunately, it is difficult at present to find cross-country data for many of these milestone indicators, and we are treating this as a priority area for future research.

□ □ □

Capturing these resource productivity opportunities would go a long way toward easing the strain on future resource demand. However, even capturing this potential in full still would not be sufficient to address the challenge of climate change. In the next chapter, we discuss what further action is necessary to attain a 450-ppm pathway of carbon emissions.

164 The peer group we use in this assessment varies according to what data are available and how easy or difficult it is to compare them (e.g., between countries with similar stages of economic development or availability of a particular resource). We include only OECD countries in our assessment of progress on building efficiency. On other productivity opportunities, we compare the performance of 19 countries where data exist. We excluded urban densification, end-use steel efficiency, and a shift to using road freight.

165 *What price reslilience? Towards sustainable and secure food systems,* International Sustainability Unit, The Prince's Charities, July 2011.

166 See the methodology appendix for a discussion of these milestone indicators.

5. The climate and energy access challenges

Our supply expansion and productivity response cases indicate how the resource requirements for global growth over the next 20 years might be met. But they do not deliver climate security. In this chapter, we discuss our third illustrative case—the climate response case—which contains additional levers needed not only to reduce the potential impact of climate change to a sustainable level but also to ensure universal access to basic energy services. Our main findings include:

- To achieve a 450-ppm pathway, carbon emissions would need to decline from 48 gigatonnes a year in the productivity response case to 35 gigatonnes in 2030. There would need to be a greater shift from high-carbon power such as coal to low-carbon power, especially renewables, combined with further abatement of emissions tied to land use through the reforestation of degraded land resources (estimated in total at more than two billion hectares), the improved management of timberland, and the increased productivity of pastureland.

- We estimate that an additional $260 billion to $370 billion a year would need to be spent over the next two decades to put this plan into action—even if we assume significant technological improvement.

- Providing universal energy access (i.e., providing all people around the world with access to clean, reliable, and affordable energy services for cooking and heating, lighting, communications, and productive uses) would cost approximately a further $50 billion a year over the next 20 years.

Additional investment of $260 billion to $370 billion a year would be necessary to reach a 450-ppm climate pathway

The emissions pathway that would result from our productivity response case (48 gigatonnes in 2030) is still 15 gigatonnes above the carbon emissions that the Intergovernmental Panel on Climate Change estimates would put the world on course for 450 ppm in 2030—the long-term stabilization of greenhouse gases needed to increase the probability that global warming could be kept within the two-degree Celsius range.[167]

McKinsey's Greenhouse Gas Abatement Cost Curve shows us that this gap could be closed through a combination of increasing investment in renewable energy sources such as wind and solar power, scaling up second-generation biofuels and sugarcane-based biofuel, investing in carbon capture and storage (CCS)

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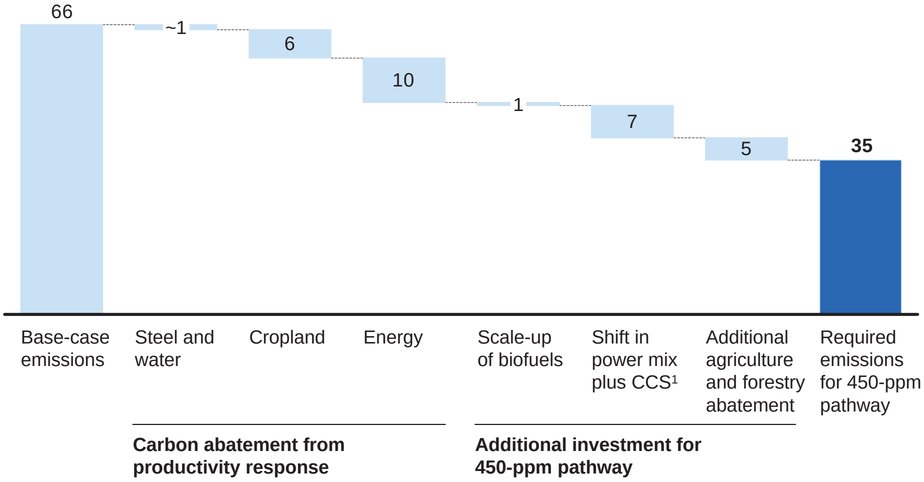
167 A 450-ppm pathway describes a long-term stabilization of emissions at 450-ppm carbon dioxide equivalent that is estimated to have a 40 to 60 percent chance of containing global warming below the threshold of two degrees Celsius.

in fossil fuel power generation, improving the management of pastureland and timberland, and afforesting on freed-up and marginal lands (Exhibit 29).

Exhibit 29

Shifting the energy mix and pursuing additional carbon abatement in land can be used to close the remaining gap to a 450-ppm pathway

Carbon emissions footprint, 2030
Gigatonnes of carbon dioxide equivalent



1 CCS = carbon capture and storage.
SOURCE: McKinsey analysis

In our supply expansion case, annual investment in the generation of renewable energy in 2030 is 30 to 50 percent higher than 2010 levels. However, we project that the renewable share of generation would still be less than one-quarter of total generation in 2030 compared with 20 percent today. A step change is required to achieve sufficient abatement of carbon emissions to reach a 450-ppm pathway.

In our climate response case, total electricity generation is 18 percent lower in 2030 than in the supply expansion scenario. We assume an increase in generation from 21,000 terawatt hours in 2010 to 26,500 terawatt hours in 2030, an increase of 27 percent. In the supply expansion case, we assume an increase to 32,500 terawatt hours in 2030, a rise of 35 percent. In a climate response scenario, renewable power, including hydropower, provides nearly half of global electricity generation in 2030. The contribution of nuclear power to electricity generation would decline from roughly 13 percent today to 11 percent in 2030 (Exhibit 30). Given the importance of nuclear energy for tackling carbon emissions, addressing safety concerns following the Fukushima earthquake will clearly be of high importance.

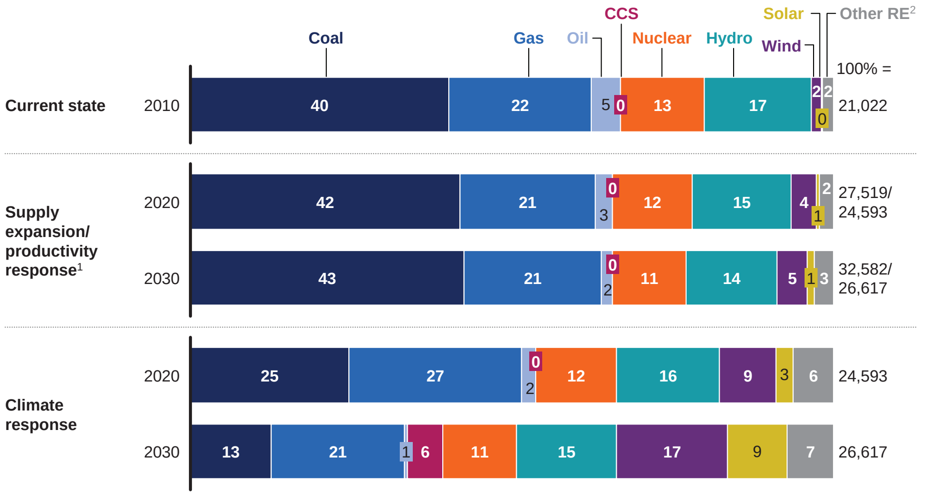
Gas plays a role in reducing global emissions in a climate response case. The share of gas increases from 22 percent of total generation today to 27 percent in 2020. By 2030, however, this share falls to 21 percent in order to bring carbon emissions down to 35 gigatonnes per annum. However, as we noted in Chapter 3, as long as environmental concerns are addressed, shale gas provides a large potential opportunity for innovation in supply. Together with strong growth in coal bed methane, tight gas, and conventional gas production, shale could contribute to an increase in gas's share of power generation in the supply expansion case to 24 percent in 2030. This higher gas scenario would hypothetically represent 29 percent of total generation in the climate change response case, given the lower demand for electricity. The higher gas scenario would be compatible with a 450-ppm pathway only with strong assumptions about the application of CCS technology to gas-fired power plants post 2030 or, alternatively, the post-2030 shutdown of a large part of the gas-fired fleet.

Exhibit 30

Power mix shifts significantly in a climate response case

Share of global power production

%; terawatt hours



1 Same power mix assumed in both the supply expansion and productivity response cases. End demand varies between the two cases—the first number shown on the 100% line refers to supply expansion; the second number to productivity response.
2 RE = renewables. Other RE include dedicated biomass, geothermal, and marine.
SOURCE: McKinsey analysis

Achieving a 450-ppm pathway would require incremental investment on top of that in the productivity response case of between $260 billion and $370 billion a year (Exhibit 31).[168] This large range reflects the uncertainty associated with learning-curve rates of renewable technologies such as solar PV and wind.[169] It does not take into account the potential capital saving associated with reduced adaptation investments (estimated at up to $150 billion per annum) compared with the supply expansion case. On the other hand, it does, however, assume full execution of the resource productivity case. If only a share of the productivity opportunities were captured, which we deem likely, then more carbon abatement—and more investment—would be needed to reach a 450-ppm pathway. For example, if difficult productivity opportunities—an estimated 43 percent of the total potential—were not captured, this would imply an additional seven gigatonnes of carbon abatement would be required to reach a 450-ppm pathway at an incremental cost (on top of that in the productivity response case) rising to between $335 billion and $450 billion a year.

This incremental investment would need to take place in carbon abatement in the waste sector; levers to mitigate greenhouse gas emissions in industry such as clinker substitution by fly ash in cement plants; CCS in cement, chemicals, steel,

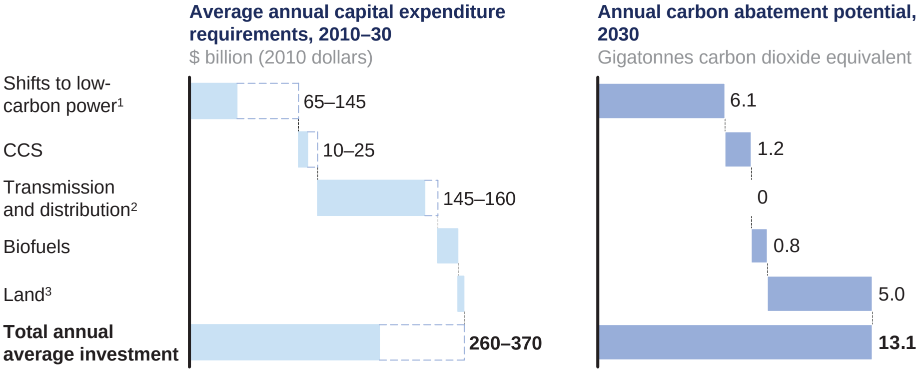
168 We base this on McKinsey's Greenhouse Gas Abatement Cost Curve.

169 In our low estimate, we assume a learning rate in solar PV of 8.7 percent per annum, declining from $3,100 per kilowatt of added capacity in 2010 to $500 per kilowatt in 2030. In wind, we assume a learning rate of 3.4 percent per annum for onshore installations and 7.4 percent for offshore capacity additions. These rates compare with our climate response base case of 5.4 percent, 0.2 percent, and 3.4 percent, respectively.

and the petroleum and gas sectors; and, finally, retrofitting incremental coal-fired power plants with CCS technology.[170]

Exhibit 31

Reaching a 450-ppm pathway would require an additional $260 billion to $370 billion in capital expenditure a year—most in low-carbon power generation



1 Key technologies include hydro, wind, solar, dedicated biomass, geothermal, marine, and coal-to-gas shifts; $65 billion in reduced capital expenditure on coal, gas, and oil power as well as reductions of $8 billion in upstream extraction of these fossil fuels is deducted from the total capital investment for shifts to low-carbon power.
2 Represents costs to scale up transmission and distribution capabilities, including grid enhancements for intermittent supply and long-distance transmission (e.g., offshore wind) and a greater number of capacity additions than in the base case because of the low conversion efficiency of intermittent sources of power.
3 Includes 85 percent capture of abatement potential from McKinsey Global Carbon Cost Curve v2.1 of afforestation/reforestation, timber and forest management, improved grassland management, livestock, and improved soil management.
SOURCE: McKinsey analysis

On the other hand, if we consider a scenario in which governments target only levers with opportunities that offer societal returns (adjusted for subsidies and including the pricing of carbon emissions) of more than 4 percent, closing the gap to a 450-ppm pathway would require less capital than a scenario in which all productivity levers are pulled. Rather than requiring incremental investment above that required for implementing a productivity response case in full of $260 billion to $370 billion per year, achieving the required abatement could require less than $65 billion per year. Such an approach could even result in net savings of $40 billion per year over the full set of productivity levers if there were to be a breakthrough in the cost of renewable energy.

Taking the high end of our estimate of the total investment that we have estimated would be necessary in a climate response case, 85 to 90 percent of the total incremental investment required, or approximately $215 billion to $330 billion, would have to be spent on shifting the power mix to low-carbon energy sources. This investment would include between $65 billion and $145 billion a year for renewables, net of the reduced capital investment in the generation and extraction of fossil fuels. Between 75 and 80 percent of the investment in renewables would need to be dedicated to wind capacity (50 percent) and solar (25 to 35 percent), according to our carbon model. Within wind, 15 to 20 percent of the incremental investment would need to go to offshore farms. In solar, around 25 to 30 percent would need to be spent on concentrated solar power with the balance of the outlay going toward photovoltaic capacity. Dedicated biomass plants, small-scale hydropower facilities, and geothermal installations would account for most of the remaining incremental spending on renewables.

170 The total capital investment for these additional levers and the supporting supply infrastructure is estimated to be up to $350 billion per year, but this is largely offset by the avoided cost of the most difficult energy productivity opportunities.

There would be some shift in investment away from large hydropower facilities to smaller-scale installations. In addition, we estimate that $145 billion to $160 billion a year would be required to improve and expand the global transmission and distribution infrastructure necessary to manage the intermittent generation of solar and wind, and to link increasingly dispersed power plants such as offshore wind and solar farms in the Middle East.

The additional investment needed would clearly be significant. And any such investment would be likely to come up against a range of barriers, particularly if the prices of fossil fuels were to decline in response to lower demand.

Universal energy access would cost only 3 percent of the annual spending needed to meet 2030 energy demand

An estimated 1.3 billion people globally lack access to electricity, and 2.7 billion people still rely on traditional biomass for cooking food, according to the IEA.[171] This has a direct impact on people's welfare. Any fully formed resource revolution would include measures to provide the world's population with access to basic services.

The productivity response case would still leave a significant share of the global population without access to energy. The vast majority of those who lack access to modern energy services live in Africa and Asia. More than 95 percent of those without access to electricity and modern cooking fuels live in sub-Saharan Africa, India, China, and other parts of developing Asia. Sub-Saharan Africa has the lowest penetration of modern energy services. Only 31 percent of inhabitants have access to electricity and only 22 percent to modern cooking fuels. Cooking with biomass causes nearly 1.5 million deaths per annum and is a significant barrier to economic growth by compromising people's productivity. In sub-Saharan Africa, for instance, people spend up to five hours a day gathering wood to use as fuel.

Delivering universal access to modern energy services could cost roughly $50 billion a year.[172] To put this in context, that's roughly 3 percent of the annual capital expenditure needed to meet projected energy demand in 2030. About 55 percent of the capital expenditure would need to go toward off-grid solutions such as small, stand-alone renewable energy technologies. These would include solar PV for lighting and clean drinking water, and micro-hydro or biomass generation for greater load demand. An additional 35 percent would need to be spent on expanding access to the grid, and the remaining 10 percent would go toward providing modern cooking fuels.

Although it is difficult to measure the impact on the environment of ensuring access to modern cooking fuels, it is quite possible that this shift could actually reduce emissions by lowering deforestation rates. Supplying electricity to all is likely to increase carbon emissions by less than 1 percent more than in our base case. In fact, this small impact could be avoided altogether if the expansion

171 *Energy for all: Financing access for the poor*, World energy outlook, International Energy Agency Special Report, 2011.

172 Ibid.

of electricity supply were led by renewable technologies as we are seeing in Bangladesh, India, and many other countries.

Enabling universal access to all modern energy services would increase global primary energy demand by roughly 7 QBTU, according to the IEA—or roughly 1 percent more than our base-case projections for demand in 2030. If energy access were to reach sufficient scale, its provision could go beyond basic residential services such as lighting, refrigeration, and cooking. It could help to unleash a revolution in light industry and service sectors in the countryside, which in turn would increase nonfarm employment and diminish rural-urban migration pressures.

□ □ □

We have laid out what we believe to be the most important measures to take to face the challenges of meeting soaring demand for resources, climate change emission targets, and the ambition of delivering universal access to energy. We have also discussed the very considerable barriers to a resource revolution. The next question is how policy makers might prioritize this very considerable agenda of action and how, practically, they are most likely to achieve success.

6. Overcoming barriers to meeting resource demand

Achieving the resource revolution will be far from easy. The barriers are considerable. All three of the illustrative scenarios that we have discussed face challenges because the investment in new hardware and institutional capacity required is so substantial. In this chapter, we discuss potential approaches to overcoming a range of barriers. Our main findings include:

- New institutional mind-sets and mechanisms are necessary to develop coordinated approaches to meeting demand for resources. Individual government departments need to avoid optimizing the productivity of a given resource without considering the trade-offs or shared benefits with other resources.

- Policy makers should consider taking action on three broad fronts:

  — Consider ways of strengthening market signals rather than dampening them. This would require tackling the $1.1 trillion of subsidies that currently distort resource prices.

  — Mitigate or remove a range of other barriers that hamper the expansion of resource supply and boosting resource productivity, notably difficulties in accessing the substantial capital that is necessary, uncertainties over property rights, principal-agent issues, and obstacles to innovation.

  — Construct more resilient, more effectively governed resource systems. This would require a step change in the quality of information, and consumer and business behavior. Further action would be necessary to reduce the exposure of the most vulnerable households and communities to resource-related shocks.

The barriers to achieving the resource revolution are considerable

The main barriers vary among the three illustrative cases we have described (Exhibit 32). In a supply expansion scenario, there are major obstacles related to supply chains. For example, more than 80 percent of available arable land is in countries with infrastructural issues. There are also concerns that political risk—uncertainty about whether or when policy might change—could deter investment. For example, assets might be nationalized, windfall taxes imposed, or export bans put in place, but such developments are not easy to anticipate. Regulation that might hamper the implementation of projects is another barrier, including concerns about land tenure.

In a productivity response case, there are political and economic challenges in ensuring that resource prices do not stand in the way of capturing the opportunities that are available. But there is also a range of obstacles that do not relate to price. These include low awareness of opportunities, concerns about property rights, a misalignment of incentives between players, and the fact that some productivity opportunities are not viable for the private sector without some form of government support. For instance, at current market prices, almost half of the opportunities in energy have returns that are likely to be lower than private-sector expectations. This means that the main reason why the private sector might invest in these opportunities would solely be as a hedge against future price increases or supply risks.

Of our three cases, a climate response scenario would face the most barriers. Of these, one of the most difficult to overcome is likely to be a need to collaborate internationally to establish some form of linked carbon-pricing mechanism, and/or efforts to generate cooperation on commitments on abating carbon intensity. The other major barrier would be the additional $260 billion to $370 billion capital expenditure a year that would be necessary largely for the generation of power-using renewables.

Exhibit 32

There are significant barriers to meeting future resource demand in each of the three cases

Large barriers
Some barriers
Minimal barriers

	Supply expansion	Productivity response	Climate response
Incentive barriers			
Capital intensity	Up to $3.1 trillion per annum	Up to $3.2 trillion per annum	Up to $3.6 trillion per annum
Return on investment		30% of opportunities have IRR<10%	Requires public subsidy (in short term) for renewables
Decision-making barriers			
Agency issues		Some agency issues in energy	Some agency issues in energy
Political risk	Risk of government interference (e.g., export bans, windfall taxes)	Some opportunities require difficult reforms (e.g., subsidy removal)	Highly challenging, requires international collaboration on carbon pricing
Information failures	Some information failures around remaining reserves	Low awareness of opportunities (e.g., energy)	Low awareness of opportunities (e.g., energy)
Implementation barriers			
Supply-chain bottlenecks	Weak infrastructure; risk of supply-chain crunch	Some specific new skills required	Many renewable technologies lack full value chain
Capital availability	Resource firms have generally easy access to capital for investment	Opportunities less familiar to financial institutions	Renewable opportunities perceived as higher risk, with weaker capital pools
Regulatory issues	Property right concerns (e.g., land tenure)	Property right concerns (e.g., land tenure)	Relies critically on subsidy/payment mechanisms for renewable energy/forests
Technological readiness	Challenging extraction may require new technologies	All opportunities based on existing technologies	Many renewable energy technologies are unproven
Entrenched behavior	No change in behavior	Requires change in behavior and mind-sets	Requires change in behavior and mind-sets

SOURCE: McKinsey analysis

Whichever mix of expanding supply and boosting resource productivity governments choose to adopt, those that take action to preempt the risk of resource scarcity are likely to strengthen their country's competitive position in world markets, protect their economies from adverse terms-of-trade shocks, and be more effective stewards of local environmental capital.

In some sectors, public policy makers may be able to put in place conditions and infrastructure that would accelerate resource-related innovation and enable domestic industries to become more competitive globally. Historically, however, many countries have a mixed track record in managing their energy, land, water, and mineral resources. With a few exceptions, the management of resources has simply not been a political priority. As a result, governments have often under-invested in their resource systems, failed to establish effective market or pricing mechanisms, treated each resource as an independent silo, struggled to enforce individual or communal property rights, created barriers to innovation, and failed to seize opportunities to boost resource productivity. Deep institutional and policy change is necessary.

Tackling barriers needs to start with a shift in institutional mind-sets and mechanisms

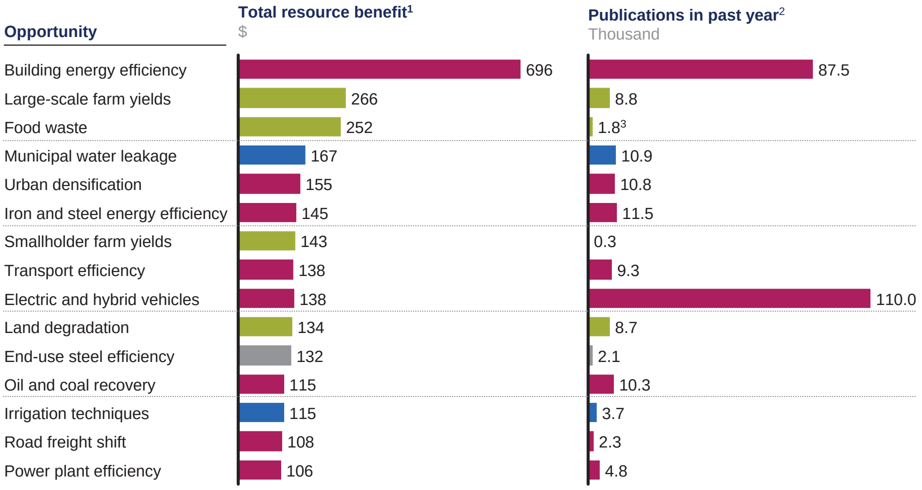
How should policy makers find their way through this complex maze? Overcoming barriers must start with new institutional mind-sets and mechanisms that develop crosscutting, systemic approaches to the management of resources that are incorporated into broader economic policy making. Such efforts need support from strengthened core ministries that deal with resource issues. Officials at the ministries most relevant to the resource system—energy, agriculture, and water—are unlikely to have ever had to deal with the complexity of today's resource markets. They will need new skills to be able to mount an effective response.

Governments tend to take a fragmented, rather than an integrated, approach to resources. For example, issues related to water such as the quality of rivers often fall between the ministries for water, agriculture, urban development, and the environment. Land use tends to fall between agriculture, forestry, and environment ministries at the national level, and between many other stakeholders at the provincial and district levels. Many countries are struggling to put in place effective coordination mechanisms that would enable them to improve their handling of rural development, to engage in climate-smart agriculture, and to ensure reduced deforestation and enhanced food security in a single integrated agenda. Without a more integrated approach, action to boost agricultural productivity could have the unintended consequence of driving up deforestation rates and/or over-exploiting groundwater resources. At times, the international system for official development assistance contributes to this fragmentation because the system has its own parallel set of international agencies, each with a vested interest in its own part of the agenda. Bilateral aid agencies that reflect the different institutional interests of their funding countries can further complicate the picture.

Today's fragmented institutional approach creates a risk that governments miss opportunities or fail to prioritize effectively. Public discourse more broadly doesn't seem to reflect the 15 priorities that we have highlighted. A broad-brush media search on the subject of resources and the issue of boosting efficiency suggests that society has only a partial view of the challenges it faces. The energy efficiency of buildings is the largest opportunity that we have identified, and this attracts a lot of column inches. But other important areas such as food waste and improving the yields on large-scale farms receive little attention compared with their potential impact (Exhibit 33).

Exhibit 33

Public attention is not focused on the most promising productivity opportunities



1 Based on current prices for energy, steel, and food plus unsubsidized water prices and a shadow cost for carbon.
2 Number of times subject appeared in major publications within the past year. Data obtained by performing Boolean searches for relevant terms. Results were evaluated for level of relevance.
3 Refers to postharvest and supply-chain food waste, rather than end-consumer waste.

SOURCE: Factiva Dow Jones Database; McKinsey analysis

An integrated approach to resource management can allow a proper assessment of trade-offs and shared benefits between resources. In Germany, waste management policies and energy taxation addressed materials and energy productivity simultaneously, and this approach resulted in more significant gains because of the linkages between steel and energy (see Box 13, "Boosting steel productivity in Germany"). Had there not been an increase in scrap steel due to Germany's waste management policies, energy productivity would have increased by only 5 percent instead of 17 percent, as there would have been less scrap availability to support EAF plants.

Resource issues often cross geographic or political boundaries, creating a need for new institutions. When it undertook its water reforms, Australia addressed this fragmentation by influencing the public to put pressure on state governments, providing fiscal incentives for reform, engaging stakeholders in the process (including through a new cross-state forum), and benchmarking performance to encourage progress.

Box 13. Boosting steel productivity in Germany

Germany produces 23 percent of Europe's steel, making it the seventh-largest producer in the world. The country has achieved this leading position despite the fact that it has few domestic sources of the raw materials needed for virgin steel production and has to import all its iron ore and most of its metallurgical coke.[1]

In 1990, Germany was producing 80 percent of its steel through the relatively energy-intensive BOF process using iron ore and coke.[2] At this time, recycling of steel was not yet a priority and there was limited availability of recycling equipment. But from the 1990s, Germany implemented an ambitious environmental policy that included increasing taxes on fossil fuels. These taxes gradually ramped up to an even higher level between 2000 and 2003. Steel production is energy-intensive—energy accounts for 20 percent or more of production costs—and these taxes incentivized substantial efficiency improvements. Germany also imposed restrictions on carbon emissions that proved a further incentive for energy efficiency.

Technological improvements increased the average energy productivity of EAF steel plants by more than 20 percent and of BOF steel plants by roughly 8 percent.[3] In addition, the new tax regime and increasing international competition led to increasing substitution in favor of more energy-efficient EAF steel plants. The expansion of EAF plants, which created demand for scrap, combined with an economy-wide waste management program that supported the recovery of scrap (with more end-of-life steel being recovered from tinplates, vehicles, and construction material), and helped to increase the consumption of scrap metal by the steel industry by 80 percent between 1990 and 2007.[4]

1 *Steel statistical yearbook 2008*, World Steel Association, 2009.

2 Wirtschaftsvereinigung Stahl, "Development of steel production in Germany," *Steel Yearbook, 2011*.

3 Jean Theo Ghenda, *CO_2-monitoring-fortschrittsbericht der stahlindustrie in Deutschland–Berichtsjahr 2009*, Stahlinstitut VDEh, June 2010.

4 Wirtschaftsvereinigung Stahl, *Crude steel production and scrap balance*, Stahl-Zentrum, February 2011.

We see three areas where we think any institutional response to the resource challenge should focus:

- **Develop more integrated approaches to resource management, embedded in broader economic policy making.** As part of its sustainable development strategy, the German government has established a cross-ministry forum on resource efficiency so that individual departments do not optimize the productivity of a given resource without considering the trade-offs or shared benefits with other resources.[173] Mexico and South Korea have also established presidential steering groups to drive more integrated resource management or "green growth." The challenge that such inter-ministerial

173 *Decoupling natural resource use and environmental impacts from economic growth*, International Resource Panel, United Nations Environment Program, 2011.

bodies face is how to focus on those resource linkages that really matter rather than becoming an additional source of bureaucratic complexity.

- **Prioritize resource productivity opportunities likely to have the greatest societal benefit.** Policy makers would benefit from taking into account linkages with other resources and the externalities that do not have a price today, as well as the feasibility and relative cost of different opportunities to boost resource productivity. As we have noted, the priorities policy makers are pursuing today are very different from the 15 areas of opportunity that we believe are critical in meeting the resource challenge—as are the indicators they are using to inform their decisions. If governments were to focus on the most promising opportunities more effectively, they would be able to use their capacity in a way that delivers more impact and puts less pressure on scarce political and institutional capital.

- **Strengthen core resource ministries.** At a time when resource-related risks are becoming more complex, the relevant government departments would benefit from gaining access to, and developing, the required talent, stronger evidence-based policy tools, and the broader capacity to implement regulation. Unless they have these in their armory, there is a risk that these ministries could underestimate resource-related risks and therefore "allow" ministries of finance to take the easy option of delaying major policy or public investment decisions in resource systems.

Beyond institutional transformation, action is necessary on three broad fronts

In addition to transforming institutional mind-sets and mechanisms, policy makers have it in their power to take action on three fronts to facilitate the resource revolution. First and foremost, they can consider how to strengthen market signals, rather than dampen them. The investment required to meet the resource challenge is being constrained by many uncertainties, but price is the major barrier. Second, they can act to mitigate or remove a range of non-price barriers. Third, they can bolster the long-term resilience of society in the face of today's resource challenges. We now discuss these three priority areas:

1. STRENGTHEN PRICE SIGNALS

Despite the fact that capturing many productivity opportunities would have sizable benefits for society, a significant number of them are not attractive to private-sector investors. There are a number of reasons for this. One factor is that uncertainty about the future path of resource prices at a time when they are particularly volatile means that it is difficult for investors to judge what returns they might make on their investment, and this acts as a deterrent. Another is that fiscal regimes in many countries are a disincentive to the productive use of resources because governments are subsidizing resources by more than $1 trillion a year. Finally, uncertainty about whether financial support from governments for opportunities such as renewable energy will continue often means that investors demand higher returns to compensate for this risk. Governments could benefit from putting in place stable, effective policy regimes that strengthen market signals and ensure sufficiently attractive returns to engage the private sector. We now explore each of these areas in further detail.

1A. Unwind resource subsidies and recognize externalities

At current market prices, up to 50 percent of productivity opportunities for some resources would require policy support to become attractive for the private sector, assuming a 10 percent real discount rate.[174] Eliminating subsidies and recognizing externalities in the pricing of resources would go a long way toward creating the necessary incentives for the private sector to pursue the productivity opportunities that are available.[175] We find that the effective pricing of resources is the single biggest consistent driver of accelerated resource productivity. Australia responded to strain on its supply of water by creating a market that enabled the trading of water within and across states and mandating the full recovery of costs.

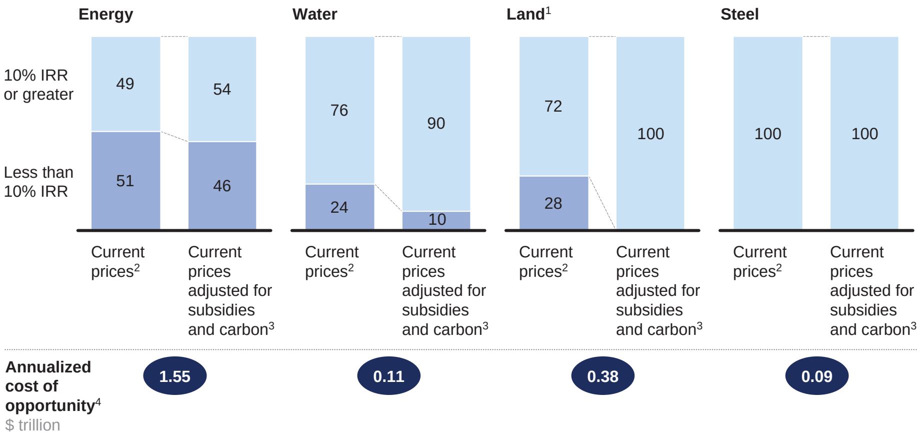
Removing water, energy, and agriculture subsidies and putting a $30 price on each tonne of carbon dioxide equivalent emissions would make the majority of productivity opportunities attractive to the private sector (Exhibit 34). Eliminating the estimated $50 billion of public subsidies spent on fisheries would not only help to strengthen government balance sheets but would also remove one set of incentives for overfishing and excess investment in the global trawler fleet. Allowing utilities to set prices that reflect supply and demand—i.e., are free from government pricing constraints—and to put in place proper billing and cost-recovery systems would also help these companies fund their large future investment requirements.

Exhibit 34

Relatively low investor returns, especially for energy, make the resource productivity agenda even more challenging

Return distribution of productivity levers by resource

%



1 Agricultural levers such as yields and food waste that save both land and water have been shown only under land.
2 Internal rate of return (IRR) based on current prices including taxes and subsidies.
3 IRR based on current prices adjusted for subsidies in water, energy, and food plus a price of $30 per tonne of carbon dioxide equivalent emissions.
4 Assuming a 10 percent discount rate.

SOURCE: McKinsey analysis

The political challenge of reforming subsidies and introducing new forms of taxation should not be underestimated. However, past experience can offer some useful lessons. In particular, shifting the tax base from labor to resources (while

174 See the methodology appendix for an explanation of the return profiles of different resources.

175 The appropriate market instruments for achieving this will vary depending on the context. The OECD's green growth strategy provides a useful overview of different market mechanisms for ensuring competitive investor returns for various green growth opportunities. See Organisation for Economic Co-operation and Development, *Towards green growth: Green growth strategy synthesis report,* May 2011.

maintaining a level total tax burden) can alleviate concerns about competitiveness among businesses and create strong support among stakeholders by potentially boosting employment. Germany, for example, introduced an ecological tax reform in 1999 that effectively increased the cost of energy use by raising taxes on transport fuels, electricity, and heating fuels. However, the reform simultaneously cut the cost of labor by reducing social security contributions. According to the German Institute for Economic Research, the reform created up to 250,000 additional jobs in Germany in the first four years after its adoption.[176] Denmark similarly offset increases in energy taxes by cuts to payroll and income taxes, ensuring that the total tax burden stayed the same.[177] These reforms helped drive an 80 percent improvement in energy efficiency in Denmark between 1979 and 2010 and generated significant growth in employment.

Many proposed approaches to carbon pricing—such as a cap-and-trade system or a carbon tax—include some upfront support from government. In some cases, governments have earmarked the revenues generated through such schemes to compensate industries that would be disproportionately hurt by the introduction of a carbon price, or to promote innovation. Alberta in Canada, for instance, uses revenue raised from a carbon tax to fund a low-carbon technology fund.

There is also a need to mitigate the impact of removing resource subsidies on the poor by providing offsetting welfare support. Indonesia, for example, put in place a conditional cash-transfer program to help cushion low-income households from higher prices that arose as a result of that country's reform of kerosene subsidies in 2005 and 2008.[178] Singapore compensated low-income households for increases in water tariffs by providing rebates in the form of "quasi-cash" that households could draw on at any time to pay utility bills, including water.[179] Mexico has focused its PRONASE energy-efficiency program on low-income households, replacing inefficient fridges and incandescent lightbulbs in a quarter of a million households and paving the way for a phased reform of electricity tariffs. The Mexican government is also considering options for eliminating subsidized electricity tariffs in rural areas and compensating farmers with a lump-sum cash transfer to help them fund investment in more efficient irrigation technologies.

1B. Shape expectations on long-term resource prices

A second area for action would be the use of fiscal instruments to shape expectations about longer-term resource prices. Denmark's energy-tax approach maintained high and stable prices when oil prices fell in the 1980s, and this encouraged continued improvement in energy efficiency (see Box 14, "Improving energy efficiency in Denmark").

176 Ernst Von Weizsäcker, et al., *Factor five: Transforming the global economy through 80% improvements in resource productivity* (London: Earthscan, 2009).

177 Organisation for Economic Co-operation and Development, *Environmentally related taxes in OECD countries: Issues and strategies*, November 2001.

178 Christopher Beaton and Lucky Lontoh, *Lessons learned from Indonesia's attempts to reform fossil-fuel subsidies*, International Institute for Sustainable Development, October 2010.

179 Tan Yong Soon, Lee Tung Jean, and Karen Tan, *Clean, green and blue: Singapore's journey towards environmental and water sustainability* (Singapore: Institute of Southeast Asian Studies, 2009).

Box 14. Improving energy efficiency in Denmark

During the 1970s, the price of oil increased by 500 percent in Denmark, negatively impacting both businesses and households.[1] At the same time, there were increasing concerns about security of supply; 95 percent of oil was imported, and oil accounted for virtually all of the transport sector's energy use and 20 percent of electricity generation.[2] In response to these concerns, the government implemented a four-pronged program focused on incentives for energy efficiency:

- **Targeted subsidies and addressing information gaps.** The government offered a range of subsidies to improve energy efficiency, the aim being to cut energy costs and the nation's dependence on imported oil. In the early 1980s, one program subsidized home energy audits, while another facilitated the installation of additional building insulation.[3] As a result of these and other programs, household energy use dropped by 30 percent between 1979 and 1984.[4]

- **Fuel switching.** In an effort to shift reliance away from imported oil, the government actively expanded its natural gas and coal industries. It succeeded in cutting oil's share of gross energy consumption from 86percent in 1975 to 51 percent in 1986. Discoveries of oil and gas in the Danish part of the North Sea provided a domestic source of these fuels. Energy imports fell from 98 percent of supply to 74 percent.[5]

- **Higher energy taxes.** As global prices fell in the mid-1980s, Denmark increased energy taxes, thereby maintaining end-user prices near to the peak prices of the late 1970s. Denmark raised taxes on gasoline, heating oil, electricity, and coal for both consumers and industry, and doubled its overall revenues from energy taxes.[6]

- **Compensation.** A central element of the Danish tax reform was compensating those most heavily affected with subsidies, exemptions, and tax reductions, thereby smoothing the transition and protecting industrial competitiveness. For energy-intensive industries, it is important to note that this compensation was conditional on meeting targets for energy-efficiency improvement.

Overall, Denmark increased its energy efficiency by 80 percent between 1979 and 2010, during which time consumption was flat, oil consumption was reduced by 50 percent, and overall emissions dropped to 25 percent below 1979 levels. Denmark has been a net oil exporter since 1993 and a net energy exporter since 1997.[7]

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1 Danish Energy Agency, *Energy statistics 2009*, November 2010.

2 Ibid.

3 Danish Energy Agency, *Public heat planning* (1970s and 1980s).

4 Danish Energy Agency, *Energy statistics 2009*, November 2010.

5 Ibid.

6 Eurostat, *Environmental tax revenue*, March 2011.

7 Danish Energy Agency, *Energy statistics 2009*, November 2010.

1C. Increase the transparency and predictability of financial support

A third approach that governments might consider is increasing the transparency and predictability of their financial support for resource productivity and innovation. Consider the unpredictability of feed-in tariffs and the higher returns investors have required because of that unpredictability. This is not an easy problem for governments to solve because, in the context of rapid technological change, they run the risk of over-subsidizing developers of renewable energy projects. There are, however, solutions to this pricing challenge. In India, for example, the government is using a multi-year program of reverse auctions to obtain the best possible deal for each vintage of renewable energy technology. Other countries, such as Germany, have put in place a predictable, relatively transparent mechanism for resetting feed-in tariffs on the basis of future cost curves of major renewable technologies including solar and wind.

2. ADDRESS (NON-PRICE) MARKET FAILURES

Governments can play a role in dismantling non-price barriers ranging from a lack of clear property rights, particularly in agriculture, to agency issues that often prevent the capture of higher energy efficiency, as well as market failures in capital markets and in resource-related innovation. We now explore each of these areas in further detail.

2A. Address property rights

In agriculture, some of the most critical barriers relate to a lack of clear property rights. Take as illustration the province of Central Kalimantan in Indonesia. Plantations have been growing by 70,000 hectares a year, implying that by 2030 their land area would total 2.3 million hectares.[180] Yet Central Kalimantan has about 1 million hectares of potentially available degraded land that could accommodate most of this growth and mitigate the pressure on these disappearing forests. Land tenure and social issues on this degraded land are the main reasons these lands are not being used. So, the government of Central Kalimantan is developing a provincial strategy on reducing emissions from deforestation and forest degradation (or REDD+) that includes a focus on addressing land tenure. Addressing land tenure is also important for ensuring that local populations benefit from investment in agricultural development. Recent research has found that foreign acquisitions of land for large-scale agriculture is often in locations with weak land governance and security of tenure, raising the risk that such investments fail to produce any benefit for the local people.[181]

In mining and other sectors that extract resources, the predictability of property rights, including licensing agreements, is a key issue for the next generation of major projects, many of which are located in non-OECD countries. As companies consider major investments in the next wave of resource supply, their ability to ensure cash flow over the lifetime of the investment could be a key criterion for going ahead. For example, 35 percent of new mining projects in copper and

180 Dewan Nasional Perubahan Iklim and the Government of Central Kalimantan, *Creating low carbon prosperity in Central Kalimantan*, 2010.

181 Rabah Arezki, Klaus Deininger, and Harris Selod, *What drives the global land rush?* International Monetary Fund Working Paper No. 11/251, November 2011.

30 percent of new projects in iron ore are in countries that have issues related to property rights.[182]

A number of countries, including Gabon, are investing in national plans for land use that aim to strike the best possible balance between the needs of the ecosystem on the one hand and, on the other, demand from urban areas and industrial and agricultural sectors, including demand with an energy aspect such as land-hungry renewables. Given the fact that spatial planning and land tenure issues cut across jurisdictions, collaboration among national, state, and district-level governments is critical.[183] Such collaboration needs to be supported by detailed technical analysis of the current allocation of land and the potential benefits of using different types of land for the range of activities that spatial planners address. Technology is an important enabler. But history shows that land titles and spatial planning involve an array of complex historical, social, economic, and political issues. To overcome these, it is important to build involved community support for any initiatives, ensuring that the process is fair and transparent and that citizens clearly understand the benefits.[184] Governments should consider how to strengthen individual and community property rights in other areas such as water and fisheries in a systematic way.[185]

2B. Tackle agency issues

In the energy field, many profitable energy-efficiency opportunities are not captured because of agency issues that can become manifest in several ways. In both residential and commercial buildings, agency issues arise when the landlord bears the cost of investing in energy-efficient insulation but it is the tenant who receives the benefit through lower energy bills. In the transportation sector, agency issues occur when auto manufacturers cannot recoup their investments in improving fuel economy because fuel savings mostly benefit consumers. In the case of industry, agency issues arise when state-owned enterprises are evaluated for their total output rather than for the efficiency with which they produced it. Government efficiency standards can be an effective, low-cost way of overcoming such principal-agent barriers and coordinating a transition to more efficient products, particularly white goods, consumer electronics products, air-conditioning, lighting, and vehicles. With the implementation of such standards, economies of scale emerge and the prices of energy-efficient products typically decline to the level of the old, less efficient products. Instead of regulating the use of specific technologies, standards are more effective if they set targets for overall efficiency, leaving the details of how to meet these targets to innovations at the company level. Including energy productivity in the performance evaluations of state-owned enterprises can achieve similar improvements.

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182 This includes countries with new projects from 2010 and beyond with more than 20 percent of respondents scoring the country's "uncertainty concerning disputed land claims" or "uncertainty over which areas will be protected as wilderness, parks, or archeological sites" as at least a strong deterrent to investment. See Fred McMahon and Miguel Cervantes, *Survey of mining companies: 2010/2011*, Fraser Institute, March 2011.

183 Spatial planning refers to the methods used by the public sector to influence the distribution of people and activities in geographical areas. It includes the planning of land use, transport, and the environment in urban areas and at the regional level.

184 For further detail on approaches to community engagement, see Dewan Nasional Perubahan Iklim and the Government of Central Kalimantan, *Creating low carbon prosperity in Central Kalimantan*, 2010.

185 McKinsey & Company, *Design for sustainable fisheries—Modeling fishery economics*, September 2011.

Several governments have introduced efficiency standards in specific sectors and across industries as a forcing mechanism toward higher energy efficiency. For example, Japan's Top Runner program mandates manufacturers improve the energy efficiency of their products to the top level of a benchmark within a specified period (with a benchmark-resetting mechanism for the next period). Indonesia recently adopted the United Nations' technical regulation on the energy efficiency of automobiles. China has introduced a raft of standards across sectors, including a three-star building-efficiency rating based on the Leadership in Energy and Environmental Design certification system. In Africa, Ghana has established standards for household appliances. Research shows, for instance, that the country's energy-efficiency standard on air conditioners will save Ghanaian consumers an average of $64 million per year on their energy bills and reduce carbon dioxide emissions by some 2.8 million tonnes over 30 years. In transportation, the main opportunity relies on fuel-efficiency technologies in cars that original equipment manufacturers have not adopted because they cannot recover the cost of their investment from consumers through higher car prices. Setting incrementally more stringent fuel-efficiency standards can address this hurdle.

2C. Support access to capital

Investment in the world's key resource systems totals about $2 trillion a year today. Over the next 20 years, this number would need to increase by at least 50 percent and potentially almost double (Exhibit 35).[186] Much of this investment would need to be in places where capital markets are less developed. We estimate that 70 to 85 percent of the opportunities to boost growth in resource productivity are in developing countries. China accounts for up to 40 percent of the productivity opportunities in some resources, and the government has proved that it is able to mobilize large amounts of capital. But outside China, developing countries still account for up to 70 percent of the productivity opportunities in resources such as land and water, and they may not be able to mobilize capital as effectively as China. These economies will need considerable amounts of capital at a time when global capital is likely to become increasingly in short supply.[187] The private sector in Vietnam, for instance, is finding it hard to obtain sufficient capital from local financial markets to implement even those energy-efficiency measures that are evidently profitable. Local banks are often not familiar enough with the potential risks and returns of lending in this area.[188]

186 See our methodology appendix for more detail on how we estimate the required capital investment.

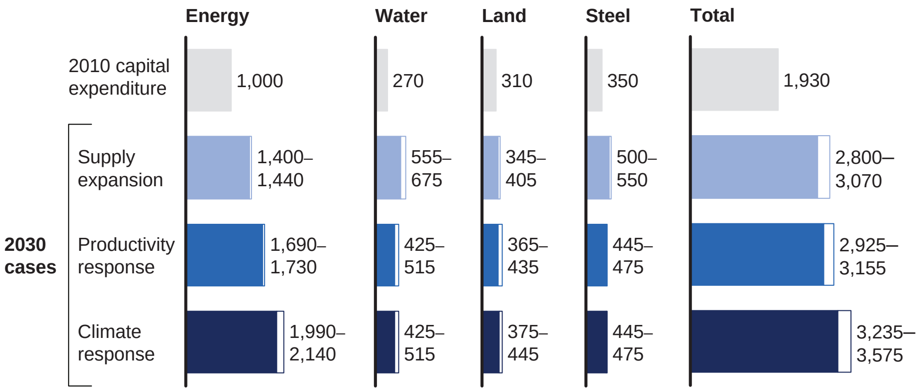
187 *Farewell to cheap capital? The implications of long-term shifts in global investment and saving*, McKinsey Global Institute, December 2010 (www.mckinsey.com/mgi).

188 Project Catalyst, *Making fast start finance work*, Briefing Paper, ClimateWorks Foundation and European Climate Foundation, June 7, 2010.

Exhibit 35

Capital investment could increase significantly under all three cases

Average annual capital expenditure requirement, 2010–30[1]
$ billion (2010 dollars)



1 Does not include capital expenditure for base-case productivity improvements; includes impact of capital price spikes due to supply constraints.
SOURCE: McKinsey analysis

The type and scale of capital and investment constraints vary according to the investor.

- **Small and medium-sized enterprises and households.** Many small and medium-sized enterprises and households do not have access to sufficient capital to finance investments in energy-efficiency measures such as insulation and variable speed drives.[189] While these measures often have attractive returns, it can be hard to attract the capital they require because the borrower may not be deemed creditworthy and/or the underlying assets are difficult to reclaim in the case of default (e.g., removing insulation from housing).

- **Project developers and utilities.** Many project developers and utilities that own and operate key energy and water assets have constrained balance sheets. In many developed countries, utilities are suffering from declining demand for energy due to the impact of the economic crisis and the adoption of various resource-efficiency measures. Utilities in developing countries can find it even harder to find the funds to invest because they often do not have strong, independent balance sheets, sometimes struggle with major losses in their distribution and billing systems, and often rely on state support for access to capital.

- **Institutional investors.** Many longer-term institutional investors including pension funds and sovereign wealth funds are not comfortable with some resource productivity risks including those related to technology (e.g., offshore wind development), regulation (e.g., due to reliance on government support in many cases), and commercial risks (e.g., due to highly volatile resource prices).

189 Variable speed drive describes equipment used to control the speed of machinery (e.g., fans, pumps), which can aid with process control and energy conservation.

Part of the solution to these capital constraints is to strengthen price signals through unwinding subsidies, shaping expectations about long-term prices, and reducing uncertainty about whether government financial support will continue, as we have discussed. Two further areas of action are also critical:

- **Address investment risks.** Beyond those related to prices, investors face additional risks associated with investing in resources, including country, planning, technology, and currency risks. For example, there are often insufficiently liquid markets to enable effective hedging. Or investment is associated with immature, and therefore risky, technologies. These risks drive expectations of returns among investors that may range from 9 to 11 percent in the case of infrastructure projects in mature technologies in developed markets but could be as high as 40 percent in some developing markets.[190] Effective approaches might include expanding financing for institutions such as the Multilateral Investment Guarantee Agency or the Overseas Private Investment Corporation that cover country risk. To reduce planning risk, governments can help to improve the performance of local planning processes. To help address technology and market risk, governments can act as lead customers of emerging technologies through public-sector procurement, and help develop new "business models" to create markets for resource-efficient technologies. An example of this approach is the United Kingdom's Green Deal.[191] Finally, an effective approach to reducing currency risk is to expand the financing of existing funds by offering long-term local currency-hedging products. This is the approach taken by the TCX Currency Exchange Fund.[192] In each case, these measures help to reduce the cost of capital whether by lowering perceived risk or squeezing time delays. Action on these fronts is likely to disproportionately benefit the more capital-intensive technologies that are characteristic of investment in resource productivity.

- **Strengthen private-sector lending.** Underdeveloped local capital markets are likely to prove a key barrier to finding sufficient private capital investment in developing countries where the bulk of resource productivity opportunities lie. The constrained balance sheets of utilities are likely to be a further barrier. Development banks of various types can play a crucial role in providing capital because they can leverage public money with additional private-sector money on their balance sheets. Such provision of capital often comes with implicit and explicit government support for the sectors in which development banks invest. This support might include a mix of policy reforms to improve transparency and the protection of investors, as well as promoting liquidity by channeling financial flows in these markets through various mechanisms such as loan guarantees and co-financing. In some cases, technical support could be provided to local financial institutions to make them more fully aware of the opportunities and the associated risks of lending to new areas.[193] Different sectors and projects need different types of capital:

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190 Project Catalyst, *Making fast start finance work*, Briefing Paper, ClimateWorks Foundation and European Climate Foundation, June 7, 2010.

191 The Green Deal is a framework established by the UK government to enable private firms to offer consumers energy-efficiency improvements to their homes, community spaces, and businesses at no upfront cost, and to recoup payments through a charge in installments on the energy bill.

192 See the fund's Web site for more detail at https: //www.tcxfund.com/.

193 Project Catalyst, *Making fast start finance work*, Briefing Paper, ClimateWorks Foundation and European Climate Foundation, June 7, 2010.

— **Debt.** Loan guarantees can be an effective mechanism for encouraging financial institutions to lend. Development banks can play a crucial role especially in supporting investment in productivity improvement in developing countries. By 2009, the International Finance Corporation had financed $512 million in loans for 99 energy-efficiency projects in China that have targeted the largest energy end users—the steel, chemicals, and cement industries. The European Bank for Reconstruction and Development has disbursed €100 million ($138 million) in credits to Ukrainian banks to finance energy-efficiency projects. The bank also supports Severstal, Russia's second-largest steel company, in an effort to cut the energy consumption of the industry. Governments can also play a role in overcoming market inefficiencies in smaller loans by bundling them and, where appropriate, providing targeted guarantees that make it easier to securitize them.

— **Equity.** Equity (co-)investment by development banks might be required if the sponsor of a project does not have a sufficiently strong balance sheet. This might be the case with undercapitalized utility companies or development banks. Equity investment helps such institutions to generate the ability to raise debt capital from capital markets that they can then provide to target sectors at commercial rates.

2D. Accelerate and deepen innovation systems

We base our analysis of the resource productivity opportunity on technology that is currently available. However, it will be crucial to continue expanding the frontier of innovation in resources. Energy, land, water, and materials have long benefited from an annual underlying improvement in productivity of between 0.5 and 2.0 percent because of advances in technology.[194] This has historically been sufficient to keep the supply and demand of resources roughly in balance without the need for large price increases. However, past rates of innovation-enabled productivity growth are nothing like the rates that we have observed in sectors such as telecommunications or pharmaceuticals. This suggests that there could be significant scope to accelerate innovation in resource productivity. It also seems reasonable to assume that the digital revolution that has accelerated productivity growth across the wider economy could have a similar impact in resource-intensive sectors.

As the OECD has noted, many of the conditions that enable resource-related innovation are the same as those that have a positive influence on the broader economy—a stable macroeconomic environment, vigorous competition, and a sound financial system.[195] However, resource markets have some specific structural features that can pose particular challenges for innovation. These include the commoditized nature of most resource markets, which makes it hard to capture value from differentiation; the capital intensity of many resource supply chains, which leads to more conservative industrial ecologies and barriers to scaling; heavy public-sector intervention in markets such as the power sector, which leads to regulated rates of return; and a lack of clear and stable price

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194 We base this on a historical analysis of yield per hectare and resource intensity of economic growth (i.e., resource inputs relative to economic output).

195 Organisation for Economic Co-operation and Development, *Towards green growth: Green growth strategy synthesis report*, May 2011.

signals and the fact that many resource opportunities are subject to the risk of policy reversal.

Periods during which resource prices have spiked—including the 1970s—have led to bursts of market-based innovation, including the deployment of a range of energy-efficiency opportunities. Today, there needs to be a new wave of resource-related innovation. Some of this will occur naturally as a result of today's higher resource prices. Increasingly cheap IT applications will also help to drive a wave of resource-productivity innovation and management (see Box 15, "The next wave of resource technologies"). Strengthening the design of markets and regulation, addressing property rights and agency issues, and supporting access to capital will also help to create the right environment for innovation but will not be sufficient to accelerate it. Two further areas of action are also likely to be critical:

- **Accelerate R&D investment in resource systems.** Over the next 20 years, investment in R&D in resource systems needs to be more substantial. The government of South Korea, for example, has placed a significant focus on R&D for green technologies as part of its overall green-growth strategy. It has increased public investment for R&D in these areas by more than 20 percent per annum since 2008, reaching more than $2 billion in 2010 (roughly 17 percent of the total government R&D budget). In addition, South Korea has recently announced an ambitious government/private-sector R&D program that will invest $40 billion over the next five years ($7 billion coming from the government and the remaining $33 billion from the private sector) to enhance national competitiveness in emerging technologies such as second-generation solar and offshore wind. Much of this R&D effort will inevitably be local, with markets driving spillover effects into the international arena. But there is also a good case for more international coordination on resource-related R&D. This could lead, for example, to the specification of technology roadmaps (including potential deployment pathways) for renewable energy, nuclear energy, CCS, and genetically modified organisms (GMO). In the 1970s and 1980s, international networks such as the Consultative Group on International Agricultural Research helped to foster the green revolution, transforming cereal production and providing greater food security for billions of people. Suitably adapted and with greater upfront private-sector involvement, there is a strong case for similar international networks to be put in place to help meet today's resource challenge.

- **Use government procurement and target spending on key infrastructure to support ramp-up resource technologies.** Governments could use procurement rules to support the ramp-up of green technologies such as advanced biofuels for military applications. Governments could also consider targeted spending—enabling the private sector to make a contribution—on the infrastructure necessary to pave the way for higher resource efficiency. Smart grids and urban transport systems are prime examples of the potential for city leaderships to capture urban network benefits. Similar IT-enabled opportunities could transform the productivity of all the main resource systems, especially agricultural supply chains that today suffer from substantial failures of coordination and information.

Box 15. The next wave of resource technologies

We base the analysis in this report on technologies that are likely to become technically and economically viable by 2030. A number of technologies now in the early stages of their development have the potential to fundamentally change the availability and price of resources. There are many such potential technologies; here we highlight a few.

- **Solar fuels.** It is possible to use photosynthetic micro-organisms (e.g., algae) to convert waste carbon dioxide and sunlight as primary inputs in the production of ethanol, "drop-in fuels," such as diesel and jet fuel, or specialty chemicals. Solar fuels would, like biofuels, be a natural alternative to oil. However, solar fuels could be up to 200 times more land-efficient than current first-generation biofuels and could be grown on non-cropland, where the sun radiation is the highest.[1] In addition, solar fuels could use brackish water, which would limit their impact on global water withdrawals. Carbon emissions could be 70 to 90 percent lower than with the use of conventional gasoline.[2]

- **Electrochromatic windows and compressorless air conditioners.** Electrochromatic windows—windows that can be darkened or lightened electronically—could manage heat gain by darkening in hot climates during peak hours of sunlight. Technologies such as compressorless air conditioners, which use evaporative cooling rather than commercial refrigerants, provide a low-energy solution to space cooling. Although these technologies are expensive today, by 2020 they could cut building energy consumption at a much lower installation cost than current state-of-the-art windows and cooling systems.

- **Advanced desalination technologies.** These technologies include forward-osmosis techniques and aquaporins—membranes that use natural proteins designed to mimic the way nature removes salt from water as it does in the kidneys. These membranes are 100 times more permeable than commercial reverse-osmosis membranes. They therefore significantly reduce the water pressure required for desalination and, at the same time, greatly improve the quality of the water produced. The saving on energy costs compared with traditional reverse-osmosis desalination is on the order of 70 to 80 percent.[3]

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1 "Joule unlimited company profile," *Technology Review*, Massachusetts Institute of Technology, 2011.

2 Algenol Biofuels, "Algenol overview," 2011, http: //www.algenol.com/Algenol_webpres_2011_3.pdf; Products: Biofuel, Cellana, 2011, http: //cellana.com/products-overview/biofuels/.

3 Sze Chai Kwok, Heather Lang, and Paul O'Callaghan, *Water technology markets: Key opportunities and emerging trends*, Global Water Intelligence, 2009.

(The next wave of resource technologies)

- **Nanostructured steel.** Higher-strength steel has a maximum tensile strength of up to 1,500 MPa compared with a theoretical strength of 13,200 MPa.[1] By adding additional elements such as tungsten or molybdenum during the steel production process, experiments have shown that it is possible to better align steel microstructures and move steel strength closer to its theoretical potential. In tests to date, steel strength has increased to 4,000 MPa, 270 percent above higher-strength steel today.

- **Soil-nutrient management.** Microbial-based ecosystems can help support the management of soil nutrients by transforming organic nitrogen and phosphorous in soil into a usable form of nutrients for plants, increasing the uptake of nutrients by crops, and providing plants with amino acids that aid photosynthesis and resistance to stress. Early results from start-ups show such ecosystems increase plant yields by 10 to 40 percent and reduce fertilizer use by 30 to 50 percent.[2]

- **Fuel cells.** The low-temperature conversion of hydrogen to electricity happens at high efficiencies of up to 60 percent. Applications in the residential sector allow the use of both the produced heat and power, increasing efficiency to over 80 percent. These applications run on natural gas and use a local reformer to produce hydrogen for the fuel cell. Fuel cells in vehicles run on hydrogen, typically produced centrally through steam methane reforming or electrolysis. From a well-to-wheel perspective, fuel cell vehicles are more energy-efficient than combustion engine cars and have a longer range than battery electric cars. Fuel cells are commercially available, and significant cost reductions (up to 80 percent) could be achieved when sales volumes increase to the order of hundred thousands. The main challenge to scaling up fuel cell applications, especially for cars, is likely to be hydrogen distribution.

1 The force required to pull an material to the point where it breaks. See D. J. Branagan, "Enabling factors toward production of nanostructured steel on an industrial scale," *Journal of Materials Engineering and Performance* 14(1): 5 9, 2004.

2 "Our products," Agrinos, 2011, http: //int.agrinos.com/.

3. BUILD LONG-TERM RESILIENCE

Societies need to bolster their long-term resilience in the face of the resource challenge, raising their awareness of resource-related risks and opportunities, creating appropriate safety nets to mitigate the impact of these risks to their poorest members, and educating consumers and businesses to adapt their behavior to the realities of today's resource-constrained world. We now explore each of these areas in further detail.

3A. Build awareness of risks and solutions

In the resource system as a whole, there is no effective early-warning system that gives investors and policy makers the necessary combination of national intelligence on demand, supply, and potential risks and an integrated global perspective. Compound risks—including water scarcity feeding into rising food prices and the shutdown of energy production, for instance—are likely to be of increasing concern. There needs to be proper understanding of these linkages, how they are likely to play out, and how policy could affect them. A range of measures could help build awareness, including:

- **Improve early-warning systems.** A global approach to providing improved information on the availability of a resource and its interdependency with other resources would be useful; so, too, would early-warning indicators such as energy imports as a share of total demand, or the amount of buffer stocks of food and energy. Much more powerful remote monitoring systems and the ability to crunch big data should make it technically possible to make significant improvements in the quality of primary resource data, geophysical models, and econometric predictive tools. Today, data pools tend to be fragmented, but integrating them so that they can be used more effectively would need stronger local and global institutional leadership.[196]

- **Create information programs to boost awareness of opportunities.** Information programs can boost awareness of productivity opportunities in consumer sectors and in industry. Many consumers do not realize the extent of the energy savings that they can achieve by investing in higher energy efficiency. Experience from around the world shows that programs that raise awareness, including campaigns and labeling schemes, help to increase the capture of higher energy productivity. Clear (and accurate) labeling raises awareness and encourages companies to offer more efficient products. Improved labeling could be deployed in the transport sector where, for instance, the industry could inform consumers about dollar savings for the average user instead of solely about the fuel economy of a particular vehicle. Examples of such approaches in action include the EU's energy-efficiency certification scheme for appliances and appliance-labeling programs in the United States such as Energy Star. Developing countries, too, have been quick to adopt labeling schemes. In China, for instance, Chongqing municipality has introduced an energy-efficiency evaluation and labeling system for buildings. India has initiated energy-efficiency ratings of building projects and a market for trading energy-efficiency certificates. South Africa mandates the labeling of appliances according to energy efficiency. Singapore has made such labels mandatory on air conditioners and refrigerators.

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196 For more detail, see Alex Evans, *How a world resources outlook could build multilateral system coherence on resource scarcity issues*, Center on International Cooperation, New York University, August 2011.

In the case of industrial end users of energy, demonstration projects and energy audits are among the tools available to spread awareness. In the United States, the Department of Energy sponsored an assessment in 2006 of steam systems and process heat in 200 facilities. More than 60 percent of the recommendations that emerged from this assessment—$307 million out of $500 million in value terms—were implemented, or were in planning for implementation, after only six months. Moreover, 90 percent of the plants that took part found that the audit played an influential or highly influential role in their implementation of energy-saving projects.

- **Support the exchange of best practice.** Supporting the adaptation of leading global technology to local conditions will be important. For example, Embrapa has pioneered more than 9,000 technology projects to develop Brazilian agriculture. Many of them have focused on adapting foreign technology to Brazilian conditions. Cities, where much of the overall productivity opportunity lies, also need to collaborate more actively (see Box 16, "The role of cities"). There are already forums such as the C40 gathering of cities that enable the exchange of knowledge among cities from developed and developing countries. But more avenues of collaboration would be useful, particularly ones focused on those regions where the most urbanization will take place over the next 20 years.

Box 16. The role of cities

The decisions governments make in the urban setting will be hugely important. Any investment they make—or support—in infrastructure such as public transport and smart grids and in public networks such as recycling can have a critical impact on the economic health and productivity of the world's cities.

Recent MGI research has shown that "middleweight" cities with populations of 150,000 to ten million inhabitants in emerging markets are poised to deliver nearly 40 percent of global growth by 2025.[1] This is more than the entire developed world and developing country megacities combined. How these cities are designed and planned will be crucial to shape attitudes toward the use of resources among the next billion urbanites and will potentially have a large impact on their resource footprints.

Taking action at the city level can face lower barriers than national or international action. However, cities need the knowledge and capabilities to execute a pro-productivity agenda. It is fortunate that most cities have a large share of the powers needed to make change happen and that many are taking action (Exhibit 36). For example, Seoul has introduced bus rapid-transit systems to reduce congestion (including dedicated bus median lanes, high-quality bus stops, real-time information for passengers and system operators, and new, state-of-the-art buses). This has resulted in a fivefold reduction in journey times and a 27 percent cut in the number of accidents—within a year. São Paulo has reduced municipal water losses by improving staff training and repairing infrastructure. Water losses have fallen from 32 percent of revenue to 24 percent. The city's 2018 target is 13 percent, well below the current Brazilian average of 40 percent.

Exhibit 36

Cities control many of the most important levers necessary to push key resource productivity initiatives

Limited control
High control

Sector	Level of city control	Key facts
Buildings		▪ Although most mayors have control over building codes, only 20 percent of mayors have mandated efficient building codes for new construction ▪ 11 percent have mandated energy-efficiency levels in existing buildings (i.e., retrofits) ▪ Urban expansion accounts for 2 million hectares per annum, 80 percent of which is in cropland
Transport		▪ Nearly 75 percent of mayors have direct control of all or part of the city transit system, and nearly 80 percent have control of roads ▪ Almost all mayors control the licensing of taxis, and a large share control procurement of city fleets (e.g., police vehicles)
Power generation		▪ Only 15 percent of mayors exercise control over electricity supply to the city ▪ Nonetheless, 25 percent of those without control have piloted initiatives in distributed solar PV generation
Water		▪ 55–60 percent of mayors control water supply and wastewater treatment
Waste		▪ More than 80 percent of mayors control residential waste collection, and more than half carry this through to disposition

SOURCE: McKinsey analysis

1 *Urban world: Mapping the economic power of cities*, McKinsey Global Institute, March 2011 (www.mckinsey.com/mgi).

3B. Strengthen resource access and safety nets

Increased investment would be necessary to strengthen access to resources and the resilience of economic and social structures. Global action to ensure the provision of universal energy access would have large social returns. As we noted in Chapter 5, providing such access at an "entry level" of 250 to 500 kilowatt hours per person per year would cost less than $50 billion a year over the next two decades. Moreover, the increased demand that would result from ensuring universal access would increase carbon emissions by less than 1 percent. There is also a need to scale up social protection schemes to help people deal more effectively with the risk of resource- and climate-related shocks.[197] Over the next 20 years, the billion people living in rural areas with the lowest incomes are likely to be exposed to increasing risks associated with the continued degradation of the ecosystem combined with adverse weather events. This may spur further rural-urban migration. Over the next 20 years, the middle class could increase by 3 billion, up from 1.8 billion today. The new entrants to these ranks are likely to be the lower middle class—those that cross a $10 consumption per day threshold—who are living in cities are likely to be particularly vulnerable to sharp increases in food and energy prices, given their consumption patterns. There is a significant risk that high, and more volatile, food and energy prices could feed into greater social and political unrest, especially in urban settings where traditional rural, family-based safety nets are not as available.

3C. Shift consumer and business mind-sets

Systems change most decisively when individuals alter their way of thinking and therefore their behavior. Action to engineer such shifts needs to be a core component of any program to increase resource productivity and to mitigate damage to the environment. There are reasons that people may tend to be disengaged from resource issues, or even resist them. For instance, in many developed countries, resource prices are only a small share of overall household budgets, and behavioral changes can offset efficiency improvements (see Box 17, "The potential impact of rebound effects"). Behavioral studies also indicate that consumers often focus on short-term costs without considering the full life-cycle implications of the choices they make—such as whether to buy high-efficiency LED lightbulbs, which cost more upfront than traditional incandescent lightbulbs.

In some cases, the capabilities required to support change may be lacking. For example, even if smallholders recognize that they need to modernize in order to boost their yields, they may not have the necessary skills or the risk-bearing capacity to do this. Finally, there is likely to be a small, but concentrated, group of stakeholders who could potentially lose out in this transition to a more resource-efficient growth path. For example, the phasing out of fossil-fuel subsidies could reduce the profitability of some energy companies and lead to concentrated job losses (e.g., in coal-mining communities). All of this means that price signals alone are not likely to be enough to alter the choices people make about the resources they use.

197 Alex Evans, *Globalization and scarcity: Multilateralism for a world with limits*, Center on International Cooperation, New York University, November 2010.

We see four critical elements to changing behavior.

- **Support demonstration and provide role models to induce a shift.** Role modeling of the desired behavior shift can be a powerful mechanism to induce change. Morocco, for example, launched pilot programs to show how the country's new contract farming approach would work. The aim of these pilots was partly to help make the argument for the transformation.[198]

- **Foster conviction and understanding about the implications of consumption.** Consumer education programs are a critical way of helping people to understand the need to improve resource efficiency and the steps that they can take and, in the process, gain the motivation to change their behavior. The Australian government focused considerable resources on ensuring that all stakeholders understood how critical the country's water situation was in order to win their support for reforms. It will be important to shape the mind-sets of up to three billion consumers who will be joining the ranks of the middle class over the next 20 years so that they make sustainable choices about their consumption of resources. For example, it has long been the case that the consumption of food shifts gradually toward high-protein commodities such as meats, dairy products, and oils as wealth increases.[199] What is quite different in the modern era is that this shift has started to happen at much lower levels of income in China and other developing countries than it has in the past. Demand for meat drives the call on cropland, and there is a large potential land saving from a combination of behavioral and institutional changes that would enable a shifting of diets from meat to fish, as long as the shift were managed in a way that avoided overfishing of already depleted stocks (see Box 18, "Shifting diets from meat to fish").

  It is encouraging that, in India and China, concern about climate change and global warming is higher than in the United States (86 and 64 percent, respectively, compared with 48 percent). Nevertheless, the share of people surveyed in China expressing these worries has dropped from 77 percent in 2009 to 64 percent in 2011.[200] Some programs are already targeting consumers in emerging markets. China's Center for Environmental Education and Communications has launched a program that delivers training for 1,000 youth ambassadors in six major cities (Beijing, Shenyang, Shanghai, Chengdu, Xi'an, and Guangzhou) on energy conservation and sustainability issues. The expectation is that these ambassadors will each train 1,000 people—bringing the message to one million people. It will, of course, be at least as important to reshape the mind-set and behavior of the relatively more affluent consumers in OECD economies whose resource footprint is a multiple of that generated by the new middle-class consumers in emerging countries.For example, in North America and Oceania, one-third of the fruit and vegetables purchased ends up being thrown away.[201]

198 Contract farming involves agricultural production carried out according to an agreement between a buyer and farmers, which establishes conditions for the production and marketing of a farm product or products.

199 Food and Agriculture Organization, *The state of agricultural commodity markets*, 2004.

200 *Sustainable efforts and environmental concerns around the world*, Nielsen, August 2011.

201 Food and Agriculture Organization, *Global food losses and food waste*, 2011.

- **Reinforce change through incentives and formal mechanisms.** Mitigating the negative impact on some stakeholders during the transition process is also crucial if governments are to win their support for change. Shifting incentives is likely to require action at a global level. International trade could be a powerful engine for driving more sustainable, higher-productivity agricultural production by, for instance, providing market access to countries that can demonstrate they are protecting their forest estates. International finance flows for cross-border investment in resource supply and productivity could be strengthened. Mechanisms to deal with differential carbon regimes given limited prospects for a global treaty on climate change could be another area of international collaboration, as would efforts to build a free-trade regime for renewable energy products and services. There is also scope for more regional, cross-border systems for optimizing the water and energy infrastructure.

- **Develop new talent and skills to support behavioral change.** The resource productivity potential could create significant new opportunities for employment and the creation of new skills. Developing skills will be important across the agricultural value chain, especially on smallholder farms and also in plumbing, electrical, ventilation, and roofing within the construction sector. Architectural and construction engineering professions will need new skills to accelerate the adoption of higher-strength steel in new commercial buildings, for instance. A similar need for new skills applies to major resource suppliers such as mining and energy companies, both upstream and downstream, and consumer goods companies. All these businesses need to adapt as business models evolve to incorporate reductions in systematic waste, water consumption, leakage, and pollution, and a greater emphasis on end-use conservation. The market and on-the-job training will develop many of the new skills required, but there will be some cases where governments may need to play a role—providing funding and setting standards for various technical and vocational qualifications, for instance. During Australia's water reforms, for example, the government put significant funds into the retraining of farmers in more water-efficient techniques.

Box 17. The potential impact of rebound effects

The resource-related rebound effects to which we have referred occur when consumption rises in response to the implementation of resource efficiency measures that reduce the price of a product or service, or due to other behavioral responses. Such rebound effects can offset the beneficial effects of higher energy efficiency. There are three types of rebound effects, the first two of which are microeconomic:

- **Direct.** Increased efficiency and the associated reduction in the cost of a product or service results in its increased consumption. For instance, improved insulation lowers energy bills, and people can afford to keep their home heated at a higher temperature. In Mexico, the introduction of more efficient irrigation pumps lowered energy costs but increased aquifer depletion rates.
- **Indirect.** Savings from efficiency enable consumers to spend more on other products and services. As an example, people who save on their energy bills might use the money for an extra holiday that involves a long-distance plane flight.
- **Economy-wide.** Greater efficiency drives economic productivity higher, resulting in more economic growth and higher consumption throughout an economy.

Much scholarly debate surrounds the question of how large these rebound effects might be, but all studies confirm that we should not ignore them. Their impact appears to vary between sectors and countries.[1] For example, the direct rebound effects from increased household energy efficiency—of space heating and cooling, personal transport, white goods, and lighting—are in the range of an estimated 10 to 30 percent in developed countries. These effects could be larger in developing countries where energy accounts for a higher share of average incomes. Rebound effects also appear higher—at 30 to 80 percent—in the case of the fuel efficiency of commercial road transport. Fuel efficiency lowers the cost of freight transport, making it cost-efficient to transport more goods over longer distances and more often.

Rebound effects have three major policy implications. First, policy makers need to reduce their estimates of the impact of energy savings programs by deducting rebound effects. The government in the United Kingdom does this—and has lowered by 15 percent its estimate of how much insulation can cut the use of energy in the home. Second, policy makers should endeavor to mitigate rebound effects by introducing price signals that align with the environmental intensity of goods and services (e.g., taxes or cap-and-trade systems). Governments can offset an efficiency-based price cut by raising taxes so that the effective price does not change. Finally, policy makers can help to change attitudes through consumer education campaigns that argue that, beyond improving efficiency, absolute reductions of energy and resources are required. Smart metering and billing give households and businesses the opportunity to evaluate and adjust their usage.

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1 D. Maxwell, et al., *Addressing the rebound effect*, final report, European Commission DG Environment, July 2011.

Box 18. Shifting diets from meat to fish

Today, approximately one-third of global cropland is used for the production of feed.[1] The type of animal protein consumed has an impact on global demand for land. In a feedlot system, beef requires roughly 6.5 kilograms of feedstock to produce a single kilogram of meat, while chicken requires only 2.0 kilograms. However, fish produces protein even more efficiently. As cold-blooded animals, fish do not need to burn calories to produce heat, and, because fish don't need to support their own weight, they expend less energy than earthbound animals. Tilapia, one of the world's most productive animals, requires as little as 1.2 kilograms of feed to produce 1 kilogram of meat. While tilapia historically has been fed fish meal, recent studies have shown that soybean meal could replace a significant portion of its feed.

The populations of Japan and Indonesia consume the most fish, obtaining 40 to 50 percent of their animal protein from fish, compared with only 8 percent in the United States. Shifting just 20 percent of the world's 2010 calorie consumption from meat to fish would save about 60 to 80 million hectares of cropland.[2] This would be roughly equivalent to three to four times the landmass of the United Kingdom and around 30 to 45 percent of new cropland required over the next 20 years.

If such a shift were to take place, higher demand for fish would have to be met either from sustainable aquaculture or via a dramatic improvement in the stewardship of ocean fishery stocks given the current extent of overexploitation. The FAO estimates that global fish consumption has risen by 120 percent over the past 30 years. An estimated 25 percent of the world's fish stocks are overexploited, and levels of wild catch have stagnated. We should note that aquaculture is not a problem-free alternative to ocean fishing. This industry, too, faces sustainability challenges, including greenhouse gas emissions, local water pollution, the loss of mangrove coastal systems (in some cases), and the depletion of marine stocks used as feed for aquaculture. Encouraging a global shift to fish from meat could also have enormous health benefits because there appears to be a relationship between a meat-heavy diet and a higher incidence of premature heart disease.

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1 Stefan Wirsenius, Christian Azar, and Göran Berndes, "How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030?" *Agricultural Systems* 103(9): 621–38, 2010.

2 Assumes incremental fish production would come from aquaculture.

7. The private-sector opportunity

Companies need to consider how to factor resource-related issues much more directly into their strategic thinking and operational planning. For much of the 20th century, companies were able to ride the wave of lower real resource prices. There was, for many businesses, no need to make resource productivity a strategic priority. However, in a world where resource scarcity—and environmental and regulatory risks—is more likely over the next 20 years, companies need to invest much more leadership capital in their resource agenda. In this chapter, we explore these trends and the strategic and operational implications for firms. We illustrate our findings with examples from brief discussions of three sectors—consumer packaged goods (CPG), oil and gas, and mining. Our main findings include:

- Nine resource-related trends will shape competitive dynamics and operational priorities across a range of sectors.

- The strategic implications of these resource-related trends will vary from sector to sector. But resource-related issues will become an increasingly important component of business strategy and operations in almost all sectors. As with policy makers and governments, the businesses that are likely to be most successful in their response to resource-related issues will be those that adopt a more integrated approach to understanding how resources might shape profitability, produce new growth opportunities, and pose new challenges for their management of risk.

- Companies need to consider how to strengthen their capacity to assess resource price and volatility trends and supply risks, to anticipate likely changes in regulation that relate to resources and the environment, and to choose how best to participate in the evolving resource technological landscape.

- Businesses need to drive resource productivity much more systematically throughout their value chains from suppliers through to end users. Companies can achieve some of this transformation by making simple, but important, tweaks to existing business practices such as giving more emphasis to the "total cost of ownership" in procurement systems. In other cases, companies are likely to need new business models to drive productivity through their supply chains or to shift customers onto services, rather than product, platforms.

Businesses need to understand the opportunity and the value at risk from resource-related trends

The large capital investment required to put in place the required resource supply and productivity agenda, and the value that this agenda could deliver, can create significant opportunities for those firms that develop the capabilities to exploit them. As we have noted, with the exception of energy, the majority of productivity opportunities that we find are available have attractive returns of more than 10 percent, even at today's market prices.

Some firms—not only those that manufacture new products but also those that commission and install new technology—have already capitalized on some of the opportunities. For instance, Otis, one of the worldwide leaders in elevators, escalators, and people-moving belts, introduced the Gen2 elevator type in 2000. Gen2 products use up to 75 percent less energy and yet are quieter and smoother than conventional elevators.[202] Gen2 has become the fastest-selling line in the company's history.

Companies might consider following a three-step process as they assess how their strategy needs to evolve given potentially disruptive, resource-related forces in a particular sector. First, they need to arm themselves with intelligence about which of these disruptive forces are likely to hit their sector. Second, they should seek to understand the likely impact that these forces could have on the competitive dynamics and value creation of their businesses. In other words, they need to assess where they have relatively more exposure to resource trends (positive and negative) than their competition. Third, they need to build on the insights they gain to design and implement strategic, operational, and organizational changes.

Companies should be aware of nine disruptive resource-related trends

We have identified what we believe are the nine main disruptive forces that companies should note as they consider how to calibrate their response to the resource challenge:

1. **More expensive sources of supply.** As global demand for resources grows, the marginal source of supply is likely to be more difficult and expensive to access—in ultra-deepwater wells and oil sands, for instance. Companies also need to take account of the fact that new sources of supply are likely to be located in challenging regions and that there are political obstacles to expanding the use of land. The rising cost of production creates significant risks for companies that rely heavily on resources in their productive processes—manufacturing being an example—especially where margins are narrow and customers are price-sensitive. In the three most recent periods of global economic recovery, prices in the CPG sector grew at an average of more than 11 percent while the prices of raw materials increased by 17 percent. This significant gap implies that CPG companies found it hard to pass on the rising costs of raw materials to consumers in full.

202 *Capturing the European energy productivity opportunity*, McKinsey Global Institute, September 2008 (www.mckinsey.com/mgi).

2. **Increasing volatility of resource prices and correlation between resources and markets.** All of the difficulties and complexities involved in expanding supply sufficiently to meet rising demand can lead to rising volatility that is likely to be compounded by the increasing correlation between different resources and between prices of the same resource in different parts of the world. Companies need to arm themselves to cope with the risk that the prices of many of their inputs could spike at the same time. They need to think in new ways about their exposure even to resources that have indirect links with others, and to the prospect of increased choppiness in the price of their resource inputs. For example, over the past year, rare earth metals have emerged from relative obscurity to become a major—if arguably temporary—risk factor for many high-tech businesses. There is a high chance that other sudden price flare-ups in response to unanticipated shortages of a particular resource will become more frequent over the coming decade. To respond effectively, the most forward-thinking companies are likely to deploy a range of tools beyond traditional hedging techniques that may include closed-loop production systems and longer-term contractual arrangements.[203]

3. **Rising environmental costs.** Environmental constraints, including the potential effects of climate change and water shortages, could become increasingly important in a range of sectors. Changes in weather patterns and rainfall could potentially have a negative impact on agricultural yields of more than 10 percent in some areas with fast-growing populations over the next 20 years. Water shortages could also become an important constraint on production in many sectors. For example, 32 percent of copper mines and 39 percent of iron ore mines are in areas with moderate to high water scarcity.[204] It is notable, too, that the global economy will become more dependent on renewable energy resources over the next 20 years. For example, hydropower is likely to deliver more than 15 percent of primary energy supply—and is critical for energy storage. Major changes in rainfall or snowmelt patterns could make the availability of hydropower much more variable. Tanzania, which relies on hydropower for more than 50 percent of its electricity, suffered a major drought in 2010 and 2011 that resulted in rolling power blackouts.

4. **Increasing geopolitical concerns.** Resource-consuming countries face increasing trade imbalances with economies that are rich in resources. This could raise the specter of political tension between the two. There are already increasing instances of export restrictions being imposed on resources. From October 2010 to April 2011, China, India, Vietnam, and other countries imposed at least 30 new export curbs on mineral resources, up from 25 during the previous 12 months, according to the WTO. In 2008, export restrictions imposed by major rice producers triggered a particularly marked period of price volatility.[205] Companies with global supply chains and just-in-time production need to be particularly on their guard for such disruptive eventualities.

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203 An environmentally friendly production system in which any industrial output is capable of being recycled to create another product.

204 Trucost analysis.

205 D. Headey and S. Fan, *Reflections on the global food crisis: How did it happen? How has it hurt? And how can we prevent the next one?* International Food Policy Research Institute, 2010.

5. **Public policy to reduce subsidies and to price for the true cost of resources.** As government budgets come under pressure, policy makers are moving increasingly to remove resource subsidies that cost up to $1.1 trillion a year and distort the true costs of resources. India abolished gasoline price regulation in June 2010 and plans to do the same for diesel. South Africa has announced plans to increase electricity tariffs by approximately 25 percent per year between 2010 and 2013.[206] A more general shift toward lowering or removing resource subsidies could have profound effects on companies in a range of sectors. In parallel, companies need to be aware of the fact that some countries are moving toward pricing the externalities of resource production and consumption, including carbon and ecosystems. Some governments are also extending requirements on producers to design environmentally friendly products, holding them liable for the costs of managing their products at the end of their life (see Box 19, "Creating the circular economy"). Companies that do business in different regions need to be aware of such policy initiatives in all the locations where they are active.

6. **The new social license for resource companies.** Businesses face increasing demands as the quid pro quo for their "social license" to operate. In extractive industries such as mining, pressure from regulators and environmental groups has already had a significant impact on companies' ability to obtain permits and operate continuously. The result has been a substantial shift in investment toward developing countries with less stringent regulatory standards. However, public policy makers in developing countries are also demanding more in exchange for access to their resource wealth. Some countries, for instance, are mandating the sharing of such wealth in order to support domestic growth and to create jobs. Some governments are also requiring companies to handle extraction in a way that minimizes the environmental impact. In many countries, utilities and oil companies are under significant political pressure to "do something" about rising energy prices. In some cases, this makes it hard for such businesses to pass on the full market cost of resource price increases. Companies that develop distinctive capabilities in shaping their license to operate can potentially create a marked competitive advantage.

7. **Supply-chain efficiency opportunities.** There are many financially attractive ways of improving resource productivity. In the production of liquid goods such as beer, for instance, companies could cut their energy costs by half. In sectors including CPG where margins can often be low, such savings can produce a significant competitive advantage. Leading CPG companies are now looking to drive resource productivity on an end-to-end basis along their supply chains. They have realized that the majority of their consumption of resources, including energy, land, and water, takes place down their supply chains and that much of this consumption is beset with inefficiency. However, driving resource productivity through the supply chain is far from straightforward. Especially in the case of secondary and tertiary suppliers, constraints on capital, skill, and managerial capacity often make it difficult to boost performance. There is also a risk that competitors can free-ride on any improved performance, which weakens the incentive to drive change.

206 For a more extensive discussion of plans for the reform of subsidies, see *World energy outlook 2010*, International Energy Agency, November 2010.

Box 19. Creating the circular economy[1]

Ten million tonnes of material in the economic system are designated as waste every day, and 70 percent of this goes to landfills. In the process, much of the potential value of the materials is lost and the management of solid waste is a drain on municipal budgets. Furthermore, landfills are a growing source of greenhouse gas emissions.

Existing waste management systems have largely been motivated by concerns about health and the environment. Thus far, countries and regions have given little thought about waste as a resource rather than waste as a problem. This is beginning to change in the face of growing geopolitical risk, soaring prices of raw materials, and improving technology for the sorting and treatment of waste and innovations in product design. The logical next step is to create a "circular economy" in which material waste is removed and the energy components embedded in products are maintained, reused, and disassembled so that they can be recovered. Eventually, material could be recycled into a raw material for use in the manufacture of new products or, for specific categories of materials, returned to the economic cycle in the form of recovered energy.

A fully closed circular approach is at work today only in niche markets and a few showcase products that tend to constitute less than 5 percent of a company's portfolio. Realizing the full potential of the circular economy would require companies to take action in four broad areas:

- **Shifting business models from "consumer" to "user" strategies.** Companies need to grasp the potential benefits of various rent, lease, and "take-back" schemes that meet customer needs for functional services without losing control of key materials or degrading their quality.

- **Rethinking design.** Companies should consider how to take a full life-cycle perspective when they are designing products with an eye to improving their ability to reuse products and maintain the quality and serviceability of their components.

- **Improving effectiveness along the materials stream.** Businesses should identify the most economically effective options for design, recovery, collection, and processing so that they can minimize leakage of materials and enable the development of scalable solutions in collection, separation, and remanufacturing or reuse.

- **Making it happen.** Finally, businesses should consider initiating new collaboration across different industries. In some cases, regulatory incentives might be required to fast-track scale and learning-curve effects.

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1 Our thanks go to Jamie Butterworth at the Ellen MacArthur Foundation for providing input on this box.

8. **Technology becoming an increasing source of competitive advantage.** Technological change related to resources has the potential to create rapid shifts in competitive advantage. For example, learning curves for renewable power sources range from 5 to 20 percent. After remaining technologically stable for more than 50 years, the global lighting market is going through its own high-speed revolution as incandescent lightbulbs are replaced by energy-saving compact fluorescent lamps (CFLs) and now light-emitting diode (LED) lamps. Companies need to pursue a strategic approach that reflects their view on the development of technology but at the same time incorporate flexibility into their planning so that they can respond to different ways in which technology might develop.

9. **Customer demand for more resource-efficient products.** Despite some information and awareness barriers, consumers are increasingly conscious of the cost of resources and are increasingly demanding more resource-efficient products. Resource-efficient products from automobiles to domestic appliances, LEDs, efficient air conditioners, or microchips are likely to become an increasing source of competitive advantage for those companies providing them to consumers.

Companies across sectors need common capabilities

The strategic implications of these disruptive resource-related trends will vary from sector to sector, but resource-related issues will become an increasingly important component of business strategy in all sectors. A very broad range of businesses would need to consider how they can adopt a joined-up approach to understanding how resources might shape profitability across their operations, produce new growth opportunities, and pose new challenges for risk management (Exhibit 37). The levers that businesses need to consider include:

- **Growth: Reorienting business models to capture new markets and growth opportunities resulting from resource trends.** The investment required to address demand for resources needs to be devoted to very different arenas (especially geographic) than in the past. Firms that position themselves to take advantage of this shifting landscape stand to profit. Siemens and General Electric, for example, have both invested heavily in emerging clean-energy resource-related opportunities ranging from wind turbines to industrial energy efficiency. Many companies are looking to strengthen their access to resources in non-OECD countries, generating a new competitive race in sub-Saharan Africa and central Asia. New south-south supply chains are being built, linking new resource regions with new demand centers.

- **Return on capital: Improving resource management and reducing the environmental impact of the value chain.** Companies can reduce costs and improve product value propositions by capturing large and very profitable opportunities to improve the efficiency of their use of resources across the value chain. CPG manufacturers have been able to achieve savings of up to 50 percent on their energy and water costs by pulling productivity levers with payback after less than three years. Wal-Mart has implemented a sourcing strategy that aims to reduce supplier packaging by 5 percent by 2013 from 2008 levels, with estimated direct savings of $3.4 billion.[207] However, capturing many of these supply-chain opportunities will require much closer collaboration between upstream and downstream players. Companies need to adjust to a new era by applying the same discipline to resource efficiency as they did in the past to labor.

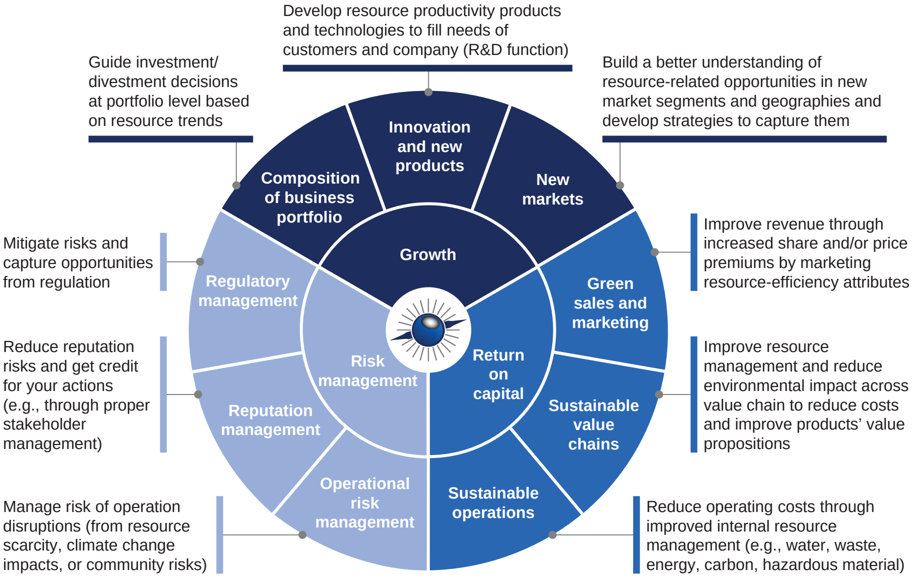
- **Risk management: Pursuing more sophisticated operational and regulatory risk management.** Many critical inputs to the production process are increasingly scarce, and companies need to take action to safeguard supplies of these inputs. They need to develop a sophisticated understanding of their exposure to different resources, including their supply-chain dependencies and regulatory risks. For example, steel is becoming increasingly important in the oil and gas sector because of the shift to offshore deepwater drilling and smaller well sizes. Steel production depends crucially on the supply of iron ore, which relies heavily in turn on the water used in the production process. A great deal of iron ore extraction is in places where water is relatively scarce and often subject to non-market allocation mechanisms. When companies participate in fast-growing, resource-constrained markets, it is highly likely that they would need to invest more heavily in the resource-related elements of their licenses to operate. They may also find themselves in de facto public-private partnerships (including implicit force majeure agreements) on their access to resources including energy and water that increase the value of initiatives and help shape the overall performance of resource systems. This is why a number of leading companies, including the Barilla Group (a global food group), the Coca-Cola Company (a global beverage company), Nestlé S.A. (a global nutrition, health, and wellness company), SABMiller plc (a global brewer), New Holland Agriculture (a global agricultural equipment company), Standard Chartered Bank (a global financial institution), and Syngenta AG (a global agribusiness) together formed the 2030 Global Water Resources Group in conjunction with the International Finance Corporation to help improve the quality of local decision making in the water sector in a number of fast-growing, developing countries.[208]

207 *Roadmap to a resource efficient Europe*, European Commission staff working paper, September 20, 2011.

208 *Charting our water future: Economic frameworks to inform decision-making*, 2030 Water Resources Group, 2009, available online at http: //www.mckinsey.com/Client_Service/Sustainability/Latest_thinking/Charting_our_water_future.aspx.

Exhibit 37

There are several resource-related value-creation levers for businesses



SOURCE: McKinsey analysis

Three sectors provide insights into the potential value at risk and opportunity from resource-related trends

We took a closer look at three sectors—CPG, mining, and oil and gas—to try to understand the value that could potentially be at risk from high and volatile resource prices (Exhibit 38). We now discuss each of these in turn.

Exhibit 38

Disruptive trends in three broad categories could shape private-sector competitive dynamics and value creation

Impact on sector: High / Medium / Low

Disruptive force		Industry: CPG[1]	Mining	Oil and gas	Illustrative facts
Resource cost-related forces	More expensive sources of supply	High	High	High	The average cost per oil well doubled from 2000 to 2010
	Rising volatility and correlation	High	High	High	Annual volatility across resources is at its highest level of the past 100 years
	Rising environmental costs	Medium	Medium	Medium	Potential impact on yields of greater than 10 percent in next 20 years
Regulation-related forces	Rising geopolitical concerns	Low	Low	Medium	>80 percent of available arable land is in countries with infrastructure or political issues
	Public policy push to realize true cost of resources	Medium	High	High	Current subsidies for agriculture, energy, and water total up to $1.1 trillion per year
	The new social contract for access to resources	Medium	High	High	Maintaining social license to operate is a top-four issue for metals/mining executives
Resource-related techno-logical forces	Supply-chain efficiency opportunities	High	High	High	CPG players can reduce energy consumption by 20 to 50 percent on average
	Impact of technology on competitive advantage	Low	Medium	High	Learning curves for renewable power sources range from 10 to 20 percent
	Demand for resource-efficient products	Medium	Medium	Medium	Half of shoppers consider green attributes in their purchasing decisions

1 CPG = consumer packaged goods.

SOURCE: McKinsey analysis

1. CONSUMER PACKAGED GOODS

For much of the past two decades, CPG companies have benefited from a positive combination of declining real commodity costs and an ability to raise prices marginally in real terms in a period of consistently low inflation. This situation has now reversed. Not only have resource prices and their volatility risen sharply in the past decade, but the financial crisis and accompanying economic downturn have led to a much harsher economic environment for CPG companies. There is now a much stronger consumer focus on value, and retailers are negotiating harder, resulting in squeezed CPG margins.

Managing the spread between prices of raw materials and final CPG goods will be a critical driver of value. Indeed, how well—or badly—CPG companies have managed the gap between the prices of their raw materials and their products has been the main arbiter of their financial performance. Maintaining prices during periods in which resource prices were declining accounted for 75 percent of the average increase in earnings before interest, taxes, depreciation, and amortization in the industry between 1996 and 2002. However, when these prices have been increasing, CPG companies that have been unable to pass on these prices fully to consumers have felt a 4 percent impact on their overall margins.

Such effects will become increasingly important if resource prices become even more volatile. Unfortunately, CPG companies are often unaware of their full exposure to changes in resource-related prices and scarcity across the value chain. Trucost benchmarked 186 FTSE 350 companies on the risk to their profits from the costs of oil, coal, wheat, and cotton embedded in supply chains. This exercise discovered that a 10 percent increase in the price of these resources had a 2 percent impact on pretax profits.[209] Of all these companies, CPG-related sectors were the most affected. In the case of food producers, for example, a 10 percent increase in the price of these commodities had a 13 percent impact on earnings before interest, tax, depreciation, and amortization.

The increasingly close links between resource prices can compound the impact of changes in the price of a given resource, as we have discussed, and potentially increase a company's cost base significantly. Companies need to consider not only the level of their resource-related costs but also their volatility. McKinsey's work with one CPG client found that, because resources were more volatile than other cost components including labor, they could account for more than 70 percent of overall changes in costs (Exhibit 39).

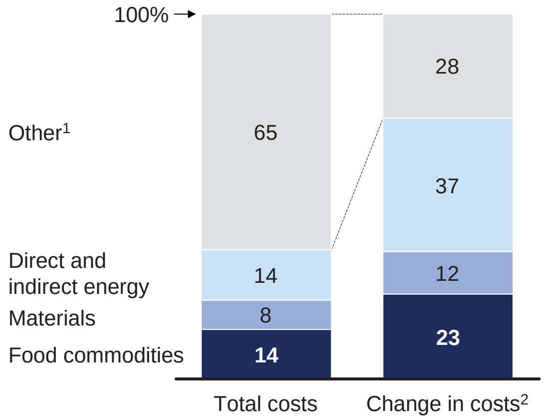
209 Trucost helps its clients understand across operations, supply chains, and investment portfolios the true cost of business in order to utilize resources more efficiently. See *FTSE 350 commodity exposure Index*, Trucost, October 5, 2011.

Exhibit 39

The high volatility of natural resource prices could have a significant impact on changes in the cost base of many firms

ILLUSTRATIVE

% of cost base



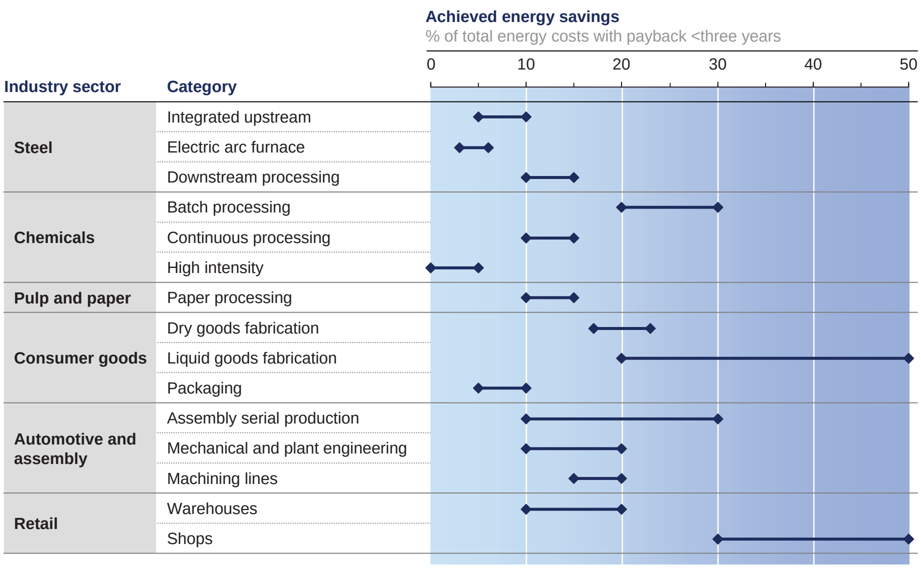
1 Includes manufacturing margin, labor cost, depreciation, and selling, general, and administrative expense.
2 Based on respective MGI Commodity Price Index real price rises from 2009 to 2011. Real price of "other" bucket was grown at 10 percent (more than the 4–6 percent real US wage growth over the period); we assume all price rises passed on to the CPG company.
NOTE: Numbers may not sum due to rounding.
SOURCE: McKinsey analysis

On a positive note, past McKinsey analysis has found that CPG companies have the largest potential to save energy of any industry, and this could provide significant cost savings and competitive advantage in an industry where profit margins have typically been low. CPG manufacturers have been able to achieve savings of up to 50 percent on their energy and water costs by pulling productivity levers with payback after less than three years (Exhibit 40). CPG companies can also tap large opportunities in waste. Waste in this sector accounts for about half of all municipal waste in the United States and currently costs $22 billion a year to recover. The increasing likelihood that recovery costs will be passed on to CPG companies should act as an incentive to improve their handling of waste.

Exhibit 40

Consumer goods companies have some of the highest energy savings opportunities of any industry

Impact achieved
Min Max



SOURCE: McKinsey analysis

CPG companies also face increasing pressure to inform customers about the unpriced environmental impact of their goods and the levels of waste they generate. For example, consumer research has found that more than half of shoppers consider green attributes in their purchasing decisions.[210] In this context, CPG companies will require a more concerted approach to consumer waste. One smart option would be to rethink the current practice of labeling with “sell by” or “display until” dates and find a more nuanced and broader way of communicating whether a product is still safe to the consumer after that date.

Some companies such as Unilever have started to capitalize on such consumer pressure. For example, in 2007, the first year of its UK launch, a new concentrated form of Unilever’s Persil washing liquid that advertised the fact that it required 50 percent less water and packaging delivered £11 million of sales. This was an increase in sales of more than 25 percent compared with the average in its product category of only 2 percent. Creating more sustainable products and using them as a way of having companies stand out from their competitors can flow in the other direction, too. Creating or modifying brands to offer a more sustainable image can raise the awareness of consumers about key issues and even help shape demand for the more efficient use of resources.

With the help of Trucost, we have assessed how the price of a common basket of CPG goods might change if it were to reflect the cost of its environmental impact in terms, for example, of carbon emissions and water use that are currently unpriced in most cases (Exhibit 41). For some goods including wheat, pricing such environmental externalities could increase their price by more than 400 percent compared with current prices. The environmental costs vary substantially across regions, with the key drivers being the volume of irrigation water used per tonne of crop produced and the level of water scarcity of the surrounding basin. In the case of wheat, Russia (9 percent of global production) uses 30 cubic meters of irrigation water per tonne, while India (12 percent of global production) uses nearly 1,200 cubic meters per tonne. Once we factor in the much higher degree of water scarcity in India, the embedded cost of irrigation water in one tonne of Indian wheat is more than 800 times as high as in one tonne of Russian wheat.[211]

CPG firms that can improve the efficiency with which they use these inputs could not only capture a competitive advantage with green-minded consumers but also hedge themselves against the regulatory risk that these unpriced environmental externalities could attract a price in the future.

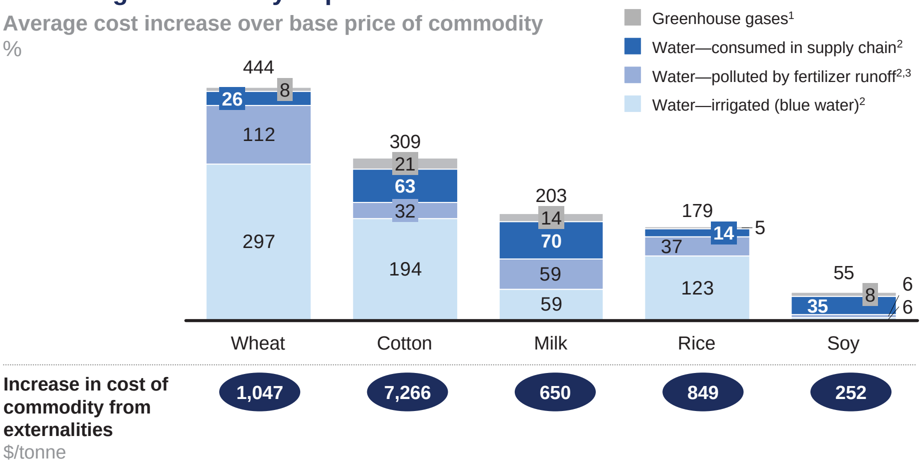
210 Deloitte, “Finding the green in today’s shoppers: Sustainability trends and new shopper insights,” Grocery Manufacturers Association, 2009.

211 The total economic value of water is modeled by Trucost from a series of basin-level water-valuation studies. The values identified in the studies reflect both direct-use values (e.g., irrigation) and indirect-use values (e.g., ecosystem services) to society now and in the future. These data are then extrapolated to other regions based on relative scarcity and purchasing power of regions.

Exhibit 41

Prices of soft commodities could increase by 50 to 450 percent if allowing for currently unpriced externalities

Average cost increase over base price of commodity
%



1 Greenhouse gases were measured in terms of tonnes of carbon dioxide equivalent. Carbon is priced at $30 a tonne. Both direct and indirect greenhouse gases were calculated for each commodity.
2 Based on true "economic cost" of water, which reflects the opportunity cost of water in the given water basin from which these commodities are sourced (or a global level of scarcity in the case of indirect consumption in supply-chain inputs).
3 Based on the volume of water required to dilute nitrogen fertilizer runoff from crop production back to a safe level.
NOTE: Numbers may not sum due to rounding.
SOURCE: Trucost; McKinsey analysis

We see three key strategic implications for the CPG industry:

- **Return on capital: Creating new partnerships across the value chain.** Forming new cross-industry and public-private partnerships and fostering greater collaboration across the supply chain is likely to become increasingly important given the linkages between resources and their impact across sectors and national boundaries. A McKinsey survey of 40 multinational and domestic CPG manufacturers in Germany found that supply-chain collaboration is one of the biggest drivers of supply-chain cost and service levels.[212] Such collaboration could cover eliminating waste and minimizing the environmental footprint of production at supplier plants, adopting lean principles, using integrated planning, and replenishing material to drive lower system inventories. For example, McDonald's has developed a sustainable fisheries program that defines sustainability standards to guide all of its worldwide purchases of fish caught in the wild. The program also works closely with fisheries to improve sustainability. Reducing postharvest food waste is an obvious area that would benefit from such collaboration, potentially requiring partnerships among governments, farmers, infrastructure providers, and CPG companies.

- **Risk management: Pursuing more sophisticated operational risk management.** Many CPG companies currently tend to take a fragmented rather than an integrated approach to managing their supplies of raw materials. Those companies that foster central coordination of their strategy on raw materials across business units may be positioned to manage their risks better than others. This could include optimizing operational processes to mitigate the impact of volatility or designing products and innovative technologies that minimize risks that relate to raw material input costs. This

212 Jochen Grosspietsch and Jörn Küpper, "Supply chain champs," *McKinsey Quarterly*, February 2004.

broader remit will require a new set of skills in procurement departments, including operational, trading, and regulatory experiences.

- **Risk management: Strategic sourcing of critical inputs.** CPG companies may need to consider strategically sourcing key resources to ensure access to critical inputs whose supply is at risk. The previous approach of purchasing inputs on spot markets or short-term contracts may need to change for two reasons. First, there is increasing risk of supply disruptions. Second, the environmental sustainability and social issues connected with sourcing of agricultural products have become more important. Measures could include increasing use of longer-term contracts, the active development of suppliers, and consideration of some level of backward integration. This poses interesting capability issues for many CPG companies in that sourcing from developing countries is not a core competency. There are several potential solutions, including CPG companies building that capacity, partnering with other organizations, or using specialized intermediaries.

2. MINING

Resource-related trends offer both opportunities and risks for players in the mining sector. Turning to opportunities first, increasing demand from rapidly growing emerging markets will require a large volume of mineral resources. Renewable technologies and EVs will also drive demand for minerals. For example, the strong penetration of new vehicle technologies that we expect in a productivity response case could drive a 120- to 200-fold increase in demand for neodymium and lithium. In a supply expansion case, demand for steam coal could increase by more than 40 percent in 2030. Even in a productivity case, demand could still increase by more than 15 percent. Only in the case of a complete transformation of the power sector, as we consider in a climate response case, would 2030 demand for coal potentially fall by 10 percent compared to today's levels.

One note of caution relates to uncertainty about China. Its economy is such a dominant factor in the overall growth of emerging markets that a slowdown in China's growth rate or an accelerated reduction in resource intensity would have a marked negative impact on the mining sector. Our estimates show that, under different plausible assumptions on China's future steel demand growth, global steel demand could vary by more than 22 percent. China's growth will also have a heavy influence on the evolution of demand for coal and uranium, among other resources. This could increase the risk to the earnings of mining players. In the 1970s and 1980s, mining houses tried to diversify across producer countries to mitigate risk. Then, in the 1990s and 2000s, they attempted to diversify across resources and this led to a rise in super-size, multi-mineral mining companies. However, the benefits of diversification could start to disappear as mining company profits across different types of resources become increasingly tied to a single market—China.

Among the risks faced by the mining sector is the fact that the cost of extraction is likely to continue to rise, driven by labor expenses and the need to access increasingly distant reserves that are frequently of declining quality (except in some of the least-developed regions). Labor accounts for a large share of rising costs as mining players scramble to find enough talent to meet surging demand. Many veteran miners are approaching retirement age, and their place needs to be filled by inexperienced workers. This has led to sharp rises in training costs.

Another risk comes from intense pressure from environmental groups and government regulators that has made it increasingly difficult for mining players to obtain permits to operate. Growing regulatory pressure particularly in developed markets has forced many mining players to begin to shift investment toward developing countries that have lower regulatory barriers. This move is occurring even without carbon or water pricing.

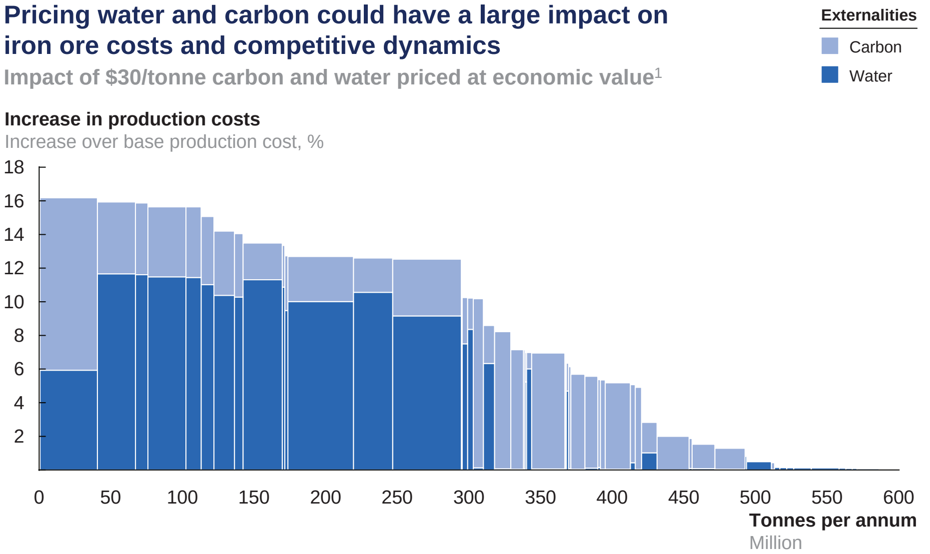
The mining industry is likely to face increasing pressure from regulators to pay for inputs such as carbon and water that currently are largely unpriced. A carbon price would affect coal producers most directly but would also have an indirect impact on other operators through increases in the cost of energy inputs. Pricing water could have a dramatic impact on costs—and constrain output—given that 32 percent of copper mines and 39 percent of iron ore mines are in areas of moderate to high water scarcity, according to Trucost. Analysis by McKinsey and Trucost shows that pricing water to reflect its "shadow cost" (i.e., the economic value of the water if put to its best alternative use) could increase iron ore costs by 3.3 percent across the industry. A price of $30 per tonne of carbon emissions could increase the cost of iron ore by 2.5 percent. In water-scarce regions, some operators could face increased costs of up to 16 percent from the combined costs of water and carbon (Exhibit 42).[213]

Many resource-rich countries are today demanding more in exchange for access to their resources. New entrants, including players from the BASIC countries (Brazil, South Africa, India, and China), are raising competition for access rights, increasing the ability of local governments to capture resource rents. As the prices of resources rise, there are increasing incentives for governments to try to capture more of the upside through either higher taxes, renegotiated royalty agreements, or, in some cases, the nationalization of company assets.

Exhibit 42

Pricing water and carbon could have a large impact on iron ore costs and competitive dynamics

Impact of $30/tonne carbon and water priced at economic value[1]



1 Based on a sample of 55 iron ore mines, accounting for about one-third of world production. The total economic value of water is modeled by Trucost from a series of basin-level water-valuation studies. The values identified in the studies reflect both direct-use values (e.g., irrigation) and indirect-use values (e.g., ecosystem services) to society now and in the future. These data are then extrapolated to other regions based on relative scarcity and purchasing power of regions.

SOURCE: Trucost; Wood Mackenzie; McKinsey analysis

213 Note that these costs for water do not reflect the cost of new supply but the total economic value, as explained in Exhibit 42.

We see three major strategic implications for mining players:

- **Growth: Understanding growth opportunities resulting from resource trends.** Mining companies should develop their understanding of the drivers of future demand for resources and prices and should stress-test strategy under different scenarios. In particular, understanding the future growth and resource intensity of China will be critical.

- **Risk management: Pursuing more sophisticated operational and reputation risk management.** Companies can map the exposure of individual mines to different resources in order to understand the potential economic implications of water and carbon pricing on their operations and help them to prioritize their efficiency efforts. Beyond the benefits of mitigating operational risks, there could also be an increasing positive impact on reputation risk from a more active focus on managing the environmental footprint of mining operations. The extensive focus in the CPG sector on the environmental impact of goods could be a harbinger of consumer-driven pressures likely to affect the mining sector in the future. Mining companies would need to more actively monitor, and improve, their effect on the environment to mitigate this reputation risk. There are large opportunities to improve the efficiency of the use of resources during the production process. McKinsey work with mine and quarrying clients shows that deploying available productivity measures can save 15 to 30 percent on the cost of energy.

- **Risk management: Pursuing more sophisticated regulatory risk management.** Companies may need to consider how to bolster their social license to operate in countries where there is pressure to demonstrate how their operations are helping the country's development or where there are environmental concerns associated with production. Past McKinsey work has found that many extractive companies are making "social investments" without much insight into what the relevant local stakeholders really value. Often these investments have a corporate social responsibility feel to them—the emphasis is on meeting corporate reputational goals rather than making a real difference on the ground. To address this concern, firms should develop more integrated, prioritized approaches to their social investment across their local employment, community (health/education), and environmental agendas. The approach that mining companies take to the development of infrastructure may prove to be an even larger lever for building mutual advantage in relatively new mining provinces. There are often complex trade-offs in the design and operation of infrastructure systems, especially for rail transport. For example, mining companies will often find it more efficient to own and operate dedicated rail networks. Mining companies that are systematically better at finding the sweet spot between their interests on transport and energy and water infrastructure and those of the local stakeholders may be best placed to win the battles over access to resources of the next 20 years.

3. OIL AND GAS

The next 20 years is likely to present large opportunities and threats for the oil and gas sector. Increasing demand from up to three billion more middle-class consumers presents an opportunity. However, the sector faces a great deal of uncertainty given today's volatility in energy prices. A degree of greater energy efficiency that allows the oil industry to grow without a sharp spike in prices is probably essential if the sector is to avoid a much larger substitution effect.

However, a broad push toward energy efficiency could reduce oil demand to the levels witnessed in the late 1990s (Exhibit 43). The availability and price of critical inputs and by-products including raw materials, steel, water, and carbon emissions will shape the competitiveness of different energy technologies.

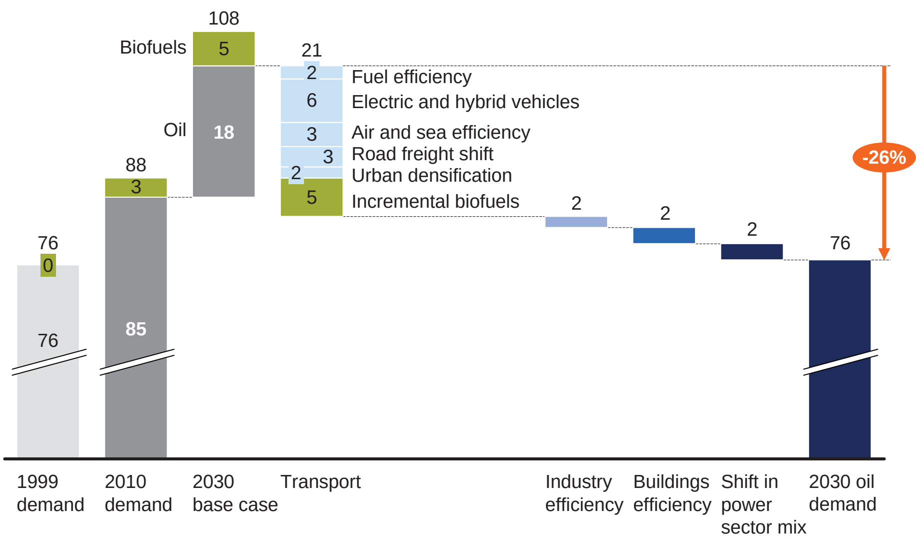
The rising capital cost of extraction is another challenge for the industry. Capital costs have increased sharply even over the past decade. Capital investment is likely to increase by 30 to 50 percent above historical levels between now and 2030. Steel accounts for around 30 percent of the capital cost of any new oil project, and steel costs are likely to increase as the oil and gas industries move increasingly into more challenging forms of exploration such as ultra-deepwater. J.P. Morgan notes that the global count of shallow water wells dropped by 25 percent between 2005 and 2009, while ultra-deepwater wells increased by 30 percent.[214] In addition, more complicated drilling methods, such as horizontal drilling, can require four times the amount of steel as traditional vertical drilling.

As in the mining industry, the oil and gas industry is likely to face increasing pressure from regulators to pay for currently largely unpriced inputs such as carbon and water, to address production-related environmental concerns, and to capture more of the value of their resource endowments.

Exhibit 43

Achieving all oil-related productivity opportunities could reduce oil consumption to the levels at the turn of the 21st century

Million barrels of oil equivalent per day



SOURCE: McKinsey analysis

We see six major strategic implications for oil and gas players:

- **Growth: Capturing resource productivity opportunities.** Many oil and gas businesses are already undertaking significant investment to improve oil and gas recovery, often spurred on by a higher oil price. In 2010, Conoco announced a $14 billion investment aimed at prolonging production from the North Sea's Eldfisk and Ekofisk South fields. Statoil said it planned to invest

214 Colin P. Fenton and Jonah Waxman, "Fundamentals or fads? Pipes, not punting, explain commodity prices and volatility," J. P. Morgan Global Commodities Research, *Commodity markets outlook and strategy*, August 2011.

the equivalent of $3.4 billion through 2015 to boost recovery and extend the life of the Troll field, home to Norway's biggest oil reserves after Ekofisk. However, extraction rates are still low, often well below 50 percent of the total hydrocarbon content of an oil reservoir. There could be particularly large potential to improve recovery rates in unconventional sources such as tar sands and extra-heavy oil, which are currently around 10 percent. While deploying enhanced oil recovery techniques can extend the economic lifetime of an oil field, it can also lead to a reduction in production rates. This creates a risk of a short-term oil shortage. This risk could be minimized through greater refinery flexibility, allowing the production of more diesel (as diesel generates more transportation miles for the same barrel). However, it may require regulators to adjust tax incentives to facilitate a change.

- **Growth: Managing composition of business portfolio.** Pushing for greater efficiency in the end use of oil and gas can limit the potential for large-scale substitution if oil prices spike. Paradoxically, supporting energy efficiency especially in the transport sector that could lower demand for their products may be one of the best long-term strategies for oil and gas companies by reducing the risk of large-scale substitution. The industry may also want to encourage the development of hydrocarbon-based substitutes for gasoline in the transport sector that would secure their role in the transportation fuel value chain. Examples are CNG, gas-to-liquids, hydrogen produced from natural gas, and biofuels (provided that these do not compete with food for the best land).

- **Growth: Deciding how to participate in the shale gas opportunity.** Shale gas has the potential to provide significant sources of gas supply and thereby lower costs, but there are significant environmental uncertainties surrounding this resource. Oil and gas companies need to be more transparent on the risks of shale gas, allow regulation to filter out rogue operators, and lead the way towards a goal of more sustainable exploration and production. Companies need to decide how they choose to participate in shale gas, including in which geographies and which parts of their value chains.

- **Return on capital: Improving capital productivity.** The industry needs to focus on improving its containment of costs and on capital productivity. Trends in new and planned wells indicate an expected 2 percent per annum increase in real capital costs per barrel. Moreover, in periods of high demand growth, particularly when there are also challenges on the supply side, past McKinsey analysis has found that the price of oil-field services can increase by 10 to 20 percent a year. Taking into account rising costs, increasing demand, and the potential for an oil services price bubble to develop, we see the annual need for upstream investment increasing from $442 billion in 2010 to $640 billion per year on average to 2030. This puts pressure on the industry to contain its costs. Given that steel represents up to 30 percent of capital costs, the industry needs to focus actively on capturing opportunities to boost the productivity of its use of this material.

- **Risk management: Pursuing more sophisticated environmental risk management.** Companies may need to reconsider their management of environmental risk. Two of the fastest-growing resource types in the industry—deepwater oil production and shale gas—have both proved problematic in the past two years. For example, while shale gas has the potential to provide a major shift in the global energy mix over the next 20 years (as it has already done in the United States), this resource still needs to prove it can be exploited in an environmentally appropriate manner. There is a substantial backlash against the environmental integrity of shale gas with people expressing particular concerns about threats to water, air, and land quality (see Box 8, "The shale gas opportunity"). Overcoming such misgivings will involve a number of industry-led steps to improve the transparency and trustworthiness of its environmental performance. Drillers need to work much harder to ensure that their operations are not damaging the environment in irremediable ways. Sometimes this will involve going beyond what current regulations insist upon. For instance, Shell has made public its operating principles in five areas (safety, water, air, footprint, and community) that include significant safety upgrades to protect water quality. Such standards do not lead to significantly higher costs. In fact, at sufficient scale, they help reduce long-term operating costs as they reduce the cost from accidents and environmental damage.

- **Risk management: Pursuing more sophisticated regulatory risk management.** As in the mining industry, companies would need to consider how to bolster their social license to operate in countries where there is pressure to demonstrate how their operations are helping the country's development or where there are environmental concerns associated with production. Firms should consider introducing a new cross-departmental sustainability function—or strengthening an existing function of this kind—and boost their government relations capacity. This will, in the first place, need to cover local climate concerns, which could include forestry protection efforts when operating in major forest nations such as Brazil or Indonesia. Second, while climate change may not be top-of-mind for oil and gas companies in the immediate political context, there is a good chance that it will return as a political priority as and when the global economy picks up. It is in the interest of oil and gas companies to maximize long-term "carbon space" in the atmosphere for gasoline-related carbon emissions, by supporting (non-fossil-fuel-related) carbon-reduction efforts. They may want to start investing in a portfolio of long-dated carbon options, including REDD+, other forms of terrestrial carbon sequestration, and, depending on commercial viability, the storage part of CCS value chains.

□ □ □

This new era presents opportunities and risks for business. Resource-related trends will shape the competitive dynamics of a range of sectors in the two decades ahead. Those businesses that successfully face up to the resource challenge will be those that adopt a more integrated approach to understanding how resources might shape profitability across their operations, produce new growth opportunities, and pose new challenges for risk and regulatory management. They have the chance to play an integral part in the resource revolution.

Appendix: Methodology

This appendix outlines key points on the methodology in the following sections:

A. MGI Commodity Index

B. Estimating 2030 demand for resources

C. Estimating capital costs

D. Identifying barriers to increasing supply and improving productivity

E. Developing the integrated resource productivity cost curve

F. Metrics that matter

G. Sizing of productivity opportunities

H. Explaining returns from productivity opportunities

I. Assumptions on the evolution of power generation

A. MGI Commodity Index

To improve our understanding of commodity prices in the long term, we have developed an index of 28 key commodities broken into four subgroups: energy, food, agricultural raw materials, and metals. Our index builds on the Grilli and Yang commodity index published by the World Bank.[215] We combine this index with additional time series for energy (oil, natural gas, and coal) and steel. We choose steel as the focus of this report given its importance in global trade flows.[216] We then deflate commodity prices using the World Bank's Manufactures Unit Value Index to adjust for both inflation and changes in currencies. We also weight commodities within each subgroup, based on their share of global export values. This gives us four subindexes. Finally, we take an average of the four subindexes to create the composite MGI Commodity Index. We do not weight the four subindexes by their share of export values, given energy's disproportionate share of global trade.

215 Enzo R. Grilli and Maw Cheng Yang, "Primary commodity prices, manufactured goods prices, and the terms of trade of developing countries: What the long run shows," *World Bank Economic Review* 2(1): 1–47, 1988. See also Stephan Pfaffenzeller, Paul Newbold, and Anthony Rayner, "A short note on updating the Grilli and Yang Commodity Price Index," *World Bank Economic Review* 21(1): 151–63, 2007.

216 We obtained updated commodity price information from a variety of sources, including the IMF, the FAO, the United Nations Conference on Trade and Development, the United Nations Commodity Trade Statistics Database, UN Comtrade, the EIA, the BP Statistical Review of World Energy, and the American Metal Market.

The four commodity subindexes comprise the following:

- **Energy.** Oil, coal, and gas (gas is excluded from the index before 1922, when price data were not available).

- **Food.** Coffee, cocoa, tea, rice, wheat, maize, sugar, beef, lamb, bananas, and palm oil.

- **Agricultural raw materials.** Cotton, jute, wool, hides, tobacco, rubber, and timber.

- **Metals.** Steel, aluminum, tin, copper, silver, lead, and zinc.

There are a few important points to note about the index:

- **Portfolio weightings.** Within the four subindexes, the weightings used are total world export values from 1999 to 2001. A potential source of bias in the results arises out of the shifts in weightings for these commodities over the period analyzed, but historical data were insufficient to introduce annual weightings of export values. For the overall index, we used a simple arithmetic average. If we based this average on market values, this would have changed the index significantly because energy (particularly oil) would tend to dominate. To capture the effects across the subindexes, we also used a simple, arithmetic average, and not one weighted for market values.

- **Inflation adjustments.** The index accounts for inflation in the prices of manufactured goods exported by the G-5 countries (the United States, the United Kingdom, Japan, France, and Germany), weighted by share of exports. Inflation measures have been criticized for failing to account for quality improvements in goods (which implies that the quality-adjusted price change may be lower), re-weightings of consumer and business consumption in reaction to price changes (meaning that the overall price increase on consumer and business budgets may be lower due to adjustment of buying decisions), or the introduction of new goods.[217] It is difficult to control for the first of these, but this is unlikely to change the overall message of the index, which indicates a rapid increase in prices since 2000. The conclusions of the index would change only if we could establish that the rate of quality improvement of a given good has increased significantly compared with historical growth rates during this period, and that seems unlikely. The failure to capture fully shifts in business and consumer consumption to lower-priced goods means that the index potentially shows a steeper decline in 20th-century prices than businesses actually experienced. However, this, too, is unlikely to affect the finding that there has been a trend break in the price index since the turn of the century.

- **Exchange-rate adjustments.** The index uses prices of manufactured goods in local currencies and converts them to US dollars at market exchange rates. A depreciation of the US dollar makes goods more expensive in US dollar terms. Therefore, the inflation deflator is larger and the commodity price increase recorded is lower, all other things being equal. This is noteworthy because it means that the large increase in commodity prices that the index has recorded over the past ten years has not been due to the depreciation of the US dollar.

217 John E. Tilton and Peter Svedberg, "The real price of nonrenewable resources: Copper 1870–2000," *World Development* 34(3): 501–19, 2006.

B. Estimating 2030 demand for resources

We have estimated the development of demand for resources using a combination of McKinsey and external data sources. We have made efforts to ensure consistency in core common assumptions across each of the resource models. Specifically, we used the following data sources:

- **Energy.** We base energy demand and supply to 2030 largely on the McKinsey Greenhouse Gas Abatement Cost Curve and the proprietary McKinsey Global Energy and Power model, developed by McKinsey energy specialists in collaboration with various international experts. The estimates of these two models were integrated by including a consistent set of sector-level drivers of energy demand as well as reconciling key assumptions on demand growth for each of these sectors. Overall, our base-case projections for primary energy in 2030 are in line with IEA forecasts in the 2011 *World energy outlook*. At 654 QBTU, our primary energy projection falls between IEA "new policies" (643 QBTU) and "current policies" (~681 QBTU). We project our base-case power mix on the basis of current policies, and we do not assume a carbon price by 2030. Our base-case projections for the primary energy mix in 2030 are also closely aligned with the IEA's 2011 *World energy outlook* estimates. Overall, our base-case projections include a slightly higher share of oil (30 percent of the primary energy mix in 2030, compared with 28 percent for IEA "new policies" and "current policies") and a slightly lower share of nuclear and renewables (19 percent in 2030, compared with 24 percent for "new policies" and 20 percent for "current policies"). Gas has a similar share at 22 percent (compared with 23 percent for "new policies" and 22 percent for "current policies"), and coal (28 percent in 2030) falls between "current policies" (29 percent) and "new policies" (25 percent). We design the power mix assumed in the climate response case to maximize carbon abatement in the power sector, subject to realistic constraints related to the ramp-up of renewables and an assessment of potential policy and technology developments for nuclear and gas. Our projections for the primary energy mix in the climate response case are closely aligned with the "450-ppm" scenario in the IEA's 2011 *World energy outlook*, which also includes a shift in the power generation mix and a raft of energy productivity levers across buildings, transport, and industry. In our climate response case, renewables, including hydropower, provide nearly half of the world's electricity generation in 2030 (versus 40 percent in the IEA's "450-ppm" scenario, which rises to 47 percent by 2035). Part of the difference in projections for renewables is due to our lower expectations for growth in nuclear power. In our climate response case, the contribution of nuclear power to electricity generation would decline from roughly 13 percent today to 11 percent in 2030 (versus an increase to 18 percent in the IEA's projections). The IEA's higher assumptions about nuclear power also explain the difference in total primary energy demand for coal across all sectors, which reaches 22 percent in our climate response case but only 18 percent in the IEA's "450-ppm" scenario by 2030. Our estimates of primary energy demand for gas and oil in 2030 align closely with IEA projections, at 21 percent and 27 percent of total, respectively. We estimate a share of 21 percent for gas in 2030 (versus 22 percent in the IEA's projections) and 27 percent for oil (the IEA projects the same share for oil in 2030).

- **Land.** We base our land estimates on projections of food and feed demand from the FAO, combined with energy demand from proprietary McKinsey models of biofuel and cropland demand for energy (e.g., unconventional oils). Productivity losses also contribute to demand for cropland. To estimate these, we use data on land degradation from the ISRIC World Soil Information's Global Assessment of Human-Induced Soil Degradation database and the FAO's Global Land Degradation Assessment database.[218] We also reviewed multiple data points on the impact of climate change to estimate yield losses and considered urban encroachment into cropland.[219]

- **Steel.** We base our estimates of steel demand to 2030 on a proprietary model of the McKinsey Basic Materials Institute. The model uses a bottom-up projection for 2010 to 2014 in North America and Europe, and the World Steel Association's short-term outlook for all other regions for 2011 to 2012, extrapolated to 2014. Beyond 2014, we project steel demand using different GDP scenarios using MGI analysis, the outlook for population using data from IHS Global Insight, and steel intensity, based on historical trends but calibrated with expert estimates. All historical data came from the World Steel Association.

- **Water.** We base estimates of 2030 water withdrawals on a model developed by McKinsey water experts in collaboration with IFPRI and Germany's University of Kassel. We base the core demand model on previous work by the 2030 Water Resources Group.[220] The model covers agriculture, industry, and municipal water withdrawal requirements to 2030 for 154 basins/regions. The model estimates demand under "frozen" productivity at 2009 levels and base-case productivity by 2030. For the agricultural sector, we estimate water demand using FAO estimates and our analysis on land. For the industrial and municipal sectors, we use research from the University of Kassel to estimate base-case productivity by country. All historical data before 2000 came from research by Igor Shiklomanov at UNESCO.[221]

- **Carbon.** Although we do not directly analyze carbon in our productivity analysis, it is important to understand base-case developments in carbon emissions given widespread interest in their impact. We base 2030 estimates on the McKinsey Greenhouse Gas Abatement Cost Curve.

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218 See http: //www.isric.org/projects/global-assessment-human-induced-soil-degradation-glasod and http: //www.fao.org/ag/agl/agll/lada/glada.stm.

219 Gerald C. Nelson, et al., *Climate change: Impact on agriculture and costs of adaptation*, International Food Policy Research Institute, 2009; Christoph Müller, *Climate change impacts on agricultural yields*, Potsdam Institute for Climate Impact Research, 2010; M. L. Parry, et al., "Effects of climate change on global food production under SRES emissions and socio-economic scenarios," *Global Environmental Change* 14(1): 53–67, April 2004; Shlomo Angel, Stephen C. Sheppard, and Daniel L. Civco, *The dynamics of global urban expansion*, World Bank, September 2005.

220 *Charting our water future: Economic frameworks to inform decision-making*, 2030 Water Resources Group, 2009, available online at http: //www.mckinsey.com/Client_Service/Sustainability/Latest_thinking/Charting_our_water_future.aspx.

221 Igor Shiklomanov, *Water resources and their use*, UNESCO International Hydrological Program, 1999.

C. Estimating capital costs

As part of our analysis, we estimate annual capital costs for energy, land, water, and steel over the next 20 years in our three cases:

- **Supply expansion.** We calculate the capital cost of implementing base-case productivity improvements over the next 20 years, together with investment in new supply sufficient to ensure that 2030 supply is equal to projected demand.

- **Productivity response.** We calculate the capital cost of capturing all productivity opportunities in energy, food, water, iron ore, and steel together with investment in new supply to cover the remaining gap with future demand.

- **Climate response.** We calculate the capital cost of capturing the potential in the productivity response case together with that of a shift to low-carbon energy and additional land-related carbon abatement sufficient to meet a 450-ppm carbon pathway.

1. ENERGY

We assess capital costs across the entire energy value chain from extraction, to conversion, and end user. The energy capital estimates come from a variety of sources including IHS Global Insight (for historical capital expenditure), the McKinsey Global Energy Perspective database and the McKinsey Greenhouse Gas Abatement Cost Curve (primary and final energy demand, generation capacity, and the capital costs of power-generation technologies), the IEA's 2010 *World energy outlook* (transmission and distribution capital expenditure, petroleum refining capital expenditure), Wood Mackenzie (oil and gas extraction capital expenditure), and McKinsey research (coal extraction capital expenditure, uranium mining and refining capital expenditure, power sector maintenance capital expenditure, capital expenditure on incremental grid enhancements for renewable capacity, impact of supply-chain bottlenecks on capital costs, and biofuels refining capacity).

The major assumptions underpinning the three cases considered are:

1.1 Supply expansion

The increase in capital expenditure is driven significantly by oil and gas extraction ($640 billion average versus $442 billion in upstream capital expenditure in 2010).[222] This represents nearly half of the total capital expenditure required of $1.4 trillion. We allow for supply-chain bottlenecks using historical evidence from McKinsey research on oil-field services equipment costs, as well as IHS Herold data on capital costs from the financial reports of international oil companies. These data show that, in periods of high demand growth, and particularly in cases where there are challenges on supply capacity, capital equipment costs can increase by 15 percent annually. Two three-year bubbles could lead to a 10 to 15 percent increase in average annual oil and gas capital expenditure between 2010 and 2030.

A major investment in power generation and transmission distribution will take place in emerging markets. China, for example, will account for 25 percent of

222 *The original E&P spending survey*, Barclays Capital, 2010.

annual spending on new power generation capacity from 2010 to 2030 compared with 16 percent in the United States and Canada combined. We compile these estimates from McKinsey analysis of retirement rates, supply mix, and installation and maintenance costs (including learning curves), viewed by technology and region. Our estimate of $385 billion per annum on investing in power generation capacity is similar to the IEA's $390 billion per annum for its 2011 *World energy outlook* "new policies" scenario, but our estimate reflects a less aggressive share of nuclear and renewables. Using the IEA's installation cost figures, our mix would cost an estimated $365 billion per annum. We base spending on transmission and distribution on IEA estimates per gigawatt across different geographies. In the climate response case, we supplement this estimate using previous McKinsey estimates of incremental spending on grid enhancements to handle the complexities of renewable capacity (e.g., underground cables for offshore wind, long-distance transmission from solar farms in the Middle East).

1.2 Productivity response

Our productivity response case has higher capital expenditure than in the supply expansion case. While the cost of supplying energy is lower in the productivity case, the cost of the productivity levers is very high, offsetting the overall supply savings. There are two major drivers of this outcome:

- Many of the efficiency opportunities identified in previous reports have now been captured (e.g., fuel economy improvements in transport).[223] Many of the remaining productivity opportunities are relatively capital-intensive (e.g., building efficiency, new power train technology).

- Opportunities that involve significant behavioral changes and a welfare loss (e.g., subsidy removal) are excluded; these opportunities typically require minimal or no capital investment.

We largely take the capital investment needed to implement major productivity opportunities from the McKinsey Greenhouse Gas Abatement Cost Curve. In the productivity response case, the capital investment required in oil and gas extraction is lower than in the supply expansion scenario, not only because of the lower volume required, but also because of a cost curve effect. Essentially, demand falls further to the left on the oil supply curve, and upstream extractors do not need to tap the most expensive marginal sources of supply (e.g., ultra-deepwater or shale oil). Instead, supply comes from a lower-cost area of the cost curve, with fewer sources at the right-hand side, yielding 30 percent lower capital expenditure per barrel in 2030. We consider this effect for oil and gas, but not for coal or uranium because the capital expenditure is less than 5 percent of total capital investment across our three illustrative cases. In power generation, we assume that there is no change in the energy mix but that total generation requirements decline due to lower energy demand (e.g., driven by more efficient lighting).

1.3 Climate response

In addition to the capital investment needed in a productivity response case, the climate response case factors in two categories of incremental capital investment:

223 *Curbing global energy demand growth: The energy productivity opportunity*, McKinsey Global Institute, May 2007 (www.mckinsey.com/mgi).

- **Power generation.** Moving toward a 450-ppm pathway requires an aggressive ramp-up of low-carbon power supplies (including renewable energy, nuclear power, and CCS of coal and gas) that are generally more expensive than fossil fuels, even with steep learning curves. This results in additional capital investment of $70 billion per year compared with the supply expansion case, or $180 billion per year more than the productivity response case (which has the same generation mix as the supply expansion case but with lower capacity needs).

- **Transmission and distribution.** We factor in increases in costs per gigawatt due to grid enhancements for intermittent supply and long-distance transmission (e.g., solar farms in the Middle East and underwater transmission from offshore wind farms), and a greater number of capacity additions than in our base case because of the low conversion efficiency of intermittent energy sources. Data come from expert interviews and McKinsey analysis for Europe.

Our annual average investment estimates from 2010 to 2030 in a climate response case are roughly $140 billion (7 percent, excluding the $50 billion required to provide universal energy access) higher than the IEA's 450-ppm scenario. While our estimates differ on several dimensions, the key driver of our higher estimates is in the higher cost of our productivity levers. The key differences in our estimates include:

- **Upstream oil and gas capital expenditure.** The IEA estimates for oil and gas extraction in its "450-ppm" scenario are more than 30 percent higher than our estimates for the climate response case, despite a 2030 level of primary demand for oil and gas that is only 5 to 10 percent greater than our projections.[224] Meanwhile, our supply expansion capital investment estimates are closely aligned with the IEA's 2011 *World energy outlook* estimates for its "new policies" reference case. The divergence in capital expenditure estimates in the climate response case is driven by two factors. First, we assume that lower demand in this case eliminates the two sources of supply-chain stress in the supply expansion scenario, which reduces the overall upstream investment. Second, we use McKinsey's 2020 oil supply curve to estimate the impact of lower demand in the climate response case on overall capital costs. The marginal well in the climate response scenario is less costly than the marginal well in the supply expansion, and we estimate that this could reduce the average capital requirement per barrel by up to 30 percent. While the IEA mentioned this supply-curve effect in its 2010 *World energy outlook*, its impact does not appear to be calculated to the same magnitude as in our estimates, if at all.

- **Uranium capital expenditure.** The IEA does not estimate the capital expenditure for mining and enriching uranium.

- **Power generation capital expenditure.** Electricity generation in the IEA's "450-ppm" case is 14 percent higher than in our climate response scenario, which leads to higher capital costs, even with the same generation mix. At the same time, our estimates of transmission and distribution are higher,

224 Note: for comparison, we have excluded IEA estimates of capital investment in LNG infrastructure, gas transmission and distribution infrastructure, and inter-regional transport for oil, as we do not estimate these costs in our analysis. These investments are roughly $100 billion per annum in WEO 2010 and WEO 2011.

partly driven by our higher estimates of the cost of renewables integration. On balance, our estimates for the total electricity supply in the climate response case are 5 percent higher than the IEA's "450-ppm" case.

- **Productivity levers capital expenditure.** The IEA scenarios include capital-expenditure-"free" opportunities (e.g., the complete removal of all fossil-fuel subsidies by 2030). In total, the investment in energy productivity in the "450-ppm" case averages roughly $460 billion per year, which is slightly higher than the capital investment requirement we estimate for levers with low to medium barriers to capture ($430 billion per year). We estimate that the total capital requirement for of all energy productivity levers (including those that are difficult to capture) is $730 billion per year.

2. AGRICULTURE/LAND

We assess capital costs across the agriculture value chain, from land supply and input and production to transport and storage, wholesale markets, and processing. Our estimates come from a variety of sources, including IHS Global Insight for historical capital expenditure; case studies of cropland expansion from expert interviews in Africa and Latin America; the 2030 Water Resources Group's *Charting our water future: Economic frameworks to inform decision-making* paper for multiple productivity levers including the improvement of yields, the prevention of degradation, and the reduction of food waste; case studies from the World Overview of Conservation Approaches and Technologies for the restoration of degraded land; and expert interviews of major agribusiness players and academics for improvements in yields and feed efficiency, waste reduction at the end of supply chains, and the accelerated penetration of second-generation biofuels.

The major assumptions that underpin our three illustrative cases are:

2.1 Supply expansion

The need to expand cropland would require an increase in annual capital investment above historical levels. The FAO and other agricultural institutions project that much of this expansion would have to be in developing regions such as sub-Saharan Africa and Latin America where the investment required would be larger because infrastructure is relatively less developed. In addition, there would have to be recurring capital investments in farm machinery, for instance, in order to maintain the expanded cropland. We allow for supply-chain bottlenecks based on agricultural GDP data from IHS Global Insight and data from the FAO. These sources show that supply-chain bottlenecks in periods of high demand increase capital equipment by 2 to 4 percent annually; a five-year bubble could lead to increases of as much as 25 percent.

2.2 Productivity response

The capital expenditure figure in the productivity response case is higher than in the supply expansion case because most of the productivity levers in agriculture are capital-intensive. Improving yields in developing regions, which accounts for more than 50 percent of the overall opportunity, would require the construction of roads to connect farms to markets. Reducing food waste and restoring degraded land would also require heavy capital investment. Our estimate of the capital investment necessary to achieve the major productivity opportunities we discuss in this report comes from a variety of sources including the 2030 Water

Resources Group 2009 report *Charting our water future: Economic frameworks to inform decision-making* for multiple productivity levers including the improvement of yields, the prevention of degradation, and the reduction of food waste; case studies from World Overview of Conservation Approaches and Technologies for the restoration of degraded land; expert interviews of major agribusiness players and academics for improvements in yields and feed efficiency, waste reduction at the end of the supply chain, and the accelerated penetration of second-generation biofuels.

2.3 Climate response

The necessary incremental capital investment in a climate response case is higher than in our productivity response scenario. We take our calculation of additional investment in land-related carbon abatement from the McKinsey Greenhouse Gas Abatement Cost Curve. These estimates include the cost of afforestation, reduced deforestation from the conversion of pastureland and cattle ranching, improved grassland management, the reforestation of degraded forests, the application of the antimethanogen vaccine to livestock, forest management, and reduced deforestation from timber harvesting. The additional capital expenditure required to implement these levers would be $13 billion a year. We assume 80 percent capture of these measures, leading to $8 billion a year.

3. WATER

We obtain our estimates of the capital needed in the case of water from a variety of sources including Global Water Intelligence for historical capital expenditure and short-term projections; the 2030 Water Resources Group project and its publication *Charting our water future: Economic frameworks to inform decision-making* for case studies on the capital required to implement various productivity levers; and data from the University of Kassel on municipal and industrial water use to determine the volume of productivity levers in those sectors.

We assess capital costs across the water value chain from extraction to conversion and end user. On the supply side, we include the capital expenditure required for bulk water supply using measures such as groundwater abstraction and reservoirs. We also include measures that improve productivity such as irrigation water management (drip and sprinkler irrigation), industrial efficiency measures, municipal leakage reduction, and the reuse of wastewater. We have not considered the capital expenditure required for water treatment and distribution—significant in industrial and municipal sectors—because we have focused on the availability of upstream resources in this report. However, we have provided an estimate for treatment and distribution. We do not include capital expenditure related to non-consumer uses of water including dedicated hydroelectric power generation, navigation, and downstream water industries such as packaged water sales.

The major assumptions underpinning the three cases considered are:

3.1 Supply expansion

We have relied on the 2030 Water Resources Group for capital expenditure estimates of both new supply infrastructure and the upgrade and repairs of existing supply infrastructure.

3.2 Productivity response

The capital expenditure figure in the productivity response case is lower than in the supply expansion case because a majority of the productivity opportunities require little capital investment compared with the expanding supply case. The 2030 Water Resources Group provides capital estimates for productivity measures across different basins in China, India, South Africa, and São Paulo. We also took into account feedback from experts within and outside McKinsey as we extrapolated our sizing and capital expenditure assumptions for the global model.

3.3 Climate response

We did not consider any water productivity lever specific to the climate response case.

4. MATERIALS (STEEL)

Estimates of steel capital requirements come from a variety of sources including IHS Global Insight for historical capital expenditure and the McKinsey Basic Materials Institute steel model for future estimates. On the supply side, we have included capital expenditure related to mining of iron ore and coking coal, and for steelmaking. Within mining, we include costs such as mining leases, land, processing plants, deforestation and other environmental restoration charges and infrastructure. Within steelmaking, we include costs related to pellet/sintering plants, coke-making plants, blast furnaces, BOF, or EAF, power plants, and other infrastructure (e.g., rail at plant). We do not include capital expenditure for the exploration and discovery of iron ore and coking coal, or the expenditure required for end-use sectors such as construction, automotive, and machinery. For productivity improvements, we include the capital expenditure required to improve recovery rates, produce higher-strength steel, and recycle scrap.

The major assumptions that underpin the three cases are:

4.1 Supply expansion

We used estimates from IHS Global Insight and McKinsey's Basic Materials Institute for both mining and steelmaking.

4.2 Productivity response

We established the capital required for different productivity measures from a range of case studies. The estimate of capital investment needed for improving recovery rates was based on McKinsey proprietary case studies on improving recovery rates using different technologies. For coke-to-steel yield improvements, we based our assessment on information from industry experts and practitioners who have experience in setting up pulverized coal injection facilities in steel mills. We based the capital requirement for higher-strength steel and scrap collection on McKinsey case studies, external capital announcements, and benchmarks from steel companies such as Tata Steel.

4.3 Climate response

We did not consider any materials productivity lever specific to the climate response case.

D. Identifying barriers to increasing supply and improving productivity

To assess the severity of the challenges facing efforts to increase resource supply and productivity, we used a framework that identifies three types of barriers that we expect decision makers could face:

- **Incentive barriers**
  - **Capital intensity.** This barrier relates to the degree to which capturing an opportunity requires high upfront capital costs.
  - **Return on investment.** There can be an issue of whether an opportunity has an attractive rate of return to the private sector, based on current prices and risk.
- **Decision-making barriers**
  - **Agency issues.** These occur when there is a misalignment of incentives between actors (e.g., tenants in residential housing lack the incentive to make capital upgrades to save energy because the landlord captures the longer-term value of the investment).
  - **Political feasibility.** This barrier arises when political interests are not aligned to the opportunity. For example, removing government subsidies to encourage improved energy productivity is politically challenging.
  - **Information failures.** These failures occur when actors do not have sufficient information about the true nature of the benefits and costs of the opportunity. For example, in the case of energy efficiency, many businesses are unaware of the potential savings that could be achieved.
- **Implementation barriers**
  - **Supply-chain bottlenecks.** These are gaps in the supply chain that prevent access to critical components needed to capture an opportunity and a lack of the skilled labor necessary for its implementation.
  - **Capital availability.** There can be a lack of access to capital markets to secure the required funding to implement the opportunity.
  - **Regulatory support.** A lack of regulatory structures to support implementation (e.g., lack of relevant standards or protocols; lack of defined property rights) can act as a barrier. For example, a major issue preventing agriculture improvements is the lack of clear land certification in many developing countries, making it difficult to assemble holding of a size that financially justifies investment in productivity-enhancing technology (e.g., modern farming equipment).
  - **Technological readiness.** The degree to which the opportunity is dependent on unproven technologies or technologies that have not yet reached commercial/industrial scale matters. We consider only productivity opportunities that rely on known technologies and only those that require ramp-up along an accepted learning curve. However, some of these

technologies may still not be widely used. For example, higher-strength steel is common in the automotive sector, but it is not yet widely applied in stationary machinery.

— **Entrenched behavior.** The degree to which significant changes in behavior are required for the opportunity to be realized is another arbiter of whether an opportunity is liable to be captured. Although our levers do not include behavioral changes that directly reduce welfare (e.g., living in smaller houses), many of the levers still require some significant mind-set shifts. One example is the adoption of low-tillage agricultural practices to limit the degradation of soil.

In each of these subcategories, we have assessed the degree of difficulty associated with a productivity lever, ranging from "readily achievable" to "difficult," which we have used to assess the feasibility of capturing the opportunities in the 15 priority areas we described in Chapter 4.

E. Developing the integrated resource productivity cost curve

The integrated resource productivity cost curve introduced in Chapter 4 is a tool developed to help policy makers prioritize productivity opportunities across energy, land use, water, and steel with regard to their total resource benefits (which includes the "priced" benefits of resource efficiency, plus the currently "non-priced" societal benefits such as carbon savings and adjustments for subsidies, all measured in dollar terms) and cost efficiency (i.e., the ratio of the costs of implementation versus the total resource benefits associated with the opportunity).

The assumptions vary depending on whether the curve is compiled from the point of view of an investor or from a societal perspective (the latter adjusts for subsidies and includes a carbon price). Table A1 summarizes the main assumptions that we use in the investor and societal versions of the curve. All prices are based on 2010 averages. Where a range is provided, price assumptions vary across the 21 regions where productivity opportunities are calculated for energy.

TABLE A1. Price assumptions for integrated resource productivity cost curve

Resource	Unit	Investor perspective	Societal perspective	Source
Crude oil	$/barrel	$50 to $313:	$105	Gesellschaft für Internationale Zusammenarbeit (GIZ)
Coal	$/tonne	$130	$130	GIZ
Natural gas	$/million British thermal units	Residential: $0.47 to $14.86 Other uses: $0.32 to $5.25	All uses: $5.00 to $13.72	Enerdata, IEA
Electricity	$/kilowatt hours	Residential: $0.03 to $0.26 Other uses: $0.03 to $0.32	All uses: $0.04 to $0.15	Enerdata, IEA
Fuel oil	$/barrel	$35 to $312	$63 to $105	Enerdata, IEA
Biomass	$/million kilowatt hours	$34.45	$34.45	GIZ
Gasoline	$/liter	$0.79	$0.46 to $2.28	GIZ
Diesel	$/liter	$0.77	$0.44 to $2.26	GIZ
Bioethanol	$/million kilowatt hours	$101	$101	GIZ
Biodiesel	$/million kilowatt hours	$103	$103	GIZ
Other fuel	$/million kilowatt hours	$55	$55	Enerdata, IEA
Coking coal	$/tonne	$146	$146	Metals Consulting International (MCI)
Food (average basket)	$/tonne	$158	$202	FAO, OECD
Food (nonperishables)	$/tonne	$148	$209	FAO, OECD
Food (perishables)	$/tonne	$279	$305	FAO, OECD
Steel	$/tonne:	$716	$716	World Bank
Iron ore	$/tonne	$146	$146	World Bank
Agricultural water	$/cubic meters	$0.02	$0.10	FAO, 2030 Water Resources Group (WRG)
Industrial water	$/cubic meters	$0.50	$0.90	OECD, WRG
Municipal water	$/cubic meters	$0.90	$1.50	Global Water Intelligence (GWI), WRG
Carbon	$/tonne	$0	$30	McKinsey Greenhouse Gas Abatement Cost Curve
Discount rate	%	10%	4%	McKinsey Greenhouse Gas Abatement Cost Curve

While we believe our model to be directionally correct and capable of providing actionable insights for decision makers, it is limited in some respects:

- **Discount rates.** We apply an average discount rate to all opportunities to calculate the cost efficiency of an investment. In reality, required hurdle rates vary significantly by opportunity (e.g., building efficiency, smallholder farm yields) and by country.
- **Additional externalities.** The only externality captured in the current sizing of opportunities is the price of carbon. Other relevant externalities would include biodiversity benefits, health impacts, water pollution, and reduced hedging costs (for renewable power when compared with fossil fuels).
- **Improved granularity in resource pricing.** We calculate energy at the regional level, with local energy prices for both the societal and the investor perspective. We base benefits available in food, water, and steel on global average prices. Applying local prices to these resources would improve the sizing and prioritization of resource productivity opportunities.
- **Expand sizing of material-related opportunities.** Here we focus only on steel as a material resource (for reasons we have explained in Box 2 in Chapter 2). Other relevant materials for a global resource model would include phosphorous and rare earth metals.

F. Metrics that matter

We base the outcome metrics described in Chapter 4 to assess the performance of countries and regions in each of the 15 priority resource productivity opportunities. We use two broad criteria:

- **Quality of metric.** We take into account the metric's specificity to the resource productivity opportunity being measured, whether it demonstrates comparability across countries, and its adaptability to different geographical contexts.
- **Availability of data.** We consider the granularity of data available (i.e., at the national, city, and local levels), and the frequency and ease of their collection.

We now give a brief assessment of the 15 outcome metrics. In addition to these outcome metrics, we have identified milestone metrics, which can be used to gauge how a region is using the key drivers that will lead to improvement on the outcome metrics. These can be a useful accompaniment to the outcome metrics given the lags between taking action and seeing actual improvements.

1. BUILDING ENERGY EFFICIENCY

- **Outcome metric.** Weather-adjusted building efficiency (kilowatt hour per square meter per degree day) is used to capture build efficiency outcomes. The McKinsey Greenhouse Gas Abatement Cost Curve gives estimates of energy consumption per square meter of floor space across 21 regions.[225] A

225 These are Brazil, Canada, China, France, Germany, India, Italy, Japan, Mexico, Middle East, rest of Africa, rest of developing Asia, rest of Eastern Europe, Rest of EU27, rest of Latin America, rest of OECD Europe, rest of OECD Pacific, Russia, South Africa, the United Kingdom, and the United States.

degree day is a unit for estimating the demand for energy required for heating or cooling. In the United States, the typical standard indoor temperature is 65 degrees Fahrenheit (18.3 degrees Celsius). For each degree Fahrenheit decrease or increase from this standard in the average outside temperature, one heating or cooling degree day is recorded. Using data from www.degreedays.net, we have developed a database of the annual heating and cooling degree days for the major population centers of the 21 regions and used a weighted average to represent the average climate of the region or country. When we divide the energy consumption per unit area by the region's degree days, we adjust for climatic variation across regions so that the comparison can be more meaningful. While this metric adjusts for weather-related factors, it does not adjust for size of residence. In the United States, for example, houses are generally much bigger than elsewhere and therefore the total energy consumption of a house is higher than in other countries—even so, the United States rates quite well on energy use per square meter. Nor does this metric distinguish between residential and commercial space. An ideal metric would capture building efficiency by residential and commercial users and adjust for weather, living standards (i.e., appliance in use), and the size of homes in a particular geography.

- **Milestone metric.** Building codes that require energy efficiency in new construction are a useful indicator of how an area is progressing in implementing resource productivity measures. For retrofits, a useful indicator could be the existence of a regulatory model that allows for a greater role for specialized energy services companies (or utilities) to provide funds for up-front investment and expertise in identifying and capturing energy-efficiency savings.

2. LARGE-SCALE FARM YIELDS

- **Outcome metric.** We use large-scale farm yields relative to agro-ecological potential as the outcome metric. Country-level data on yields come from the FAO.[226] Information by the type of farm (i.e., large-scale farms and smallholder farms) is not publicly available. Using data on the relative split of farm area by smallholders and large-scale farms alongside expert interviews, we have estimated yields and production on both types of farm by country.[227] We then related these yields to the cultivation potential for rain-fed and irrigated crops with high inputs in various global agro-ecological zones.[228] Further research into the yield performance of different farm sizes and at the subcountry level would be useful for refining this metric.

- **Milestone metric.** Given that capital intensity relates strongly to productivity in large-scale farming, capital investment per hectare could be a useful milestone indicator.

226 Food and Agriculture Organization, www.faostat.fao.org, 2011.

227 Klaus Deininger and Derek Byerlee, *The rise of large farms in land abundant countries: Do they have a future?* World Bank Policy Research Working Paper No. 5588, March 2011. See also Shenggen Fan and Connie Chan-Kang, "Is small beautiful? Farm size, productivity, and poverty in Asian agriculture," *Agricultural Economics* 32(1): 135–46, 2005; and Food and Agriculture Organization, *FAO Country Briefs*, 2010.

228 Günther Fischer, et al., *Global agro-ecological assessment for agriculture in the 21st century: Methodology and results*, International Institute for Applied Systems Analysis, 2002.

3. FOOD WASTE

- **Outcome metric.** The percentage of food wasted in the value chain (excluding consumer waste) is a useful outcome measure. Unfortunately, data on food waste from public research are limited. A recent study by the FAO gives a picture of food waste along different points of the value chain by region.[229] Given the importance of food waste as a major resource productivity opportunity, this is an area where more investment in tracking and monitoring would add significant value.

- **Milestone metric.** In developing countries, most food waste results from postharvest losses and lack of infrastructure. A useful milestone indicator could be the number of farms with storage devices that safeguard grain and other food.[230]

4. MUNICIPAL WATER LEAKAGE

- **Outcome metric.** We use the share of water consumption that is non-revenue water (i.e., delivered to the end user but not paid for) as a proxy for water leakage. However, we have sized the opportunity using country case studies where actual leakage estimates are available, and then scaled these to the global level. The International Benchmarking Network for Water and Sanitation Utilities collects data on non-revenue water, but the organization has information for some, not all, countries.[231] A preferred metric would capture water losses per kilometer of network.

- **Milestone metric.** Lessons from case studies include conducting regular water audits, reviewing network operating practices, developing information systems, and training and incentivizing staff on relevant metrics. Indicators based on these factors could be a useful guide to progress on water leakage issues.

5. URBAN DENSIFICATION

- **Outcome metric.** Due to the lack of availability of a satisfactory dataset that would allow us to compare urban densification at the country level, we have not included this metric in the report. Measures of public transport use are generally not available at a national level. Many cities report statistics on the use of public transit, but there is little consistency in these metrics. For example, data compiled by Metrobits give the number of daily riders on the world's top 100 metro systems, while other metrics capture meters of railway track per capita.[232] A preferred metric would capture the share of population driving to work compared with the share using public transport or walking.

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229 *Global food losses and food waste*, Food and Agriculture Organization, 2011.

230 Jason Clay, "Freeze the footprint of food," *Nature* (475): 287–89, July 2011.

231 The International Benchmarking Network for Water and Sanitation Utilities, www.ib-net.org, 2011.

232 Metrobits, www.metrobits.org, 2011.

- **Milestone metric.** The fundamental driver of transport energy efficiency is the level of urban density.[233] For example, Jeffrey Zupan of the New York Planning Association has suggested that public transport becomes viable at a threshold of around seven dwellings per acre.[234] Policy decisions such as zoning laws and infrastructure investments can in turn influence density.

6. IRON AND STEEL ENERGY EFFICIENCY

- **Outcome metric.** Millions of BTUs per tonne of steel produced is a useful indicator. Using World Steel Association steel production statistics by country and data on the energy consumption of the steel sector in McKinsey's Global Energy Perspective and Greenhouse Gas Abatement Cost Curve model, we have developed an estimate of the energy input required to manufacture one tonne of steel in each region.[235] To achieve a more ideal measure, it would be useful to separate the production of higher-strength steel from that of standard steel, since the production of higher-strength steel is more energy-intensive. However, obtaining estimates of higher-strength steel production across all of the regions can be difficult. Readers should consider the estimates in this report to be high-level and directionally correct.

- **Milestone metric.** Mandatory standards that promote the use of EAF, for example, could be useful indicators.

7. SMALLHOLDER FARM YIELDS

- **Outcome metric.** Smallholder farm yields relative to agro-ecological potential could be a useful outcome measure, but its use is currently limited in the same way as measures of large-scale farm yields.

- **Milestone metric.** A useful indicator would be the percentage of households having title to the lands they cultivate.

8. TRANSPORT EFFICIENCY

- **Outcome metric.** For fuel efficiency, liters per kilometer can be used as a proxy for transport efficiency. The McKinsey Greenhouse Gas Abatement Cost Curve includes estimates of the fuel efficiency of light-duty vehicles (i.e., passenger vehicles and light trucks), medium-duty trucks, and heavy-duty vehicles, split across 21 regions.

- **Milestone metric.** There is a strong correlation between the price of fuel and transport efficiency. Fuel taxes per liter of fuel could therefore be a useful indicator. A more direct indicator could be adoption of a transportation version of Japan's Top Runner program, in which manufacturers must improve the energy efficiency of their products to the top level of the benchmark within a specified period.

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233 Another key factor for successful public transit that David Owen points out is a lack of palatable alternatives. As Owen remarks, people in New York don't ride the subway because they are more environmentally conscious; they ride the subway because owning and using a car is so disagreeable due to such issues as traffic congestion and a lack of parking. See David Owen, *Green metropolis: Why living smaller, living closer, and driving less are the keys to sustainability* (New York: Riverhead Books, 2009).

234 Ibid.

235 *Crude steel production statistics*, 2011, World Steel Association, www.worldsteel.org.

9. ELECTRIC AND HYBRID VEHICLES

- **Outcome metric.** We use the penetration of electric and hybrid vehicles as a percentage of vehicle fleets as a measure of progress. Data come from multiple sources including industry reports at the country level.

- **Milestone metric.** In addition to fuel taxes (already mentioned), the availability of infrastructure (e.g., recharging points per square mile) would be a useful indicator.

10. LAND DEGRADATION

- **Outcome metric.** Net rate of land degradation by hectares per year is a useful outcome measure. The "net rate of land degradation" measures ongoing degradation of land and future restoration potential of degraded land in a nation, on a yearly basis. To enable a consistent comparison between different countries with different land areas, we calculate this metric as a percentage of total cropland. Because the agricultural community lacks common definitions, estimates of productivity losses in degraded land vary among different organizations that assess land degradation. Therefore, in order to aggregate the two different data sources of degradation—the Global Assessment of Human-Induced Soil Degradation for historically degraded land and the Global Land Degradation Assessment for recent and future rates of degradation—we convert degraded land into an area equivalent to 100 percent of productivity loss. For instance, ten hectares with 50 percent yield loss translates into five hectares of "actual" degradation. In this way, it is possible to estimate how much actual land loss results from the degradation of cropland.

- **Milestone metric.** As in the case of smallholder farm yields, the percentage of households having a title to the land they cultivate would be a useful indicator of progress toward greater productivity.

11. END-USE STEEL EFFICIENCY

- **Outcome metric.** Data on higher-strength steel penetration are currently unavailable.

- **Milestone metric.** Government standards that mandate the use of higher-strength steel in machinery, autos, and construction could be useful indicators.

12. OIL AND COAL RECOVERY

- **Outcome metric.** We use recovery rates of a given reserve as an outcome measure. The recovery rate of an oil well is the share of oil in place that can be extracted over the lifetime of the well. When a well expires, most of the original oil remains in the ground. The 2005 IEA *Resources to reserves* report estimated a global recovery rate of only 35 percent.[236] There is no central source of data on oil recovery rates. For this report, we have compiled data from many sources including the IEA, press releases from producing companies, technology conferences, and academic articles. Ideally, recovery rates would be segmented by the quality of reserve, particularly for unconventional sources such as extra heavy oil in Venezuela or tar sands in Canada that have much lower recovery rates (e.g., 10 percent on average). In

236 *Resources to reserves: Oil and gas technologies for the energy markets of the future*, International Energy Agency, 2005.

this report, we have not evaluated the recovery rates of coal across regions but have taken a deeper look at Chinese coal mine recovery rates as a source of potential productivity improvements. Based on McKinsey research, we estimate that the average recovery rate in coal mining is approximately 50 percent.

- **Milestone metrics.** A regulatory framework to manage the level of recovery in coal mines and oil wells, and tax incentives for the full recovery of resources could be useful indicators.

13. IRRIGATION TECHNIQUES

- **Outcome metric.** The adoption of micro-irrigation technologies is a potential proxy. Improved irrigation techniques include both sprinkler irrigation and micro-irrigation (e.g., drip irrigation). However, for simplicity, we have looked at the percentage of farms in each country that have micro-irrigation. This information is not regularly monitored, and we therefore use the latest overview from 2006.[237] The crop mix in a given country can bias this metric because micro-irrigation systems are currently limited to crops such as fruits and vegetables. More regular monitoring of efficient irrigation practices would be useful.

- **Milestone metric.** The degree to which water is priced at cost-recovery levels would be one useful indicator here.

14. ROAD FREIGHT SHIFT

- **Outcome metric.** The percentage of total revenue tonne-kilometers of inland freight transport using rail or barge could be a potential proxy. While there is generally widely available data on individual transport channels (e.g., rail, trucking), there is a lack of integrated data that show all freight transport channels for a given region.

- **Milestone metric.** The availability of rail and barge transport (e.g., share of main freight transport channels covered by rail and barge transport) would be useful indicators.

15. POWER PLANT EFFICIENCY

- **Outcome metric.** We use the conversion efficiency of coal- and gas-fired power plants as an outcome measure. The conversion efficiency of a power plant is the ratio of the amount of heat energy used (e.g., by burning coal or gas) to generate one unit of electrical energy. Increasing power plant efficiency means less fossil fuel is necessary, and this reduces fuel costs and mitigates emissions per unit of electricity generated. The IEA's *World energy balances* provides detailed estimates of recovery rates of coal- and gas-fired products across many locations, including electricity generation, combined heat and power, and heat plants. In our comparison, we focus on electricity generation.[238]

- **Milestone metric.** Indicators would include the presence of incentive frameworks for the adoption of efficient power conversion technologies.

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237 S. A. Kulkarni, F. B. Reinders, and F. Ligetvari, *Global scenario of sprinkler and micro irrigated areas*, International Commission on Irrigation & Drainage, 2006.

238 *World energy balances*, International Energy Agency, 2008. http: //www.iea.org/.

G. Sizing of productivity opportunities

Table A2. Energy

Size in 2030 QBTU	Key sizing assumptions	Key cost assumptions
Building energy efficiency Improving energy efficiency in residential and commercial buildings including improved building heating and cooling performance through retrofitting existing buildings and improved energy efficiency in new buildings; and switching to efficient lighting, appliances, and electronics		
31	Residential buildings improve efficiency in base case by roughly 14%, from 140 kilowatt hours/square meter/year in 2010 to 120 kilowatt hours/square meter in 2030, with the potential to improve a further 20% to 91 kilowatt hours/square meter. Commercial buildings increase their energy efficiency by roughly 12% in the base case, from 310 kilowatt hours/square meter to 275 kilowatt hours/square meter, with the potential to improve a further 20% to 213 kilowatt hours/square meter	Cost assumptions split by retrofit, new builds, and lighting/appliances and electronics, and also by commercial and residential. Learning rate for LEDs based on McKinsey LED research; learning rate for solar water heaters based on 18% historical improvement for solar technology 1950–2000
Oil and coal recovery Improving recovery rates from coal and oil mines		
14	Increased mechanization could enhance recovery rates by 50% in a subset of small coal mines (those producing less than 500 kilotonnes a year) in developing countries. In oil recovery, we assume ~75% of the opportunity will be captured in the base case with the rest captured in fields in the Middle East and former Soviet Union with currently low recovery rates. These wells represent roughly 23% of production, and we estimate an increase in well life of 10% from enhanced oil recovery	Capex costs are an incremental $2/barrel for the duration of the extended life of the well; opex costs are an incremental $10/barrel
Urban densification Densely planned cities enabling a shift away from traveling in private cars and toward public transit over the next 20 years		
5	Shift of nearly 23% of passenger kilometers from light-duty vehicles to public transit buses and bus rapid transit, shift of nearly 3% of passenger vehicle kilometers to metros. No shifts are explicitly calculated in the base case	Cost of transit systems based on regional case studies for metro, bus, and bus rapid transit. In the United States in 2030, shifting to metro requires a capital investment of $1,300/passenger kilometer, buses $60, and bus rapid transit $200
Transport efficiency Improvements in fuel efficiency of ICEs in light-duty, medium-duty, and heavy-duty vehicles		
4	LDV: By 2030, fuel economy improves from 7 L/100 km today to just under 5 L/100 km in 2030 in base case. In productivity case assume technical potential to reduce fuel consumption by an additional 0.6 L/100 km, to a final consumption of 4.3 L/100 km. MDV/HDV: improve by 11% and 13%, respectively (with 15% captured in base case)	Improvements and costs separated by vehicle type and fuel (e.g., diesel, gasoline). The cost of optimizing the ICE of an LDV (not hybrid) is an incremental €1,900/vehicle relative to a basic ICE in 2030

Size in 2030 QBTU	Key sizing assumptions	Key cost assumptions
EVs/PHEVs Increased penetration of EVs, PHEVs, and hybrid EVs in LDVs		
7	Assuming aggressive policies could mean that EVs comprise 62% of new LDV sales in 2030 (51% PHEV and 11% EV) vs. base-case penetration of 15% sales penetration of PHEVs and 4% of EVs in 2030	Base case assumes battery prices fall from ~$500/kilowatt hour to $300 in 2020 and $250 in 2030. In productivity case, assume battery costs could fall as low as $100 by 2030
Iron and steel energy efficiency Improving the energy efficiency of iron and steel production		
7	Base case assumes energy efficiency will increase by 0.7% per annum from 2010 to 2030, driven primarily by a shift from blast furnaces and BOF to EAF. In productivity case, we estimate that a set of targeted energy-efficiency measures could increase the annual improvement to 1.4%	Co-generation installation costs estimated at roughly €18/tonne of steel production capacity; direct casting costs estimated at €110/tonne of steel production; energy-efficiency measures in BOF production €35/tonne; energy-efficiency measures in EAF production €53/tonne
Power plant efficiency A shift toward more energy-efficient power plants for energy generation		
5	In base case, assume nearly one-third of coal plants to still be using subcritical technology in 2030, and half of gas plants to use basic gas turbines rather than combined-cycle gas turbines. By 2030, assume that half of these plants could upgrade to more efficient technologies, including ultra-supercritical coal and combined-cycle gas turbines	Costs based on the incremental cost of upgrading from subcritical coal to ultra-supercritical coal across key geographies ($250–$730/kilowatt hour) and from open cycle to combined cycle ($260–$360/gigawatt) (Source: IEA WEO 2010)
Road freight shift Shifting some freight transport from road to other more efficient sources of transport such as rail and shipping		
4	Switching 25% of passenger kilometers from truck-based freight to rail (20%) and barge (5%) could reduce oil demand by 2.3 million barrels per annum by 2030. No shifts are explicitly calculated in the base case	Costs based on capex and operating expenditure (including fuel) requirement for truck, rail, and ship, adjusted for regional differences. In the US in 2030, e.g., we assume that shifts to rail can be implemented at a capital investment of $175/thousand passenger kilometers and shipping at $65 vs. trucking at $115

Table A3.Land

Size in 2030 Million hectares	Key sizing assumptions	Key cost assumptions
Large-scale farms Improving yields on large-scale farms		
150–185	Developed countries: 5–10% total improvement from improved practice; 20–30% total improvement from genetic variety advancements (EU with 25–35% upside due to lower use of modern genetic variety). Overall 15% over base case Developing countries: reach top quartile of yield achievement vs. "maximum attainable" yield; 50% penetration of modern genetic variety adoption relative to commercial developed assumed. Overall 50% increase over base case	Developed countries: capex of $80/hectare for improved equipment for advanced precision farming; opex of $120/hectare for improved genetic variety, $7.50/hectare for operating advanced precision farming equipment Developing countries: capex of $455/hectare for improved capital equipment; opex of $40/hectare for improved genetic variety; infrastructure investment of $240–$480/hectare depending on existing level of infrastructure
Smallholder farm yields Improving yields on smallholder farms		
75–105	Developed countries and advanced smallholder farms (including India and China): 10–20% improvement based on empirical case studies and expert interviews; 50% penetration of modern genetic variety adoption relative to commercial developed assumed. In total, 10% over base case Developing countries: approximate doubling of yield improvement based on empirical case studies, depending on climate. 50% increase over base case	Developed countries/advanced smallholder farms: capex of $155/hectare for advanced precision farming equipment; opex of $60/hectare for improved genetic variety Developing countries: capex of $600/hectare for improved capital equipment; opex of $75/hectare for improved inputs; infrastructure investment ranging from $480–$960/hectare depending on existing level of infrastructure
Land degradation Reducing the degradation of land and restoring land that is already degraded		
70	Expert interviews suggest it is possible to restore 80% of land suffering low to moderate levels of degradation and 60% in the case of severe to very severe degradation. On current trends, the share of restoration stands at only 15%. We estimate that degradation could be prevented on 45% of cropland versus a base-case estimate of 10%	Based on case studies from World Overview of Conservation Approaches and Techniques. Moderate degradation restoration: sample of case studies from Niger, Nicaragua, Ethiopia, South Africa, Bolivia, Kyrgyzstan, China, and Peru; capex of $690/hectare; opex of $55/hectare Severe degradation restoration: sample of case studies from Tajikistan and Nepal; capex of $2,800/hectare; opex of $320/hectare Prevention of land degradation: capex of $55/hectare based on costs to implement no-till agriculture across irrigated and rainfed croplands

Size in 2030 Million hectares	Key sizing assumptions	Key cost assumptions
Food waste Reducing food waste in the value chain, including postharvest waste reduction in developing countries and end supply-chain waste reduction in developed countries. Excludes consumer food waste		
65	Supply-chain waste: developed countries reduce 8% of end supply-chain waste; developing countries achieve 50% of packaging/distribution waste of developed countries Postharvest waste: developing countries meet 50–80% of postharvest waste performance of developed countries, depending on food type (perishable vs. nonperishable); no base-case productivity improvement assumed due to lack of historical data	Postharvest waste: Nonperishables: capex of $200/hectare to prevent waste during storage and transportation Perishables: capex of $140, opex of $200/hectare to prevent waste during storage and transportation Supply-chain waste: capex of $600/hectare, opex of $200/hectare based on case study to set up cold supply chain plus $480/hectare of infrastructure investment
Feed-efficiency improvement Improved feed-efficiency ratios through use of better timing and mix of feedstocks as well as additive nutrients to support animal growth		
30	15–20% feed efficiency improvement through feed additives and improved practice (based on expert interviews). 10% improvement assumed in base case	Opex of $123/hectare for additive nutrients based on expert interview
Accelerated penetration of second-generation biofuels Ramp up of investment into second-generation biofuels by accelerating production of second-generation plants		
2	Acceleration of second-generation biofuels in bioethanol from 13% in the base case to 21% by 2020	Capex: $11/gallon for incremental upfront investment into second-generation plants

Table A4. Water

Size in 2030 Cubic kilometers	Key sizing assumptions	Key cost assumptions
Irrigation techniques Replace flood irrigation with micro-irrigation systems that use sprinklers and drip irrigation		
250–300	Sprinkler: average yield improvement of 15%; 10% higher penetration than base case for relevant crops Drip: average yield improvement of 45% (varies by area and crop); 15–20% higher penetration than base case for relevant crops	Sprinkler: capital expenditure (capex) varies from $564/hectare in India to $2,400/hectare in South Africa; operational expenditure (opex) saving of $50–100/hectare (country, crop dependent) Drip: capital expenditure varies from $1,000/hectare in India to $4,000/hectare in South Africa; opex saving $150–200/hectare (country, crop dependent)
Municipal water leakage Reduce water lost from leaking pipes		
100–120	Case study results extrapolated to rest of the world based on their level of development and starting point on leakage: e.g., 5% reduction in South Africa, 16% in Brazil, and 5–8% in China	Based on individual country case studies (e.g., China: $0.2/cubic meter; India: $0.04–$0.38/cubic meter) and extrapolated to other countries based on level of development
Wastewater reuse Reuse wastewater in power generation, manufacturing, domestic, and municipal sectors		
55	Base case based on Global Water Intelligence forecast for 2015, extrapolated to 2030 by region; in the productivity case, we assume level of collection, treatment, and reuse reaches top quartile for high-income countries, mid-quartile for middle-income countries, and bottom quartile for low-income countries	Incremental treatment cost of $0.4/cubic meter; energy cost is 60% of opex
Industrial water efficiency Improve water efficiency in industry through condensed water cooling, dry quenching, dry de-dusting (steel), concealed filtration, dry debarking (pulp/paper), dust suppression, paste tailing (mining), and radical water (food/beverage)		
55	Improvement potential over base case based on level of development of country: 10–30% (food), 5–75% (textiles and paper), 0–20% (chemicals), and 5–10% (other)	Detailed assumptions on cost and capex available from 2030 Water Resource Group report
Irrigation efficiency Reduce waste of water from source to farm using canal lining, piped conveyance, and channel control		
30	Water saving over base case: canal lining 3%; channel control 10%	Canal lining: capex of $270–$500/hectare; opex saving of $6/hectare Piped conveyance: capex of $1,000/hectare Channel control: capex of $40/hectare
Municipal water efficiency Pull other municipal levers including replace water apparatus, new/retrofit showerheads, faucets, and toilets		
30	Extrapolation of savings based on case studies in China, India, South Africa, and Brazil (São Paulo) to other countries based on level of economic development	Incremental cost: dual-flush toilet $45–$150/unit; faucet $15–$30/unit; laundry machine $200–$300/unit
Power generation Reduce water use in power generation from condensed water cooling, dry cooling, fluidized bed combustion, and ultra-super critical technology		
10	Based on University of Kassel modeling	Condensed water cooling has relatively small capex; unit cost $0.2–$0.8/cubic meter; dry cooling has incremental capex of $118 million with lifetime of 30 years

Table A5. Steel

Size in 2030 Million tonnes	Key sizing assumptions	Key cost assumptions
End-use efficiency of steel Increasing efficiency among the main end users of steel—the construction, machinery, and automotive sectors, which today account for 80% of global demand		
165 (steel)	10% higher penetration of 500 MPa rebars in developed countries vs. base case, and 30% higher penetration of 450 Mpa rebars in developing countries vs. base case. For beams and columns, weight saving of 30% and penetration of 50%. For automotives, 15% additional weight reduction over base case for cars and 20% for light and heavy commercial vehicles	Additional capex for making higher-strength steel vs. regular steel of $240/tonne (with a lifetime of 15 years)
Scrap recycling Significant increase in obsolete scrap recycling rate		
132 (steel equiv-alent)	Base case: old scrap collection rate of 50–65% across regions Productivity case: old scrap collection rate reaches 60–65% by 2020 and 70% by 2030	Capex required for scrap collection infrastructure and transport of $50/tonne
Conversion efficiency Improve coking coal to crude steel yield and shift from blast furnace to EAF-DRI		
110 (coking coal)	Base case: fuel rate of 521 kg/tonne Productivity case: fuel rate of 490 kg/tonne	Estimates based on regional project cost figures
Iron ore recovery Improved recovery rate from iron ore extraction		
30 (iron ore) and 20 (coking coal)	Additional overall recovery improvement potential over base case of ~1% (iron ore) and 1.7% (coking coal), with variation across developing and developed regions	Capex of $400,000 for 80 tonnes/hour capacity with a lifetime of ten years (based on a case study on the SLon recovery method)

H. Explaining returns from productivity opportunities

In the report, we discuss different returns on resource productivity opportunities, depending on to whom those returns might accrue—i.e., society as a whole or investors. Here, we discuss the different approaches we use to estimate the returns of the productivity opportunities, the return profile of opportunities across different resources, and some of the sensitivities in this analysis.

1. DIFFERENT APPROACHES TO ESTIMATING RETURNS

We use three different approaches to estimating the returns of productivity opportunities, allowing for different investor perspectives:

- **Integrated cost curve, private-sector investor perspective.** We estimate that 70 percent of the opportunities from an investor perspective have returns of 10 percent or more. We chose 10 percent as a proxy for private-sector returns based on a weighted average of the private-sector hurdle rates across industries and regions contained in McKinsey's Greenhouse Gas Abatement Cost Curve. We calculate the benefits as the resource saved relative to the technology or process used in the base case, times the 2010 average resource price. For example, installing a more energy-efficient air conditioner could reduce electricity consumption by 20 percent in a residential environment compared with a less efficient unit. We then multiply this reduction in electricity use by the local electricity price paid by the investor. Prices include taxes, which increase the prices of resources, and subsidies, which lower the prices of resources. We estimate incremental cost relative to the base case. In the case of the air conditioner, this is the incremental cost of purchasing the more efficient air conditioner relative to the less efficient unit.

- **Integrated cost curve, private-sector investor perspective adjusted for subsidies and carbon.** We estimate that 80 percent of the opportunities from a private-sector perspective, adjusted for subsidies and carbon priced at $30 per tonne, have returns of 10 percent or more. We calculate the benefits on the same incremental basis. However, we add the estimated subsidy to the average 2010 price. For example, global subsidies on electricity totaling $122 billion in 2010 are added to the average price based on the average subsidy per megawatt hour for the region. In this cut of the curve, we still include taxes.

- **Integrated cost curve, societal perspective.** We calculate that 90 percent of the opportunities from a societal perspective have returns of 4 percent or more. We use 4 percent as a proxy for the average public-sector borrowing rate, using the same assumptions as the McKinsey Greenhouse Gas Abatement Cost Curve.

2. DISCUSSION OF RETURN PROFILES BY RESOURCE

- **Energy.** From a private-sector investor perspective, 49 percent of opportunities have returns greater than 10 percent.[239] Energy opportunities with returns greater than 10 percent include basic retrofits, lighting improvements, adoption of more energy-efficient appliances, iron and steel energy-efficiency improvements, and electric vehicles. The opportunities that do not meet this 10 percent threshold include high-efficiency new builds, shifting private transport to metro, and the advanced retrofits of buildings. Retrofitting a building by improving airtightness (by sealing baseboards), weather-stripping windows, and adding attic insulation has a high return on investment. However, further retrofitting through installing high-efficiency doors and windows; increasing the insulation on a building's outer walls, roof, and basement; and replacing heating and ventilation systems with heat-recovery capabilities lowers returns below the 10 percent internal rate of return threshold in many regions. After adjusting for subsidies and carbon, 54 percent of opportunities have returns greater than 10 percent. Opportunities such as residential replacement of water heating and direct casting in steel switch to having returns at about the 10 percent threshold.

- **Land.** From a private-sector investor perspective, 72 percent of opportunities have returns greater than 10 percent. Land opportunities with returns greater than 10 percent include commercial farm yield improvement, postharvest nonperishable food waste, prevention of land degradation, and restoration of

239 The weighting used to estimate the share of resource-specific opportunities with returns greater than 10 percent is based on share of total resource savings accounted for by the particular productivity opportunity (e.g., QBTU, hectares, tonnes of steel, etc.). For the overall integrated cost curve, the weighting used is the share of total resource benefits (calculated in dollar terms).

moderately degraded land. Restoring severely degraded land, however, has returns lower than 10 percent due to the substantial improvements required. Other opportunities with returns below 10 percent include low-infrastructure smallholder yields (due to the significant investment required to build roads to better connect farmers to the market), reduction in postharvest perishable food waste in developing countries, and acceleration of second-generation biofuels (due to already aggressive ramp-up assumed in the base case). After adjusting for subsidies and carbon, all of the land opportunities have returns greater than 10 percent.

- **Water.** From a private-sector investor perspective, 76 percent of opportunities have returns greater than 10 percent. Water opportunities with returns greater than 10 percent include adoption of irrigation techniques (drip and sprinkler), industrial water efficiency and municipal leakage. Approximately 10 percent of the opportunity to reduce water withdrawals comes from the adoption of improved irrigation techniques such as drip irrigation. Interestingly, this opportunity has significant returns despite the fact that governments subsidize water to a substantial degree. The adoption of drip irrigation requires some upfront capital expenditure but also saves on inputs (predominantly fertilizer) and energy (in pumping water, for instance) and increases yields. In India, for example, drip irrigation could reduce the consumption of fertilizer by 40 percent and increase yields by as much as 60 percent where that fertilizer is applied. Water opportunities with returns lower than 10 percent include wastewater reuse, municipal water-efficiency improvements, and improved water efficiency in the power sector. After adjusting for subsidies and carbon, all of the water opportunities have returns greater than 10 percent.

- **Materials (steel).** All opportunities in steel have returns higher than 10 percent. These opportunities are in two key areas. First, adoption of higher-strength steel is advantageous to the manufacturer as this is usually a higher-margin product. The buyer of this steel has to pay a higher price but needs a lower quantity. Second, increasing recycling rates, due to high iron ore prices, is also attractive. Using the scrap to switch from BOF to EAF saves energy as EAF use one-tenth of the fuel with only 30 percent more electricity than a BOF.

3. KEY SENSITIVITIES

It is important to note that we base our calculations of societal returns from resource productivity explicitly on 2010 prices. Depending on how prices evolve, the mix of opportunities that has returns higher than 10 percent would shift, too. For example, if food prices were to decline by 20 percent below 2010 levels, only 30 percent of the opportunities (from a private-sector investor perspective) would have returns of 10 percent or more (versus 72 percent based on 2010 prices). Alternatively, if energy prices (adjusted for subsidies) rose by 20 percent—taking oil to $145 per barrel or the retail price of electricity to between 13 and 16 cents per kilowatt hour, for instance—80 percent of the energy opportunities (from a private-sector investor perspective) would have returns above 10 percent (versus 49 percent based on 2010 prices).[240]

240 Based on a global average price of electricity, weighted by total consumption.

I. Assumptions on the evolution of power generation

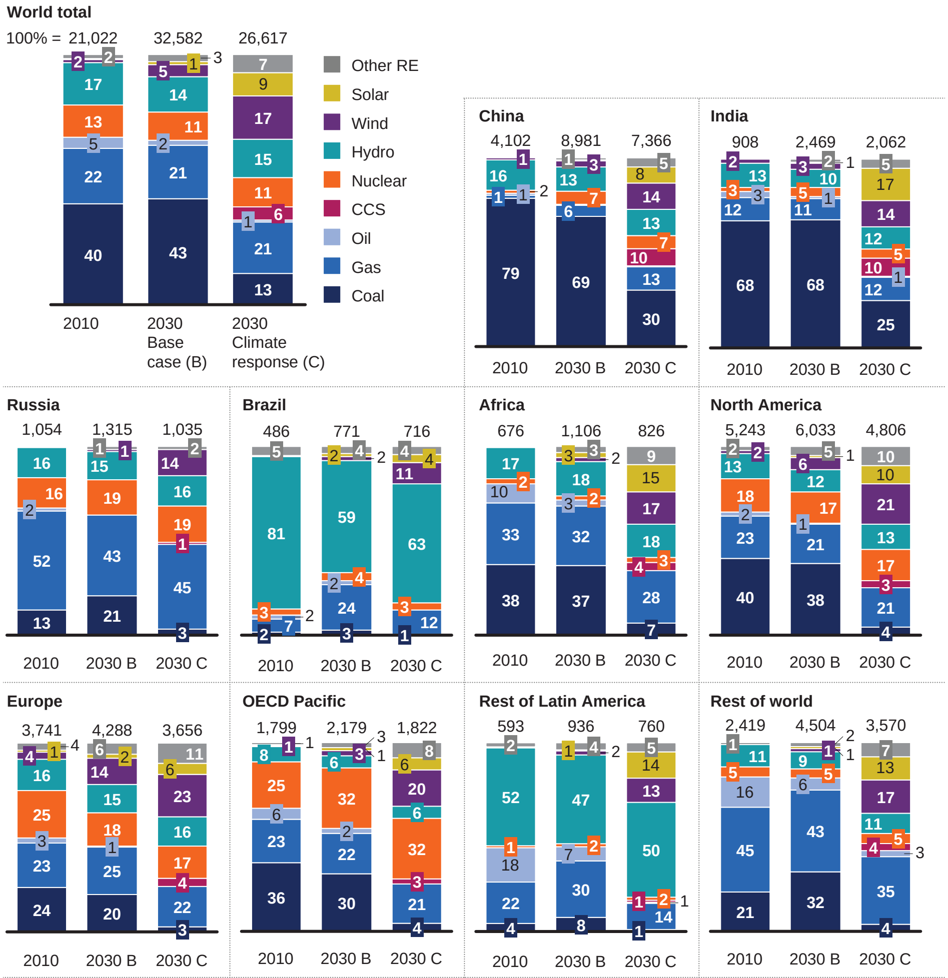
Across each of the cases, we have made assumptions about the mix of the power generation. In this report, these assumptions are laid out at a global level. Exhibit A1 shows a more detailed set of the figures by region.

Exhibit A1

Assumptions on the evolution of power generation

Share of total power generation

%; terawatt hours



NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey analysis

Glossary

Key metrics

Energy (QBTU)

Quadrillion British thermal units is a common metric to describe energy use across all energy resources. A British thermal unit is equal to 1,055 joules. A single QBTU would provide all of the energy demand for New York State for approximately three months.

Land (million hectare)

A hectare is 10,000 square meters (100 meters by 100 meters). Spain is approximately 50 million hectares in total land area.

Steel (million tonne)

Steel demand is measured in millions of tonnes. One tonne is equal to 1,000 kilograms.

Water (cubic kilometer)

Global water withdrawals are often measured in cubic kilometers. Global water withdrawals today are roughly 4,500 cubic kilometers. A single cubic kilometer is equal to one billion liters.

Key terms

Agency issues

A conflict arising when people (agents) may have different incentives from others whose interests they are interested to look after (principals). In residential and commercial buildings, agency issues arise when the landlord bears the cost of investing in energy-efficient insulation but it is the tenant who receives the benefit through lower energy bills. In the transportation sector, agency issues occur when auto manufacturers cannot recoup their investments in improving fuel economy because the resulting fuel savings mostly benefit consumers.

Basic oxygen furnace (BOF)

A type of furnace used during the steelmaking process that injects pure oxygen into a batch of pig iron and other materials to burn the contents and produce steel. Together with the electric arc furnace, it is one of the two modern ways of making steel.

C40

A group of major cities globally committed to implementing action to deliver sustainable climate change.

CAFE

Corporate Average Fuel Economy regulations were first enacted in the United States in 1975 in response to the Arab oil embargo with the intention of improving the average fuel economy of cars and light-duty trucks.

Carbon capture and storage

A technology for capturing, transporting, and storing carbon dioxide emissions from large point sources, such as power stations.

Carbon dioxide equivalent

A standard unit of measurement using carbon dioxide that is used to compare different greenhouse gases for their global warming potential over a 100-year timescale.

Closed-loop production system

An environmentally friendly production system in which any industrial output is capable of being recycled to create another product.

Common resource pool

A type of good consisting of a natural or human-made resource system (e.g., fishing fields) whose size or characteristics makes it costly to exclude potential beneficiaries from obtaining benefits from its use.

Contract farming

This is where agricultural production is carried out according to an agreement between a buyer and farmers that establishes conditions for the production and marketing of farm products.

Crop-per-drop

The amount of crop produced from a set amount of surface water or groundwater.

Decision-making barriers

Conditions that may discourage actors from pursuing productivity opportunities that are in their own interests, usually because of a misalignment of incentives, a lack of information, or political difficulties in implementation (also see Incentive barriers and Implementation barriers).

Discount rate

The rate at which interest is paid for the use of money borrowed from a lender. We use a discount rate to calculate the current value of future resource benefits.

Drip irrigation

A method of irrigation that saves water and fertilizer by allowing water to drip slowly to the roots of plants (either onto the soil surface or directly onto the root zone) through a network of valves, pipes, tubing, and emitters.

Electric arc furnace (EAF)

A type of furnace that uses electric arcs to burn a combination of pig iron and other materials to produce steel. Together with the basic oxygen process, it is one of the two modern ways of making steel.

Feedback loop

A circular chain of cause and effect, whether positive or negative.

Feed-in tariffs

A policy mechanism designed to accelerate investment in renewable energy technologies.

Greenhouse gases

Gases that trap heat in the atmosphere. Some occur naturally and some are caused by human activity. The base case projects that greenhouse gas emissions could reach 66 gigatonnes of carbon dioxide equivalent by 2030.

Horizontal drilling

A drilling technique that drills sideways to increase extraction from a given reservoir. One method involves drilling vertically to a "kickoff point" and then drilling along a more horizontal plane to reach the "entry point" of a reservoir.

Hydraulic fracturing

Also known as "fracking," this technique is used to create additional permeability in a producing reservoir to allow gas to flow more readily to the wellbore. The process can involve pumping large volumes of low-viscosity water and sand mixture into shale rock to induce new fractures and augment existing fractures.

Implementation barriers

These are factors such as supply-chain bottlenecks, weaknesses in technology, and availability of capital that may prevent the implementation of a productivity opportunity even if there is an incentive for implementation (see also Incentive barriers and Decision-making barriers).

Incentive barriers

Conditions that make decision makers less likely to pursue a productivity opportunity, such as returns on investment and associated capital intensity (see also Decision-making barriers and Implementation barriers).

Integrated resource productivity cost curve

McKinsey's grouping of more than 130 potential resource productivity measures into areas of opportunity, the top 15 of which account for roughly 75 percent of potential resource savings. One version of the curve takes the perspective of a private-sector investor, and the other takes a societal perspective.

Intermittency

An intermittent energy source is any source of energy that is not continuously available due to some factor outside direct control (e.g., amount of wind to power wind turbines).

Internal rate of return (IRR)

The rate of return used in capital budgeting to measure and compare the profitability of investments.

Kondratiev cycle

A long-term growth cycle typically lasting 30 to 50 years that can be attributed to major technological innovations such as the invention of steam power, railroads, and software information technology.

Land degradation

Deterioration in the quality of land for the growing of crops. Causes include the pollution of land and water resources, soil-nutrient mining, and soil salinization.

Large-scale farms

These are farms with more than two hectares of land.

Productivity

The degree to which the transformation of resources into productive inputs (e.g., yield per hectare) and the economic value achievable from a given volume of resources (e.g., reduced food waste, improved building efficiency) is maximized. Behavioral changes that involve a loss of welfare (e.g., smaller apartments, changing diets, and the removal of energy subsidies) are excluded from our definition of productivity.

PRONASE

Programa Nacional para el Uso Sustentable de la Energía, or the National Program for Sustainable Energy Use.

Purchasing power parity (PPP)

A conversion factor that measures the number of units of a country's currency required to buy the same amount of goods and services in the domestic market as a US dollar would buy in the United States.

Rebound effect

Rebound effects in resources occur when, for instance, behavioral changes happen that can at least partially offset productivity gains. This might happen if consumption rises in response to the implementation of resource efficiency measures and reduces the price of a product or service. Lower prices might, in turn, boost consumption again. Rebound effects can be direct, indirect, or economy-wide.

Resource intensity

Resource intensity is the amount of resource inputs (e.g., tonnes of steel) relative to economic output. At an economy level, resource intensity is distinct from what we define as resource productivity because it includes the impact of sector mix and is not therefore a true measure of the efficiency of resource usage.

Revenue tonne-kilometer

Utilized (sold) capacity for cargo expressed in metric tonnes, multiplied by the distance flown.

Shale gas

A natural gas found in shale rock that is expected to become an increasingly important source of energy.

Smallholder farms

These are farms with less than two hectares of land.

Spatial planning

This refers to methods used by the public sector to influence the distribution of people and activities in geographical areas. It includes planning for land use, transport, and the environment, within an urban or regional context.

Tonnes

Tonnes are metric tonnes, or 1,000 kilograms. This is not to be confused with tons (sometimes called short tons) that are equal to 2,000 pounds.

Top Runner

Japan's program mandates manufacturers to improve their products' energy efficiency to the top level of a benchmark within a specified period.

Universal energy access

The provision of access to clean, reliable, and affordable energy services to all people around the world. The vast majority of those who lack access to modern energy services today live in sub-Saharan Africa, India, China, and other parts of developing Asia.

Variable speed drive

This describes equipment used to control the speed of machinery (e.g., fans, pumps) that can help processes control and energy conservation.

Water consumption

Water consumption is defined as the net between the initial withdrawals and the return flow.

Water supply

In this report, we define water supply as a renewable water resource that is accessible, reliable, and environmentally sustainable. For more details, see *Charting our water future: Economic frameworks to inform decision-making* from the 2030 Water Resources Group.

Water withdrawal

Water withdrawals define the amount of water that is removed from a given source including surface water or groundwater, or nonconventional sources such as desalination. A portion of the withdrawn water may subsequently be available for other uses, depending on the time, place, and quality of the "return flow."

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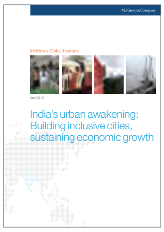

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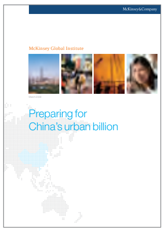

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