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TRANSFORMING ECONOMIES THROUGH GREEN INVESTMENT

NEEDS, PROGRESS, AND POLICIES

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Transforming Economies Through Green Investment: Needs, Progress, and Policies

Climate & Energy Paper Series

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Executive Summary

Changing the trajectory of the world's energy economy to avoid the worst impacts of a warming atmosphere will require tremendous leadership and innovation. Worldwide, greenhouse gas emissions must peak over the next ten years and decline sharply before the middle of the century. Rather than slowing down, however, greenhouse gas emissions may well double in the next few decades.

An economic transformation of unprecedented scale will be needed to reverse this trend and bring nations on the path toward a sustainable, low-carbon global economy. And there is little time to spare: each year of delay in limiting carbon emissions will dramatically increase the cost of this paradigmatic transformation. The problem thus calls for swift, urgent action. Much will depend on the ability to channel public and private resources into the deployment of sustainable technologies over the short term. In this study, investment needs are hence estimated starting in 2011.

Current economic frameworks have not succeeded in channeling the required capital flows into the sustainable energy technologies that will form the basis of a low-carbon economy. To drive investment at the required scale, a range of different policy approaches, combined in a balanced policy mix, can serve as a powerful catalyst toward the clean energy economy of the future. Investment in and adoption of new technologies will help stabilize greenhouse gas concentrations at safe levels, promote energy independence, and offer numerous opportunities for growth and jobs in the rapidly expanding market for clean technology.

Investment needs

According to recent estimates, the level of investment needed to transform the global economy is nearly $480 billion annually in the near term, rising to just over $1.2 trillion per year by 2026. Table ES-1 shows the authors' ballpark estimates, based on recent data, of how much investment will be needed in key sectors in the United States, China, and Europe.

Three key sectors—power, transport and buildings—account for nearly 80 percent of this investment. Each of these three key abatement sectors has specific areas where substantial near-term investment is essential:

- Power—the power sector will require roughly 16 percent of global clean technology capital investment in 2011, increasing to 18 percent by the end of 2030. Key investment needs include renewable energy, energy efficiency, grid infrastructure, and electricity storage.

- Transport—transport will require roughly 15 percent of annual clean technology investment worldwide starting in 2011, rising to 37 percent by 2030. Investment is especially needed for improved vehicle efficiency, electric vehicles, freight transport, and planning.

Changing the trajectory of the energy economy to avoid the worst impacts of a warming atmosphere will require global investments of nearly $480 billion annually in the near term, rising to just over $1.2 trillion per year by 2026.

Table ES-1. Approximate estimates of capital investment needs in abatement, by region and sector (billions $ per year)

	Billion $ per year					
	2011-2015			2026-2030		
Sector	N. America	W. Europe	China	N. America	W. Europe	China
Transport	16	12	13	78	57	117
Buildings	40	32	33	51	37	77
Power	17	13	14	38	28	58

Source: Ecologic Institute estimate based on McKinsey 2009, pp. 42-43

Both Europe and North America saw a slowdown of clean energy investment in 2008 due to reduced availability of project finance as well as decreases in tax incentives.

• Buildings—clean investment needs in buildings start high at 39 percent in 2011, falling to 24 percent of global investment by 2030. Investment here is needed principally in the weatherization of existing buildings, low-energy design of new construction, and more sustainable urban infrastructure.

Despite steadily growing capital flows into these sectors, we are still far from achieving the required levels of investment; yet how can this investment gap be quantified, and how can it eventually be closed?

The investment gap: Sustainable energy investments by region

Recently published data make it possible to compare sustainable energy investments across regions. Fairly comprehensive data on investment in clean energy technology is now available, a situation that is unfortunately not the case for the other key sectors. Nevertheless, a comparison of North American, European, and Chinese investment levels in sustainable energy sheds important light on the extent to which these regions are investing in a low-carbon future.

Sustainable energy investments have grown significantly over the past six years. In 2008, however, both Europe and North America saw a slowdown of investment due to reduced availability of project finance in increasingly tight credit markets and decreased overall tax incentives.

While China leads Asia in sustainable energy investments, investments within Europe and North America continue to make up the lion's share of sustainable energy investment, responsible for two-thirds of global investment in sustainable energy in 2008. Europe is ahead of North America in terms of investment per GDP, yet even North America has invested nearly twice as much as China per ton of CO_2 emitted.

Because of Europe's past sustainable energy investments and other factors, its economy already has a carbon intensity that is significantly lower than North America's, with a GDP nearly 60 percent higher for every ton of CO_2 emitted. Of the three regions, China has by far the highest carbon intensity, producing twice as much CO_2 as North America for every unit of GDP.

The latest round of new investments has been in the form of "green stimulus" allocations that several countries included in their economic stimulus plans to combat the financial crisis erupting in 2008. More than $180 billion in stimulus funds have been earmarked for sustainable energy investment—a

Table ES-2. Regional comparisons of GDP, CO_2 emissions, and sustainable energy investment

	GDP (2008) in billions of $		CO_2 emissions (2007) in millions of tons		Sustainable energy investment (2008) in billions of $	
Region	**Actual**	**% of world total**	**Actual**	**% of world total**	**Actual**	**% of world total**
Europe	15,128	22%	3,926	14%	49.7	42%
N. America	15,568	22%	6,342	22%	30.1	25%
China	7,916	11%	6,071	21%	15.6	13%
Rest of world	30,656	44%	12,622	44%	23.5	20%
Total	69,268	100%	28,962	100%	119	100%

Note: GDP data are from IMF (2009) and are in billions of current dollars adjusted for purchasing power parities; CO_2 emissions are from IEA 2009, pp. 44-46 and include emissions from fuel combustion only. Sustainable energy investment totals are from UNEP/NEF 2009, Fig. 13, p. 19. Percentage figures do not total 100% due to rounding.

substantial boost to public spending on clean energy investment. But this boost will be offset by a drop in private finance induced by the crisis, and is in most cases a short-term jolt, not a sustainable source of financing. Public deficit spending cannot serve as a vehicle of clean energy investment in the long term. Both a quantitative and qualitative shift will thus be required in terms of relevant funding channels.

Policy options for green transformation

Changing the trajectory of the global energy economy will depend on whether policies and markets can channel the foregoing levels of investment into clean energy technologies over the near term. As mentioned above, current stimulus programs can, at best, provide a temporary source of funding: ultimately, policymakers must correct the market failures responsible for climate change by designing policy frameworks that include the right incentives and public expenditures to drive innovation and sustainable private investment in clean energy.

A range of policy instruments can rapidly revolutionize the way we use and produce energy. To support a rapid transition to a low-carbon economy, policies will need to meet ambitious criteria, effectively achieving environmental objectives at the lowest cost. Where the objective is to drive capital investment, measures should also be evaluated on their ability to trigger spillover effects.

Private equity and debt will need to make up a majority—up to 86 percent—of new investment. Policies to encourage private investment in clean technology should be designed to help overcome a number of barriers that currently prevent the required capital flows. Public spending remains crucial, however, and should be leveraged in key areas where private investment is not readily available, especially at the early stages of technology research.

A number of central recommendations emerge from these considerations. Introducing a clear

$180 billion in global stimulus funds for clean energy will temporarily narrow the investment gap, but sustained private capital flows are required in the long term to achieve a low-carbon future. Ultimately, policymakers must correct the market failures responsible for climate change.

Figure ES-3. Opportunities for green transformation

Electrical Power	Transport	Buildings
Carbon Pricing*		
Renewable Energy Promotion	Vehicle Efficiency Standards	Building Codes and Standards
Advanced Transmission Grids	Research and Development	Information and Education
Supply-Side Efficiency Improvement	Sustainable Infrastructure and Planning	Demand-Side Energy Efficiency

*Other sectors subject to carbon pricing: industrial emissions; via offsets: agriculture, forestry and reliable price on carbon is the single policy likely to have the largest effect in promoting cost-effective low-carbon growth over the longer term. Additionally, a price on carbon can generate significant revenue to help fund necessary public expenditure. In the short term, however, politically viable price levels will prove insufficient to spur a comprehensive shift to clean energy, necessitating a portfolio of additional measures to target individual sectors.

For the key sectors described above, this report highlights a number of policies to channel private investment into clean technology:

- **Feed-in tariffs** and **renewable portfolio standards** have proven highly successful in increasing renewable energy generation without necessitating public expenditure.

- **Efficiency standards** can encourage investment into low- and negative-cost abatement options, such as combined heat and power generation on the supply side, or advanced vehicle technologies, more efficient household appliances and improved building practices on the demand side.

- **Public funding** also will be required in many areas, including education, research and development, planning, and technology deployment. Public investment is particularly crucial in public transportation, advanced power storage technologies, grid infrastructures, and urban planning.

Figure ES-3 outlines a policy strategy based on a complementary portfolio of these approaches. Given the urgency of achieving bold emissions-reduction targets, these measures need to be adopted in a focused, coordinated manner and without delay. It will ultimately remain a question of political will whether the necessary policy framework can be adopted and implemented to spur green investment that will form the foundation of a low-carbon economic future.

1 Introduction

As recently as December 2009, the leaders of major greenhouse-gas emitting nations agreed that global average mean temperatures should not increase beyond 2°Celsius (2°C) above preindustrial levels, widely considered a threshold beyond which climate impacts may become irreversible (O'Neill et al., 2002). Limiting climate change below 2°C entails steep challenges—it means that greenhouse gas (GHG) emissions worldwide must peak in the next decade and decline sharply before the middle of the century (IPCC 2007, p. 100).

Rather than slowing down, however, growth in global GHG emissions is expected to accelerate again once economies emerge from the current recession. If current trends are left unchecked, emission levels may well double in the next decades (IPCC 2007, p. 110).

A transformation of unprecedented scale will be needed to reverse this trend and set the global economy on the path toward a sustainable, low-carbon future. This transformation will affect virtually all economic sectors, as the energy systems that power them still rely heavily on carbon-intensive fossil fuels. And it will not come without a price: estimates vary, but clearly a substantial flow of capital will have to be channeled into the development and deployment of cleaner, more efficient technologies before the necessary changes can occur. Timing is also of the essence—experts widely agree that delayed efforts will eventually prove far costlier than early and decisive action (IEA 2009a; Stern 2006).

Yet mobilizing the required levels of public and private investment will not be easy, particularly during a period of global recession and widespread budget deficits. Even the massive spending programs, fiscal incentives, and other measures adopted by national governments over the past year go only a short way to achieving the transition to sustainable energy consumption and production patterns.

At the same time, this analysis suggests that not all public investment has to draw on already strained budgets. The right policies and regulatory frameworks can successfully stimulate private investment in clean technologies and infrastructures, and also leverage new sources of public revenue for investment in areas where private equity and debt are not readily available. No single policy can overcome all barriers to a transformation of our current economic paradigm; but as this study hopes to illustrate, a range of different approaches, combined in a balanced policy mix, can serve as a powerful catalyst toward the clean energy economy of the future.

The right policies and regulatory frameworks can successfully stimulate private investment and leverage new sources of public revenue. A range of different approaches, combined in a balanced policy mix, can serve as a powerful catalyst toward the clean energy economy of the future.

2 Achieving the Transition to a Low-Carbon Economy: Investment Needs and Progress

Total investment needs are expected to rise from about $450 billion annually in the short term to approximately $1.2 trillion annually 20 years from now.

Sustained worldwide investment on a massive scale is needed to support the development of a global low-carbon economy that will forestall the worst effects of climate change. This section details some of the latest estimates of the level of investment required to limit global warming below 2°C. Total investment needs are expected to rise from about $450 billion annually in the short term to approximately $1.2 trillion annually 20 years from now.[1] The investment needs outlined in this section represent a combined total of public and private financing.

The second part of this section describes the sustainable-energy investments made so far by China, North America, and the European Union, comparing these investment levels to illustrate the investment gaps among the regions. Section 2.2 also provides an overview of how public and private investment flows interact to bring new technologies to market.

Section 3 goes on to detail not only how much, but what kind of investment is needed in each of the three key sectors, and how public policy and investment can create the right market conditions to encourage the needed private capital flows.

2.1 Estimating low-carbon investment needs

In gathering data for this report, the authors relied on recent energy-investment estimates made by the International Energy Agency, the Stern Review and McKinsey & Company. These studies—each widely recognized and of broad political impact—arrive at similar estimates of the investment needed. As the most recent global surveys of the issue, together they provide a solid numerical basis for the following country-level examination of low-carbon investment needs.

The 2008 edition of the International Energy Agency's *World Energy Outlook* estimates that around **$540 billion** in investments in renewable energy and energy efficiency are required annually to limit concentrations of greenhouse gases to 450 parts per million (ppm) CO_2e, the level of greenhouse gases considered to be compatible with the 2°C goal (WEF, 2009, p. 14).[2] In order to reach a less ambitious stabilization goal of 550 ppm CO_2e, the 2006 Stern Review estimates that, each year, 1 percent of GDP (about **$600 billion** in 2008) must be invested in clean energy and efficiency (Stern, 2006, p. 211 and World Bank, 2009a, p. 4). The report *New Energy Finance Global Futures* estimates that **$515 billion** in annual investment is needed in renewable energy and energy efficiency (NVCA and Thomson Reuters 2008).

In its 2009 report, *Pathways to a Low-Carbon Economy*, the consultancy McKinsey & Company found that it is indeed technically feasible to reduce global GHG emissions to 35 percent below 1990 levels by 2030. This abatement scenario translates to GHG emissions that peak at 480 ppm CO_2e and eventually reach a long-term stabilization level of 400 ppm, which matches the scenario used by the IEA and which may well be enough to keep global warming below the 2°C threshold.

The McKinsey authors argue that, to reach this level of emissions reductions, private and public actors must implement all technical GHG-abatement measures costing $90 or less per ton of CO_2e and some additional measures costing between $90 and $150 per ton of CO_2e, and adopt key additional behavioral changes (McKinsey 2009, pp. 8–10). The total cost of these measures, combined, is in the same range as both the IEA and the Stern Review.

[1] All figures in this report are in U.S. dollars. In cases where the original currency figure was in euro, figures have been translated into dollars at an exchange rate of $1.5 per euro.

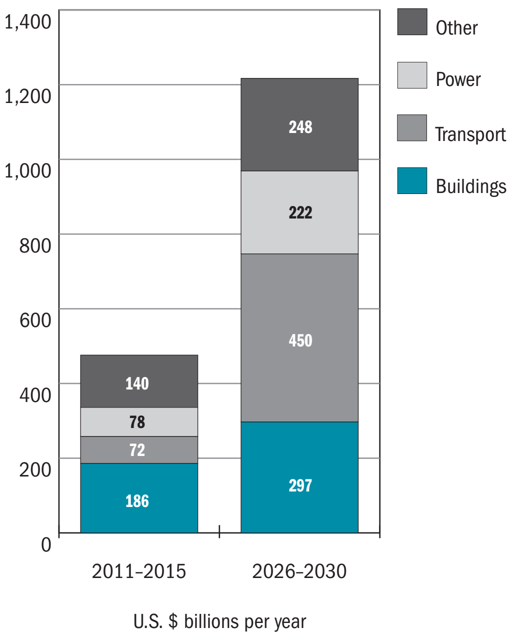
[2] CO_2e stands for "carbon dioxide equivalent" and is a standardized measure used to compare and combine greenhouse gases based on their global warming potential.

The McKinsey report goes further than either of the other two reports to offer the most detailed look to date at how investment needs range over time, region and sector. For this reason, the following analysis relies mainly on the McKinsey results. The McKinsey study calculates estimated investment needs for two five-year periods: the near-term period of 2011–2015 and the period 2026–2030. Together, the two time periods show that investment should be ramped up over the coming decades, beginning with incremental capital investment of $476 billion annually during 2011–2015, increasing to $1.22 trillion per year in the 2026–2030 period, equal to approximately 5 to 6 percent of annual global investment in fixed assets (McKinsey 2009, p. 42).

Figure 1 shows the total investment needs identified by McKinsey & Company, breaking out totals for the three largest sectors—buildings, power, and transport—that together are expected to account for 80 percent of investment needs by 2030. Eight other sectors combined account for the remaining 20 percent of investment needs: agriculture, cement, chemicals, forestry, iron and steel, petroleum and gas, waste, and other industry.

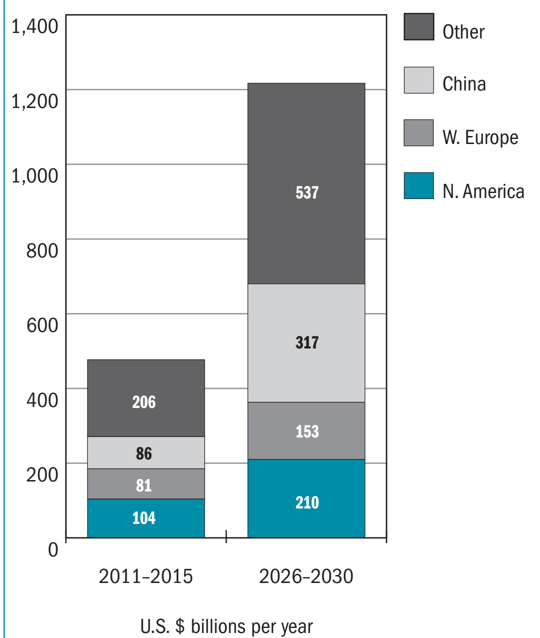
Three sectors—buildings, power, and transport—are expected to account for 80 percent of global investment needs by 2030.

Figure 1. Global capital investment needs in GHG abatement, by sector



Source: Figure based on data from McKinsey 2009, p. 42. Investment needs shown are those above business as usual that are required to reach the 2°C target. The category labeled "Other" includes agriculture, cement, chemicals, forestry, iron and steel, petroleum and gas, waste, and other industry. Figures are real 2005 €, converted here into US$ using an exchange rate of 1.5 U.S. dollars per €.

Figure 2. Total capital investment needs in GHG abatement, by region



Source: Figure based on data from McKinsey 2009, p. 43. Investment needs shown are those above business as usual that are required to reach the 2°C target. The category labeled "Other" includes all regions outside North America, China and Western Europe (i.e., Africa; India; Latin America; Middle East; OECD Pacific; Russia and non-OECD Eastern Europe; rest of developing Asia; as well as global air and sea transport). Original figures are in real 2005 €, converted here into U.S.$ using an exchange rate of 1.5 U.S. dollars per €.

An identification of sector-specific investment targets for regions and countries will be necessary for monitoring the adequacy of future investment levels.

Table 1. Approximate estimates of capital investment needs in abatement, by region and sector (billion $ per year)

	Billion $ per year					
	2011-2015			2026-2030		
Sector	N. America	W. Europe	China	N. America	W. Europe	China
Transport	16	12	13	78	57	117
Buildings	40	32	33	51	37	77
Power	17	13	14	38	28	58
3-Sector Total	73	57	60	167	122	252

Source: Ecologic Institute estimate based on McKinsey 2009, pp. 42-43

Figure 1 shows that the building sector has the greatest near-term investment needs, which are actually expected to remain fairly steady over time. Transport investment needs will be the smallest of the three sectors initially, but by 2026, transport is expected to have the highest annual investment needs of all sectors. Similarly, annual investment needs in the power sector will nearly triple over the time period 2011–2030. The required abatement investments in 2030 correspond to approximately 1.3 percent of an expected $90 trillion global GDP for that year (McKinsey 2009, p. 42).

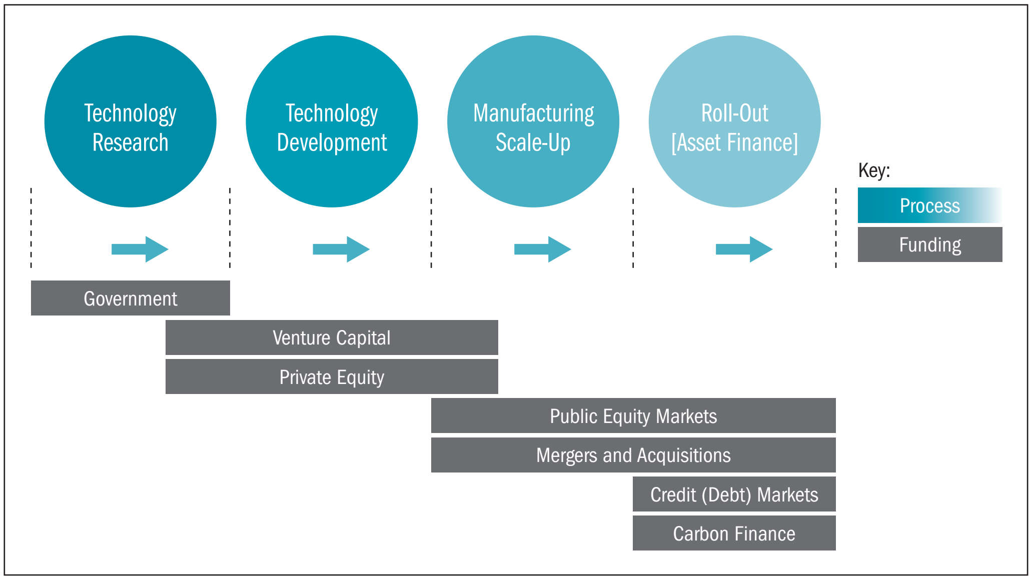
Figure 2 shows how investment needs break down by region over the two time periods studied. Together, the regions of North America, Western Europe and China are estimated by McKinsey continually to require just over 55 percent of the global investment in GHG abatement. China already has investment needs exceeding those of every other region except North America. By 2030, the required investment in China will increase nearly fourfold, while the investment needs of North America and Western Europe are expected to double.

An identification of sector-specific investment targets for regions and countries will be necessary for monitoring the adequacy of future investment levels. Table 1 shows the authors' initial ballpark estimates of the investment needed in each of the three biggest sectors in Western Europe, North America and China.[3] The data provide an idea of the magnitude of investment required and are a good starting point for discussion. According to the authors' scenario, in which the global proportions for key sector investments hold true across regions, in North America the power, transportation, and building sectors will require about $73 billion in annual investment from 2011–2015, rising to $167 billion per year by 2026–2030. In China, investment needs in the three sectors start slightly lower at $60 billion annually, rising to a level of $252 billion in the latter period—the highest investment needs of any country in the world. Western Europe will require investments of $57 billion annually in these three sectors over 2011–2015, rising to $122 billion by 2026–2030.

While the investment needs identified are indeed large, some world regions have been ramping up investment levels significantly in recent years. The following section takes a look at recent changes in the level of clean-energy investments.

[3] These are ballpark estimates based on the currently available McKinsey data (the authors applied the sectoral breakdown of global investment needs to each region's investment figures). The accuracy of these numbers could be improved in the future once well-founded estimates of the region-specific sectoral percentages are available, which should take into account investments and state of technology to date.

Figure 3. The sustainable energy financing continuum



Source: Figure reproduced from UNEP/NEF 2009, p. 9

Early-stage financing in basic R&D must come from the public sector to the extent that the market potential is too uncertain to interest private-sector funders.

2.2
Current levels of sustainable energy investment: A gap analysis

In China, Europe, and North America, investment in clean technology has been an important component of the stimulus packages adopted by national governments to counteract the economic contraction associated with the 2008–2009 financial crisis. However, recent investment represents only a very small fraction of the total investment needs described in the previous section.

Recently published data make it possible to compare investment levels in sustainable energy across the three key regions China, Europe, and North America.[4] In this section, the authors put recent North American investment levels in sustainable energy into context by comparing them with the data available on EU and Chinese investments.

[4] Unfortunately, comprehensive data for other key sectors—notably green buildings and clean transport—is not available.

2.2.1
The financing continuum

Both private- and public-sector financing are essential in bringing an array of new technologies to market to achieve a level of technological transformation sufficient to avoid the worst impacts of global climate change (see Figure 3). Early-stage financing in basic R&D (technology research) must come from the public sector to the extent that the market potential is too uncertain to interest private-sector funders. In contrast, development of technologies with more predictable market potential attracts the interest of venture capitalists and private-equity funders with an appetite for higher potential risk and returns (Section 3 explores in greater depth how public policies like efficiency standards can make such opportunities more attractive to private investors).

As technologies are proven, financing through public-equity markets as well as mergers and

The vast majority of investment in sustainable energy must come from the private sector, which government policy can stimulate with appropriate incentives.

acquisitions becomes possible. Large-scale roll-outs of well-established technologies can obtain additional financing through access to debt financing and carbon financing. The path sketched out in Figure 3 depicts the financing continuum typical of technologies and projects moving from public to private financing.

Other types of activities, such as large infrastructure projects, education and other so-called public goods with low immediate profit potential may require public financing even in situations where technologies are well developed and ready for deployment. These infrastructural improvements, too, can provide an important platform for growth in the private sector, opening new opportunities.

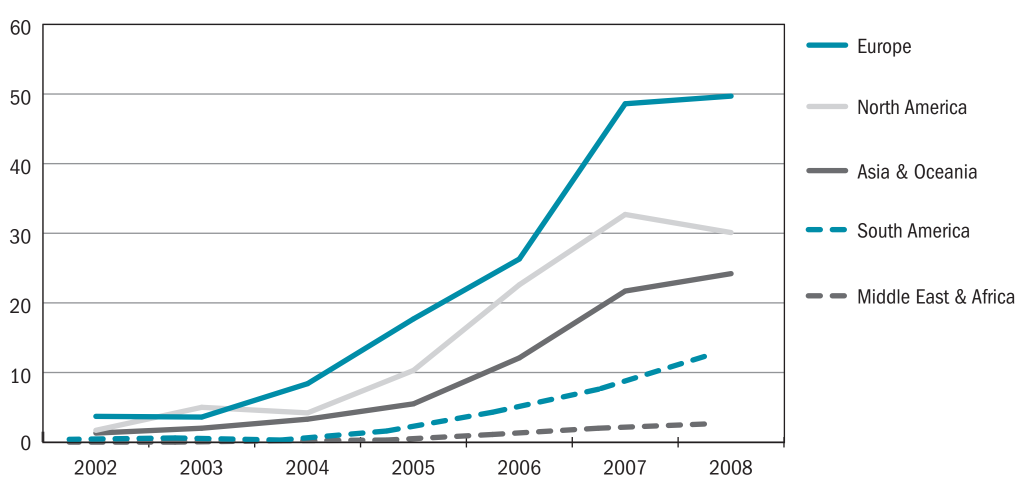
Overall, the vast majority of investment in sustainable energy must come from the private sector, which government policy can stimulate by providing appropriate incentive frameworks.

2.2.2
Regional gap analysis

As discussed in Section 2.1, China, Europe, and North America together will account for over half of the world's expected need for capital investment in renewable energy and improved efficiency. In recent years, understanding of current global investments in sustainable energy has also improved dramatically, and a newly published study authored jointly by the United Nations Environment Programme (UNEP) and New Energy Finance (NEF) provides regional investment and capital data for many investment categories over the past seven years.

The primary purpose of comparing recent investments across regions is to put their investment initiatives into context with one another. An improved data basis could enable a robust comparison of investment levels with investment needs within each region as a means of identifying specific investment gaps.

Table 2. Financial new investment in sustainable energy by region 2002-2008, billion $



Note: Does not include government stimulus spending in response to the 2008 financial crisis.
Source: UNEP/NEF, Global Trends in Sustainable Energy Investment 2009, Figure 14, p. 21

As illustrated in Table 2, sustainable-energy investments have multiplied over the past six years. In North America, from 2002 to 2008, annual new financial investment (public and private) in sustainable energy grew nearly 18-fold, from $1.7 billion to $30.1 billion. Global annual new investment grew at about the same pace, from $7.1 billion to $118.9 billion. However, since the beginning of the global economic downturn, due to reduced availability of project finance and a decrease in the effectiveness of tax incentives, investments in North America and in Europe slowed significantly or even decreased between 2007 and 2008 (UNEP/NEF 2009 p. 12).

Table 3 below separates out 2008 investment information for China, which led Asia in sustainable-energy investments, generating, in 2008, $15.6 billion in new investment as a result of timely policy interventions to improve energy independence and address a rapidly deteriorating environment. That represents an 18 percent increase on the preceding year, giving China a 13 percent share of total world sustainable-energy investment (UNEP/NEF, p. 19). However, investments within Europe and North America continue to make up the bulk of sustainable-energy investment, comprising two-thirds of global investment in 2008.

The investment numbers in Table 3 are unfortunately not directly comparable to the data on investment needs presented in Section 2. One key inconsistency between the two data sets is the fact that the McKinsey study only identifies investment needs above business as usual (BAU) whereas the new-investment numbers in Table 3 include BAU investments. Still, it is possible to use the two sets of investment numbers to make some regional comparisons of needs versus actual investment. For example, whereas the above-BAU investment needs in North America are nearly 30 percent higher than those of Europe, the total clean-energy investments in Europe, in 2008, are actually 65 percent higher than those seen in North America. Looking at China, 2008 clean-energy investments were half those of Europe, whereas the McKinsey data point to current clean-energy investment needs in China that are on par with those of Europe.

Table 4 puts the regional data on actual investments into context with each region's GDP and CO_2 emissions. Despite the fact that North America and Europe each contribute 22 percent of global GDP, Europe's sustainable energy investment accounts for 42 percent of global sustainable energy investment compared to only 25 percent for North America. On the other hand, despite the fact that North America and China each contribute about

North America and Europe each contribute 22 percent of global GDP, but Europe's sustainable energy investment accounts for 42 percent of global sustainable energy investment compared to only 25 percent for North America.

Table 3. Financial new investment in sustainable energy by region, 2008, billion $

Region	New investment ($ billions)	Percent of total
Europe	49.7	42
North America	30.1	25
China	15.6	13
Asia and Oceania (not including China)	8.6	7
South America	12.3	10
Middle East and Africa	2.6	2
Total	119	100

Note: Regional percentage figures do not total 100% due to rounding.
Source: UNEP/NEF, Global Trends in Sustainable Energy Investment 2009, p. 19

The carbon intensity of Europe's economy is significantly lower than that of North America's, with a GDP nearly 60 percent higher for every ton of carbon emitted.

22 percent of global CO_2 emissions from energy, the level of sustainable energy investment in North America is nearly double that of China. Due to past sustainable energy investments as well as other factors, the carbon intensity of Europe's economy is significantly lower than that of North America's, with a GDP nearly 60 percent higher for every ton of carbon emitted. Of the three regions, China has the most carbon intensive economy, producing twice as many CO_2 emissions as North America for every unit of GDP.

The overview of regional investments takes a long-term and aggregated perspective. This analysis avoids a detailed discussion of the dramatic effects that the current economic recession and falling fossil-fuel prices have had on the ability of clean-energy technologies and individual projects to obtain financing. To wit, a comparison of the last six months of 2007 and 2008 reveals a global drop in sustainable-energy investments of 23 percent year-on-year. New investment levels in the first quarter of 2009 were just under half of what they were for the same period one year earlier (UNEP/NEF 2009, pp. 14 and 16).

While these fluctuations certainly have important effects on individual firms and the development of the clean-tech industry as a whole, this study focuses on the practical policy options to create the conditions for a large and sustained increase in sustainable-energy investments by private firms, even—and especially—within a contracting economy.

2.2.3
Green stimulus allocations

In their efforts to combat the financial crisis that erupted in 2008, several countries have included "green stimulus" allocations in their economic stimulus plans announced in 2008 and 2009. Over $183 billion in stimulus funds for investments in green energy have provided a substantial boost to public spending on clean energy investment (UNEP 2009, p. 58). Table 5 provides a summary of this green stimulus by world region and country. The United States and China have provided nearly identical levels of new funding to sustainable energy initiatives (approximately $67 billion), while Europe has allocated approximately $26 billion in green stimulus funds. The UNEP/NEF study assumes that the total expenditure of green stimulus funds will be allocated as follows: 22 percent of the green stimulus funds will be spent in 2009, 41 percent in 2010, 23 percent in 2011 and 14 percent over the following years. This trajectory

Table 4. Regional comparisons of GDP, CO_2 emissions and sustainable energy investment

	GDP (2008) in billions of $		CO2 emissions (2007) in millions of tons		Sustainable energy investment (2008) in billions of $	
Region	**Actual**	**% of world total**	**Actual**	**% of world total**	**Actual**	**% of world total**
Europe	15,128	22%	3,926	14%	49.7	42%
N. America	15,568	22%	6,342	22%	30.1	25%
China	7,916	11%	6,071	21%	15.6	13%
Rest of world	30,656	44%	12,662	44%	23.5	20%
Total	69,268	100%	28,962	100%	119	100%

Note: GDP data are from IMF (2009) and are in billions of current dollars adjusted for purchasing power parities; CO_2 emissions are from IEA 2009, pp. 44-46 and include emissions from fuel combustion only. Sustainable energy investment totals are from UNEP/NEF 2009, Fig. 13, p. 19. Percentage figures do not total 100% due to rounding.

Table 5. Green stimulus allocations to sustainable energy, billion $		
World region	Country/region	Green stimulus allocation (billion $)
Asia (86.6 billion $)	China	67.2
	Japan	11.7
	South Korea	7.7
	India	0
North America (68.6 billion $)	United States	67.8
	Canada	0.8
Europe (25.8 billion $)	EU27	11.3
	Germany	8.4
	Italy	2.6
	France	2.4
	Spain	0.8
	United Kingdom	0.3
South America	Brazil	2.5
Total		183.4

Note: Stimulus allocations as of April 2009. Country/region totals do not add to 183.4 due to rounding.
Source: UNEP/NEF, Global Trends in Sustainable Energy Investment 2009, Figure 18, p. 24

reflects the short-term nature of stimulus funding, intended to provide a "shot in the arm" to the clean technology market, not a stable source of financing.

Furthermore, much of this public stimulus will be offset by the crisis-related drop in private finance, and public deficit spending is not a sustainable solution in the long term. Thus, policy should be designed to initiate both a quantitative and qualitative shift in the type of financing provided for sustainable energy technology and efficiency improvements.

Taken together, the data presented in this section show that despite substantial increases in sustainable energy investment in recent years as well as the sizable one-time boost through fiscal stimulus packages, massive, sustained investments in sustainable energy are still required to avert a catastrophic climate change of more than 2°C. Well-designed policies can accelerate the closing of investment gaps while ensuring that financial resources are invested in an economically efficient and environmentally effective manner. The following section sets out central recommendations for an appropriate policy framework.

Despite substantial increases in sustainable energy investment in recent years as well as the sizable one-time boost through fiscal stimulus packages, massive, sustained investments in sustainable energy are still required to avert a catastrophic climate change.

3 Policy Options for Green Transformation

Widespread adoption of transformational technologies will depend on the availability of significant capital flows, which will in turn require an enabling policy environment to channel investments into the right kinds of technology.

Given current emissions trends and the scope of mitigation efforts called for by climate science, near-term deployment of new technologies will be an important determinant of whether all nations, especially major emitters, can change the trajectory of their energy economies and avoid the worst impacts of a warming atmosphere. Investment decisions reached in the next decade will play a critical role in defining a long-term emissions trajectory, as the infrastructure public and private investors finance today will lock in technology for decades to come (Cameron et al. 2009, p. 6). As in the past, however, widespread adoption of transformational technologies will depend on the availability of significant capital flows. And these, in turn, require an enabling policy environment to channel investments into the right kinds of technology.

3.1
The role of public and private investment

As the previous section has shown, current investment levels are far from meeting the financial flows recommended to achieve full transition to a low-carbon economy. In particular, the widely advertised injection of recent stimulus funds into a "green economy" is but a temporary and ultimately insufficient source of investment in clean energy technology. As the economy recovers, governments will rein in deficit financing to avoid the risk of default on sovereign debt and higher inflation; financial debt accrued in the process will require years to pay off, constraining public spending and potentially incurring future reluctance to commit new public investment (Mabey 2009, p. 12). Meanwhile, the underlying market failures that gave rise to anthropogenic climate change

BOX 1. A portfolio of policies for green transformation

Available policies and measures to limit the release of greenhouse gases into the atmosphere include regulations and standards, taxes and charges, tradable permits, voluntary agreements, informational instruments, subsidies and incentives, and research and development (IPCC 2007b, p. 750). The shift to a low-carbon energy economy will need to be supported by a balanced and coordinated strategy that integrates a combination of these tools. In such a portfolio of approaches, the selection of individual instruments will be typically guided by the following criteria:

- **Environmental effectiveness:** How well does the policy meets its intended environmental objective? How certain is its level of environmental impact?
- **Cost effectiveness:** Can the policy achieve its objectives at a lower cost than other policies? Does it create revenue streams that can be reinvested?
- **Distributional considerations:** How does the policy impact consumers and producers? Can it be considered fair and equitable?
- **Institutional feasibility:** Is the policy instrument likely to be viewed as legitimate, gain political acceptance, be adopted and finally implemented? (IPCC 2007b, p. 751).

In the context of clean technology investment, the ability of policies to foster efficient levels of innovation and diffusion may additionally depend on the speed at which measures can be decided and implemented, the ability to trigger investment and multiplier effects, and the effect on public budgets and public debt burden (Edenhofer et al. 2009, p. 18).

BOX 2. Barriers to sustainable energy investment

Despite the widely acknowledged potential of sustainable energy technologies not only to reduce greenhouse gases but also to frequently lower energy costs, generate employment and provide access to new and competitive markets, actual deployment figures in many areas have lagged behind expectations. A number of barriers to clean technology investment have been identified to explain this observation, including:

- **Behavioral barriers,** such as the agency problems faced by property owners when deciding on efficiency investments in buildings that will primarily benefit tenants, but not the owners themselves;
- **Knowledge externalities,** locking investors into technologies they already have experience with—typically conventional, carbon-intensive technologies—and preventing capital flows into new and uncertain technologies;
- **Institutional barriers,** such as economic and political frameworks that provide investors with little predictability over the long term, and rather promote short-term decision making in line with electoral cycles and quarterly earnings reporting;
- **Limited ability to appropriate returns on innovation,** with high spillover rates and complexity in the clean technology sector rendering classic patent protection less effective as a way to guarantee returns on clean energy investments.

To help overcome these barriers and deploy capital at the scale required, investors need policy and price signals that are long-term, clearly defined, and legally enshrined (Cameron et al. 2009, p. 9).

Innovative instruments can help finance public spending programs and drive private investment to stimulate activity in green technology markets while suppliers drive down their costs.

in the first place will remain largely unchanged (Edenhofer et al. 2009, p. 18).

Identifying a suitable policy framework to address these challenges over the long term is therefore of critical importance. Given the fiscal constraints mentioned above, a central objective of such policies has to be moving affected sectors away from reliance on public spending and toward sustained financing from the private sector. Rather than increasing government borrowing on international capital markets and pursuing further stimulus programs, innovative instruments can help finance public spending programs and drive private investment to stimulate activity in green technology markets while suppliers drive down their costs. Quantifying the investment flows triggered by such policies is difficult, as abatement-cost variability renders estimates contingent on individual circumstances;[5] yet the ability of these policies to effect environmental change is a direct function of the stringency of the respective measure. Box 1 provides an overview of key policy tools available to achieve green transformation and criteria commonly used to guide their selection in a balanced policy mix.[6]

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[5] Differential analysis can yield indicative values for certain policies, again with widely varying results across regions and sectors. Yet such calculations have only limited value, as they tend to give limited consideration to a broad spectrum of spillover effects, ranging from downstream investment to more diffuse impacts such as changes in the merit order of energy sources in the energy mix.

[6] Institutions to implement and oversee financial flows—particularly between developed and developing countries—are also important elements of an enabling framework for clean energy investment; due to their political nature, however, these are not discussed within the ambit of this paper.

Providing a strong, stable carbon price is the single policy action that is likely to have the largest effect in promoting economically efficient low-carbon growth over the longer term.

A significant part—up to 86 percent—of required investments will need to come from the private sector through equity and debt (UNFCCC 2008, p. 170). Governments have an important supportive role in providing the appropriate enabling environment, such as institutional and regulatory frameworks that sustain investment flows. Policymakers can apply a number of measures to promote private investment in clean technology and direct funds where they are needed over the long run. In particular, such measures should help overcome barriers to investment in low-cost abatement opportunities (see Box 2).

Given current private sector weakness, however, public sector spending will remain important, particularly in the short term. Because the public benefits of investment into technology research, innovation and deployment are typically larger than the benefits captured by the private sector, government support is a necessity.[7] Generally, such support is necessary to overcome market failures responsible for underinvestment in climate-friendly technologies and processes. Also, government expenditures can be used to leverage private investment in low-carbon sectors through the multiplier effects they have on the wider economy (Cameron et al. 2009, p. 12), and can result in notable spill over effects on productivity and job creation.

3.2 Introducing a price for carbon

The World Economic Forum has described the introduction of a price on carbon emissions as "the logical foundation of any policy regime for clean energy" (WEF 2009, p. 39). Providing a strong, stable carbon price is the single policy action that is likely to have the largest effect in promoting economically efficient low-carbon growth over the longer term. It allows emissions reductions where they yield the largest social net benefits, and allows for maximum flexibility in reducing emissions at minimum cost. A price on carbon influences the expectations of market participants and ensures that investment triggered by fiscal spending promotes low-carbon technologies and sustained growth and employment instead of locking in ultimately unsustainable methods of production and consumption (Edenhofer et al. 2009, p. 39). Moreover, the introduction of a carbon price can generate stable revenue streams for public spending on sustainable technology (see Box 3).

Governments can implement a price signal through either carbon markets or taxes. Carbon markets have garnered increasing attention as a central mitigation policy and are particularly suited for GHG abatement in sectors where emissions come from a limited number of large point sources that are easy to measure and monitor. A carbon market is created by setting a cap on emissions and allowing companies to either reduce their emissions to meet the cap or to buy tradable emission allowances from other companies. Generally, the tighter the emissions cap is, the higher the carbon price and the greater the incentive to reduce emissions (OECD 2008, pp. 18–19; Edenhofer et al. 2009, p. 40). By allowing use of offsets as an alternative compliance option, carbon markets can also create an incentive for substantial investment in sectors and regions not covered under the emissions trading system.[8]

By contrast, an emission tax requires individual emitters to pay for every ton of GHGs released into the atmosphere. As a result, emitters will weigh the cost of emissions control against the cost of emitting and paying the tax; the end result is that polluters undertake to implement those emission reductions that are cheaper than paying the tax, but will not

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7 As a rule, public support remains necessary until the new technology has deployment costs that are within 20 percent of the cost of conventional technology,

8 Between 2002 to 2008, for instance, the Clean Development Mechanism (CDM) set out under the Kyoto Protocol leveraged $95 billion of investment in clean energy (World Bank 2009b, p. 41).

BOX 3. Generating revenue for public expenditure

According to UNFCCC estimates, only a share of clean energy investment—approximately 15 percent—will need to be covered by public spending (UNFCCC, 2008, p. 170). Providing stable revenue sources to fund such expenditures will be crucial to avoid straining public budgets and incurring sovereign debt or inflationary pressures. Numerous instruments have been proposed to yield such revenue streams, including innovative instruments such as “green bonds” (Cameron, 2009, p. 10). Mostly, however, these revenue streams are based on carbon markets or some form of carbon tax, and some examples currently under discussion are described below.

A budget plan submitted by the U.S. President in February 2009, for instance, assumed $78.7 billion in revenue in 2012 from the sale of greenhouse gas allowances, rising to a total of $645.7 billion by 2019 (OMB 2009). Likewise, about half of all allowances in the EU Emissions Trading Scheme will be auctioned beginning in 2013, potentially yielding revenues of up to $60 billion annually (CCAP 2009 p. 11). At the international level, Norway has proposed to withhold a small portion—between 2 and 6 percent—of Assigned Amount Units (AAUs) from national quota allocations, auction it to developed countries through an appropriate international institution, and thereby raise revenues of $15-25 billion annually (Norway 2009, p. 2).

Auctioning 50 percent of allowances in emissions trading systems already in operation or likely to be implemented in the OECD over the next years could raise $90-180 billion a year between 2010 and 2020, assuming carbon prices of $25-45 per ton of CO_2e (Project Catalyst 2009, p. 17). However, revenue from auctioning funds will typically be earmarked for a range of domestic purposes, such as deficit reduction. Allocating only half of these revenues to activities related to climate change, as the European Commission has proposed for the EU, could still raise $45-90 billion, more than covering the public investment needs outlined above. Alternative sources of financing, such as levies on bunker fuels used in aviation and maritime shipping, have also recently featured in the political debate and could yield $10 billion in funds each year.

implement those that are more expensive (IPCC 2007: 755).

Both taxes and carbon markets introduce a price signal for greenhouse gas emissions, attaching a cost to polluting behavior. Over upcoming decades, such a price tag will transform the economics not only of the energy sector, but of all energy-using sectors. Currently, however, the price signals created by existing carbon markets and fiscal mechanisms have been too low, too volatile, or too fraught with longer-term policy uncertainty to catalyze low-carbon investment on the scale required for a fundamental shift toward clean energy (Cameron et al. 2009, p. 11). Nor can carbon prices be realistically expected to achieve sufficiently high levels in the short to medium term: political opposition and institutional inertia will initially limit the stringency of pricing mechanisms (WEF 2009, p. 35), and it will require time and political effort before carbon prices alone can provide an economic rationale for the large-scale deployment of high-cost abatement options, such as renewable energy or carbon capture and sequestration. A broader portfolio of policy instruments is hence required in addition to carbon pricing, tailored to specific geographical and socioeconomic circumstances (OECD 2008, p. 20).

However, carbon prices cannot be realistically expected to achieve sufficiently high levels in the short to medium term to provide an economic rationale for the large-scale deployment of high-cost abatement options. A broader portfolio of policy instruments is hence required.

Meeting emission reduction targets will only be possible by drastically reducing the greenhouse gas emissions per unit of energy produced.

BOX 4. Eliminating subsidies on fossil fuels

A corollary to the introduction of a price on carbon is the elimination of price supports for carbon-intensive technologies and especially for fossil fuels. Globally around $300 billion is being spent on energy subsidies annually, with the largest share used to artificially lower or reduce the real price of conventional fuels such as oil, coal and gas or electricity generated from fossil fuels (UNEP 2008, p. 10). Cancelling these subsidies might reduce greenhouse gas emissions by as much as 6 percent a year while contributing 0.1 percent to global GDP (UNEP 2008, p. 15).

Prevalent in developing countries as a means of assisting low income groups and promoting access to energy, fossil fuel subsidies are also used in advanced industrial economies such as the United States, where a recent survey by the Environmental Law Institute (ELI) found price support for fossil fuels to substantially exceed subsidies for renewable energy sources: fossil fuels benefited from approximately $72 billion between 2002 and 2008, while subsidies for renewable energy totaled only $29 billion in the same period (ELI 2008, p. 3).

It is encouraging, therefore, that G20 leaders convening in Pittsburgh on 25 September 2009 pledged to "phase out and rationalize over the medium term inefficient fossil fuel subsidies while providing targeted support for the poorest" (G20 2009, p. 3). Without a specified timeline or detailed commitments, however, it remains to be seen whether and how this pledge will ultimately be implemented.

3.3
Recommendations for key sectors

The three largest sectors—buildings, power and transport—are together expected to account for 80 percent of clean technology investment needs by 2030.[9] For each of these key sectors, the following chapters outline investment needs and priorities as well as central policy recommendations. Because the largest part of capital flowing into clean technology will need to originate in the private sector, a distinction is made between policy options relying on public expenditure and measures to help overcome barriers to private investment. Where possible, low- and negative-cost abatement options are particularly attractive solutions in the near term.

[9] Eight sectors account for the remaining 20 percent of investment needs: agriculture, cement, chemicals, forestry, iron and steel, petroleum and gas, waste, and other industry.

3.4
Electrical power

The power sector, in most countries firmly wedded to a fossil fuel-based energy paradigm, accounts for 25.9 percent of global GHG emissions (Rogner et al. 2007, p. 105). Per-capita energy usage is still increasing in many developed countries, and total energy usage is rapidly expanding throughout the developing world. Meeting emission reduction targets will only be possible by drastically reducing the greenhouse gas emissions per unit of energy produced, requiring massive investments to transform the power sectors in each country. Based on McKinsey estimates, the power sectors in the United States, Germany, and China each will require roughly 16 percent of the total clean technology capital investment above business as usual (BAU) starting in 2011, and increasing to 18 percent by the end of 2030.

Great potential exists for reducing emissions in the energy sector, assuming long-term public policy commitments and redirected private investment. Each of the following areas warrants particular attention:

- **Renewable energy generation.** Key renewable technologies include wind, solar photovoltaic (PV), concentrated solar thermal (CSP), geothermal, biomass and hydropower. The World Economic Forum anticipates a need for policy responses that are sector- and stage-specific to support the shift to lower emissions. These include supporting renewable energies until they are within 20 percent of the cost of fossil energy ("almost commercial"), specialized funds to support technologies that have worked in the lab but have not been scaled up ("ready to scale"), and increased ("blue sky") public investment in universities, national labs and other publicly-funded research into future energy technology (WEF 2009, p. 39).

- **Grid infrastructure.** As the World Economic Forum notes, "the world's electricity grids were designed to distribute power cheaply and reliably from large centralized power stations to broadly distributed demand" (WEF 2009, p. 32). To meet the future needs of a dynamic decentralized low-carbon power supply while also reducing demand for energy, the WEF report cites research by New Energy Finance estimating that grid investment will cost $10 trillion, including $6.8 trillion to upgrade the transmission and distribution components of the existing network (WEF 2009, p. 32). So-called smart-grid technologies will be a central component of the future grid.

- **Electricity storage.** Investment is needed in the area of power storage, especially to support the large-scale integration of renewables, which generate power according to variable factors like wind speeds, cloud cover, etc. Current research indicates that storage prices must fall to $50/MWh to be economically feasible, far from the current cost range of $114–180/MWh (WEF 2009, p. 32).

- **Energy efficiency.** Policymakers should couple cost-effective and viable options to improve the power supply and distribution efficiency with efficiency standards for both energy suppliers and users to support a transition from fossil fuels (IPCC 2007, p. 10; WEF 2009, p. 12). In particular, there are important efficiency opportunities in China and other emerging markets, where the average cost of improving industrial efficiency is 33 percent lower than in the United States (WEF 2009, p. 31).

The electrical power sector will need long-term sustained investment to achieve emissions reductions. Some of these investments will go into known technologies that are commercially available today (e.g., efficiency and grid upgrades), and other investments will go into not-yet-developed technologies (e.g., energy storage and renewable technologies). No single technology will reduce all emissions in this sector, requiring a balanced combination of investment approaches. A majority of investment will again need to come from the private sector, especially in the mid- and longer term, with public investment mainly important to restart stalled projects and spur financing in the wake of the financial crisis as well as promote activities that will be underfunded by the private sector. Additionally, governments must also expand public investment in early-stage research and development, in order to promote the development and deployment of future generations of renewable energy technology.

A majority of investment will need to come from the private sector, especially in the mid- and longer term, with public investment mainly important to restart stalled projects and spur financing in the wake of the financial crisis. Governments must also expand public investment in early stage research and development.

3.4.1
Encouraging investment in renewable energy

Renewable sources of energy—including sources of electricity (such as wind and solar) and transportation fuels (such as biomass)—tend to have a much lower greenhouse gas emissions profile than conventional fossil fuels. As the technologies used to harness these renewable energy sources tend to remain more expensive

While renewable portfolio standards provide greater certainty in terms of deployment levels, evidence from implementation suggests that feed-in tariffs are ultimately more effective in promoting rapid deployment of renewable energy.

than conventional energy technologies and the size of necessary emission reductions in the energy sector are of such scale, governments must induce the requisite capital flows into renewable energy through policy.

A number of countries have successfully promoted renewable electricity through feed-in tariffs. A feed-in tariff establishes a set price per kilowatt-hour for electricity produced by various renewable sources; to be most effective, the policy should provide guaranteed access to the grid and allow residential producers to sell electricity back to the grid. Stable, guaranteed prices for an extended period of time of up to 20 years and tariff differentiation in accordance with the generating technologies were key to the success of the feed-in tariff system in Germany, where renewable energy capacities have grown from 1 percent of electricity production in 1995 to 14 percent in 2007 since the deployment of feed-in tariffs (HBSa 2009, pp. 11–12). While this has resulted in an estimated net transfer of $9 billion from ratepayers to renewable electricity producers in 2009 (Nitsch 2005, p. 54), electricity prices for end-consumers have risen only marginally as a result,[10] while the availability of large amounts of renewable energy sources has actually had a net dampening effect on spot market electricity prices (Sensfuss et al. 2009). Additionally, the promotion of renewable energy sources has helped reduce dependence on fossil fuel imports in Germany and has created significant new employment. In 2008, more than half of the 278,000 jobs in the German renewable energy sector were attributed to the Feed-In Tariff Act (BMU 2008, p. 36).

An alternative to feed-in tariffs are renewable portfolio standards, or renewable energy quotas. This policy tool has been used in several European countries and U.S. states; it sets an obligation for utilities to supply a certain percentage or wattage of their electricity production from renewable sources. While renewable portfolio standards provide greater certainty in terms of the renewable energy deployment levels to be achieved, evidence from actual implementation suggests that well-designed feed-in tariffs are ultimately more effective in promoting rapid deployment of renewable energy (see Box 5). The tools themselves are not mutually exclusive, however: the U.K., for instance, has imposed a feed-in tariff alongside its portfolio standard. In such a combined approach, a portfolio standard could be used to set out the macroeconomic deployment targets for renewable energy use, and the feed-in tariff could be the microeconomic means of achieving these targets.

Like any policy, the success of mechanisms to promote renewable energy depends on their design. Spain, for instance, offered tariffs that proved excessively generous, setting off a speculative bubble and subsequent downturn. More importantly, feed-in tariffs are not inexpensive. The price support for renewable energy is paid for by ratepayers, frequently differentiated by technology, and can hence be politically contentious. In Germany, for instance, where the feed-in tariff rates for high-cost renewable sources such as photovoltaics are five to six times higher per kWh than market rates, the recently elected governing coalition has pledged a reduction of feed-in tariff rates to reflect falling prices in underlying raw materials (CDU/CSU/FDP 2009, p. 19).

While a renewable portfolio standard uses market forces to promote lower-cost renewable technologies, feed-in tariffs rely on a government decision setting the rates for different renewable energy sources. A corollary of these decisions is the danger of technology lock-in, as high tariff rates for some technologies could encourage investment in technological dead ends. Renewable portfolio standards are therefore likely to be

[10] In 2008, the surcharge only accounted for about 5 percent of total household electricity costs (BMU 2008, p. 27).

BOX 5. Stimulating green-power generation—Germany's feed-in tariffs versus the U.K.'s renewable obligations

The two biggest economies in the EU took very different pathways in promoting the deployment of renewable energy in the electricity sector. Germany introduced guaranteed prices for each kWh produced from renewable sources. In contrast to the German feed-in tariff, the U.K.'s renewable energy support system has primarily relied on the Renewables Obligation (RO)—a quota system comparable to the Renewable Portfolio Standard (RPS) widely used in the United States. The U.K. scheme obliges utilities to supply a certain share of their power generation from renewable sources or to pay a buy-out price. Compliance is proved through freely traded certificates (Renewable Obligation Certificates), which are the main source of income for operators of renewable-energy installations.

Even though a direct comparison of the schemes is subject to some caveats (most importantly a much later starting point of the U.K. scheme), current installation rates suggest that feed-in tariffs have fuelled more dynamic growth in Germany than the RO policy has in the United Kingdom. Starting with a share of 3.4 percent renewable energy in total electricity consumption in 1990, Germany had doubled the contribution of renewable energy to 6.7 percent in 2001 and then doubled it again by 2007, when the share reached 14 percent. Despite its enormous wind-energy potential, the United Kingdom only increased its share of renewable electricity by 2 percentage points, from 3 percent in 2000 to 5 percent in 2007. Certainly, the support regime is not the only explanation for different outcomes in the two countries, as planning procedures and grid structure also play an important role. However, the planning security provided by fixed feed-in tariffs has clearly made renewable energy projects a more attractive investment in Germany for all types of investors, including small-scale developers and private households, as well as banks financing the capital investments required. In addition, the technology differentiation built into Germany's various tariff rates has allowed the promotion of all forms of renewable energy (e.g. more expensive solar generation) while the British RO scheme has mostly benefitted the technology closest to cost-effectiveness: onshore wind.

more cost-efficient, while feed-in tariffs have proven to be more effective at deploying large scale investment in renewable energy and are the preferred policy option.

3.4.2 Advanced electricity grids

A new type of electricity grid, a "smart grid," will be needed to incorporate the various sources of renewable electricity and to realize possible efficiency gains. On the supply side, a smart grid introduces sophisticated monitoring equipment and software to evaluate changes in production from intermittent sources like solar and wind, thereby helping avoid power shortages or blackouts. On the demand side, smart appliances and meters in homes and commercial buildings provide grid operators with real-time information about demand, allowing non-critical systems to be shut down during times of peak demand.

Accordingly, a smart grid has the potential to integrate renewable sources of energy and to reduce superfluous demand, both of which will result in lower greenhouse gas emissions. Yet, this type of transformational change will be costly and will not be developed by the private sector without appropriate policy and the investment of some public funds. As mentioned earlier, the cost of overhauling existing transmission networks across the globe to create a smart grid infrastructure is estimate at $10 trillion, with nearly 70 percent going to repairs and replacement of the current network (cited in WEF 2009, p. 32).

A smart grid has the potential to integrate renewable sources of energy and to reduce superfluous demand, both of which will result in lower greenhouse gas emissions.

Without new infrastructure such as transmission lines, the barriers to investment in large-scale renewable projects far from the existing grid are too large.

At the local level, policymakers should introduce standards for smart meters and appliances in order to ensure their development and their swift integration with the smart grid. Infrastructure investments have a longer time horizon, but quick policy action on metering and appliances would have them ready in advance of the rest of the smart grid system. In addition to forcing private investment in part of the backbone of the smart grid system, metering offers advantages to consumers. They give consumers the opportunity to become more familiar with their energy usage—not just the total amount, but also the timing of use—and provide them with data to be able to optimize energy consumption and potentially reduce electricity bills.

Much of the investment required to introduce a smart grid will need to come from public budgets, in particular in the area of new infrastructure. In many situations, the best sites for renewable energy production are far from current development and energy infrastructures. The scale of possible generation far exceeds the needs in the general vicinity, requiring the installation of high-voltage direct current transmission lines over long distances as well as other infrastructure needed to integrate these sources into the evolving smart grid. Without transmission lines, the barriers to investment in large-scale renewable projects far from the existing grid are too large. Governments will therefore have to devote some funds to basic transmission infrastructure, but policy change is also crucial. Governments must adapt transmission siting rules to facilitate the development of large-scale renewables.

Furthermore, general capacity of the grid must be expanded in order to handle electricity from new and various sources at different times and in varying amounts. Illustrating this challenge, capacity constraints in New York have caused wind turbines to stand still during periods of strong wind, as the local grid network was too crowded to take the additional supply (Ward, 2009). Some of the additional capacity could be stored in batteries and other power storage technologies, which could offset grid capacity constraints and also provide power to the grid when the wind is not blowing or the sun is not shining. Research to improve this type of power storage will augment the smart grid; governments can provide investment funding for basic research. Power storage will be vital in addressing supply and demand fluctuations, expanding the fleet of electric and hybrid vehicles, and balancing the intermittent supply of different renewable sources of power (HBS 2009, pp. 10–13).

The combination of standards for equipment and infrastructure, public investment in early stage research and some transmissions infrastructure, as well as policy changes to allow for long-distance transmission lines and other necessary construction will spur private investment in the development of the smart grid.

3.4.3 Energy efficiency

Investing in energy efficiency projects can deliver net benefits over the lifecycle of such investments. McKinsey & Company have detailed numerous options for both demand-side and supply-side energy efficiency investments that would lower greenhouse gas emissions and also have negative costs (McKinsey 2009). However, the current policy structure and other barriers stand in the way of large-scale investments in energy efficiency. These barriers must be addressed by public policy in order to hasten investments in demand-side and supply-side energy efficiency.

Changing the incentive structure for electric utilities can lead to additional private sector investments in demand-side efficiency, especially buildings. In developed countries, at least, building-

BOX 6. Carbon capture and storage: A controversial option

Reflecting the wide availability of coal and the role it plays in the production of electricity, many studies and policies promote investment in carbon capture and storage (CCS) (WEF 2009, p. 32; UCS 2009, p. 77). CCS is a technology through which carbon dioxide is captured at the point of emission, compressed, and transported to a storage site, such as an aquifer. CCS has received limited support from environmental groups, although there is recognition that significant barriers to full-scale deployment of renewable energy may justify investment in CCS to produce low-carbon energy on a large scale (UCS 2009, p. 77). The World Economic Forum identifies "insufficient legislative incentives, incomplete regulatory frameworks, and a lack of public acceptance" as impediments to the deployment of CCS at this point (WEF 2009, p. 32).

The development and deployment of CCS does have potential to drastically reduce the carbon profile of coal-fired power plants. In addition to demonstrating the technology at scale, however, widespread use of CCS would require tremendous infrastructure investments to develop the system of pipelines that would transport carbon captured in the production process to underground storage sites. Environmental risks from the storage of vast amounts of carbon dioxide underground—including, notably, the risk of leakage—can only be assessed by demonstration projects. Furthermore, CCS reduces the efficiency of a coal-fired power plant, requiring the mining, transportation, and burning of more coal (WEF 2009, pp. 79–80), all with inherent negative environmental impacts.

Despite these concerns, the political barriers for other sources of energy may very well be too real to ignore in the short term, and thus CCS should not be altogether omitted from the toolbox of policy options. As mitigation strategies are deployed over the long term, moreover, and other abatement options are increasingly exhausted on the path toward a carbon-neutral economy, CCS can prove an essential technology to sequester unavoidable process emissions in various sectors, such as cement and steel. More research and development and actual deployment projects are required to better assess the costs, potential, and risks of using large-scale CCS to provide low-carbon energy.

efficiency measures reduce demand, which affects the bottom line of utilities. "Decoupling" electricity sales from profits should be implemented to give utilities an incentive for investments in demand-side management programs, such as the installation of energy saving light-bulbs or loan supports for highly-efficient energy equipment or building retrofits (WEST 2008, pp. 19–22), which moderate energy bills for consumers and simultaneously help the bottom line of the utilities. Tax credits and other tax incentives can also help builders and owners overcome financial barriers to investments in energy efficiency to lower demand (and ultimately energy costs). In order to promote significant investment, the tax credits should promote investment in advanced products, must be significant, and cannot phase out quickly (UNEP 2007, p. 37). Local tax codes and conditions must be taken into account when using tax credits—for example, energy tax credits will not be useful in a country with subsidized energy prices.

In terms of supply-side investment, governments should set policies that remove barriers to investment in combined heat and power (CHP) systems. Also known as cogeneration, this technology entails the simultaneous production of electricity and heat and thereby improves the overall efficiency of power stations. Conventional power plants waste the heat produced in electricity

Climate stabilization scenarios rely heavily on the concept of a rapid transition to hybrid and electric cars.

generation; CHP systems, by contrast, use the waste heat in the form of steam or hot water and use it for heating, cooling, and other applications, thereby dramatically improving efficiency. Greater efficiency decreases fuel costs and fuel usage, which reduces greenhouse gas emissions. The Environmental Protection Agency estimates that CHP systems could improve the efficiency of fossil fuel-fired power plants in the United States from an average of 33 percent to between 60 and 80 percent (EPA 2009). The installation of CHP systems can hence reduce emissions by 45 percent or more (Worldwatch 2009, p. 141). In addition to their installation at the power plant level, CHP systems are also suited for numerous industrial processes, large buildings and facilities, and municipal and residential purposes. A minimum efficiency standard for new power plants and retrofits would encourage the use of CHP systems, and setting an industry efficiency benchmark would induce investment in CHP systems for heavy industry. Regulatory changes may also be necessary in some contexts, including standards for connecting CHP systems to the electric grid and tax treatment. The U.K. government has a series of incentives to encourage investment in CHP systems, including: reduced VAT for small-scale CHP, favorable treatment under the EU Emissions Trading Scheme, eligibility for certain capital allowances, and exemption from its climate change levy (DECC 2009).

3.5
Transport

The transport sector currently accounts for 13 percent of global greenhouse gas emissions and is one of the most rapidly growing sources of emissions (Rogner et al. 2007, pp. 105–10). Current reports suggest that significant gains can be made in this sector with the right investment levels. Based on estimates by McKinsey & Company, transport will require roughly 15 percent of the annual capital investment above BAU starting in 2011, and 37 percent by 2030.

Key opportunities for investment include:

- **Transitioning to hybrid and electric vehicles.** Climate stabilization scenarios rely heavily on the concept of a rapid transition to hybrid and electric cars. A transition toward commercial viability is needed in the following areas: second-generation biofuels, higher efficiency aircraft, and advanced electric and hybrid vehicles with more powerful and reliable batteries (IPCC 2007, p. 10). Restructuring vehicle taxation based on carbon emissions would also help support the move toward electrification of transport (Edenhofer and Stern 2009, p. 25).

- **Public transportation and transportation planning.** Lowering emissions in the transportation sector will require significant improvements in public transport and a modal shift from road transport to rail, including improved transport planning that integrates complementary land-use patterns (EDF 2009). In addition, it is critical that developing countries facing rapidly expanding transportation sectors avoid making poor investment choices that lead to car-dependent and inefficient transport systems.

- **Improving vehicle efficiency.** Lowering emissions in the transportation sector requires both short- and long-term approaches. According to the Pew Center on Global Climate Change, the fuel economy of light-duty vehicles (e.g. passenger cars and light transport vehicles) can be increased in the short term by about one-fourth to one-third with existing technology and at a cost lower than the resulting fuel savings, resulting in a net benefit to vehicle owners (Pew 2003, p. 13). In the long term, there needs to be more R&D investment in technologies that will further lower emissions via efficiency gains.

• **Freight transportation.** Significant gains in freight transport efficiency are also achievable. The Pew report found that the fuel efficiency of heavy-duty vehicles can be improved by about 25 percent in long-distance transport and 50 percent in short-distance transport (Pew 2003, p. 18). The Pew report points to significant efficiency gains possible for heavy-duty vehicles in areas of thermal efficiency during long distances, improving aerodynamics to reduce drag, recovering braking energy (as used in hybrid cars) and eliminating idling energy use (turning off engines during idling) (Pew 2003, p. 19). In addition, rail transport will benefit from the thermal efficiency improvements in heavy-duty vehicles, while additional research can be focused on aerodynamics, weight reduction and wheel resistance (Pew 2003, p. 21).

How humans fuel their cars, how the infrastructure is designed, and how goods are transported are all investment opportunities that require policymakers' immediate attention to maintain a 2°C limit. As with the other sectors, comprehensive and coordinated investment is needed to achieve the required emissions reductions. A major part of required capital flows will again have to come from the private sector. Governments have a role in setting the regulatory framework to incentivize such capital flows; public investment will be needed in research and development, especially at the early stages of technological innovation. Two areas particularly in need of R&D funding are advanced battery technologies and alternative transportation technologies. Public investment is also needed to both maintain and improve current transportation infrastructures, and to support a modal shift to improved low-carbon public transport. Below is an outline of key policies for private and public investment in the transport sector to facilitate a transition to low-carbon mobility.

3.5.1
Vehicle efficiency standards

Government policies should incentivize investments in more efficient transport technologies by setting mandatory technology standards. One promising option are emission standards limiting CO_2e output per distance travelled, frequently in relation to vehicle size (UCS 2009, pp. 101–5). Such emission standards would go beyond current fuel economy standards, and shift the focus toward emissions reductions by establishing a long-term policy that is technology-neutral and covers all greenhouse gases simultaneously.

Due to their mandatory nature, these requirements would push industry-wide adoption of existing and emerging technologies to reduce emissions in the areas of personal transportation and freight. Commercially available technologies that can be used to meet the new requirements include: hybrid technology for freight and personal transportation, plug-in electric hybrids, efficient tires, and improved aerodynamics. Recently adopted EU legislation (Regulation (EC) No 443/2009) exemplifies this approach by standardizing the fleet average emissions of all cars registered in the EU at 130 grams CO_2 per kilometer (g/km) by 2015. As an alternative or additional incentive to consumers, deployment of more efficient vehicles can be encouraged by implementation of a so-called feebate, in which buyers of new cars pay a fee for cars with higher emissions or receive a rebate for purchasing vehicles with lower emissions. The schedule of fees and rebates could be coupled with a Top Runner approach that dynamically sets emission level criteria based on the current best-performing technologies (see Section 3.6.1).

Vehicle standards coupled with a feebate mechanism would reduce emissions by pressuring producers to invest in more efficient vehicles, while also incentivizing consumer choice in

How humans fuel their cars, how transportation infrastructure is designed, and how goods are transported are all investment opportunities that require policymakers' immediate attention to maintain a 2°C limit.

As in other sectors, public investment to upgrade and expand transportation infrastructure and regulatory changes to remove disincentives for transit-oriented private real-estate investment can, in combination, create new opportunities for profitable private investment in low-carbon alternatives.

sustainable options. The policies would spur immediate investment to increase the production of technologies that are or soon can be commercially available, such as hybrid cars, plug-in hybrids, and fuel-efficient tires.

3.5.2 Research and development

While current technology can take economies a long way on the path toward a low-carbon transportation sector, achieving true carbon neutrality in the long term will require significant technological developments and breakthroughs. Public investment will be needed to spur the development of the next generation of energy storage and fuels. Public investment in R&D should be focused on two key areas in the transportation sector. The electrification of transportation is critical to a future low-carbon transportation system, and batteries will play a major role in that system's expansion. Further research in battery technology is an absolute necessity, as current batteries' cost, lifetime, and range are barriers to their commercialization. Beyond this, the role of public investment is to encourage and invest in all advanced transportation technologies. Government support is also essential in developing, demonstrating, and deploying ultra-low-carbon vehicles, fuels, and infrastructure. Such support should focus on technologies that offer significant cuts in carbon emissions but that will have difficulties entering the market on their own, such as low-carbon biofuels and vehicles that run on electricity (Cleetus et al. 2009, p. 191). Finally, the role of public spending must also be to maintain the investment in R&D, especially given the current economic crisis (Cleetus et al. 2009, p. 191).

3.5.3 Infrastructure and sustainable cities

A significant impediment to reducing greenhouse-gas emissions is the state of current transportation infrastructure. Public investment is needed to both maintain and improve current conditions.

First, public investment in the transportation infrastructure should shift toward low-carbon alternatives, with a greater focus on increasing public transportation capacity instead of increasing road capacity. Where investments in public transportation are made, new systems should rely on low- or no-carbon inputs and vehicles such as hybrid technology and biofuels.

Second, immediate public investment can be made in the areas of sustainable urban planning practices. Planning authorities should create opportunities for transit-oriented development by changing density and zoning regulations to ensure that the areas surrounding transit stations can be developed to meet growing demand for dense, walkable neighborhood options. Planning practices should carefully align public transportation routes with existing travel patterns and eliminate current restrictions that prevent private real estate developers from building up desirable land closest to transit stations. This will allow more people to travel from home to work, shopping, and entertainment using low-carbon public systems rather than carbon-intensive private vehicles.

As in other sectors, public investment to upgrade and expand infrastructure and regulatory changes to remove disincentives for private real-estate investment can, in combination, create new opportunities for profitable private investment. Part of an overarching plan would also include an assessment mechanism to measure the impact of transportation changes. However, most of the emissions reductions will not be seen from those decisions immediately, but will be realized in the long term (Pew 2003, p. 50).

Research and development will be critical to the next generation of transportation fuels, whether they are biofuels or electrons. In addition, the overall transportation infrastructure needs investment to decrease GHG emissions: Current funds in the stimulus packages are committed to a system that is part of the emissions problem. Therefore, public money must be redirected toward the shift the transport sector must undertake to lower emissions.

3.6 Buildings and energy efficiency

In order to meet future global emissions targets, significantly reducing emissions attributable to buildings is imperative. This sector already accounts for a large share of global CO_2 emissions (7.9 percent) (Rogner et al. 2007, p. 105), and the built environment is expected to grow considerably in coming decades. Based on McKinsey estimates, investment in buildings should therefore constitute roughly 40 percent of capital investment above BAU starting in 2011 in North America, Western Europe and China. The buildings sector is the largest single investment category in the near term, but does not see nearly the same dramatic growth over the 2011–2030 time period as the power and transport sectors. This is consistent with the need to undertake large-scale retrofitting of existing building stock in the near-term. By 2030, needed capital investment in the building sector is expected to grow in absolute terms, but in relative terms it will decrease from 39 percent of capital investment in GHG abatement in 2011 to 24 percent of the total by 2030.

Key areas for GHG-abatement investment include:

- **Building design and retrofitting.** Some of the lowest cost and most effective emission-reduction investments are in buildings, notably in areas such as insulating and retrofitting (McKinsey 2009, p. 27). According to an evaluation by the IPCC, commercially available technologies to decrease net building GHG emissions include chromic glass, heat-exchangers/pumps, smart devices and metering, smarter architectural building designs, and integrated solar PV on roofs, facades and windows (IPCC 2007, p. 10).

- **Improved energy efficiency.** The IPCC points out the following building and improvement strategies that are already commercially available: efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves; improved insulation; and passive and active solar design for heating and cooling (IPCC 2007, p. 10). Nearly 80 percent of investments in the residential sector should be directed at just one key action: installing more advanced heating and cooling systems in existing and new homes (WEF 2009, p. 31). Again, these solutions are low-cost or even net-positive approaches to lowering emissions (McKinsey 2009, p. 27).

- **Urban planning.** Improved urban planning practices should incorporate both efficiency measures in building practices, and also overall transportation planning. Incorporating efficiency measures in new buildings is a low-cost abatement measure. A movement toward less motorized transport, a partial solution advocated by the IPCC, will require adequate urban density and suitable infrastructure to make increased biking, walking, and transit use viable transportation alternatives (IPCC 2007, p. 10).

The bulk of investment will, and should, come from the private sector. While governments, especially in developed countries, will play a comparatively small role in terms of capital investments, government action is central to overcoming barriers impeding private investment in energy efficiency for buildings (UNEP 2009, p. 8). Recent studies demonstrate that substantial global reductions in greenhouse gas emissions can be achieved in the building sector with current technology (IPCC 2007, p. 17). Many investments would even have negative costs, with savings exceeding the cost of investment (McKinsey 2009, p. 107), yet absent the right policy framework, these opportunities are currently not being explored.

Although current technologies, design, and processes can already produce significant savings in the building sector, several studies highlight the fact that the full future reduction potential in the building sector will only be realized with an ambitious R&D agenda (USGBC 2008, pp. 1–5; NSTC 2008, pp. 5–8). Public investment will therefore be needed to support research and development in advances in materials and products, which is essential for continued improvements in the building sector. Government-funded information campaigns and education will also alert the public to new developments and train future inventors and builders. What follows are key policy recommendations for private and public investment in the building sector.

3.6.1
Building codes and efficiency standards

Governments should develop and enforce strong building codes. The codes can take two forms: separate prescriptive codes for the building envelope and major equipment (i.e. heating, ventilation and air conditioning systems, etc.) or comprehensive performance-based codes that set an energy consumption level or energy cost budget. The former is simpler to enforce, which might fit better in the developing country context (UNEP 2007, p. 19), while the latter provides more room for innovation.

For countries with strong enforcement, a three-tiered performance standard may be most suited: 1.) a minimum mandatory standard for all buildings would be established legally; 2.) to encourage the use of the best available technologies, a best practice standard would be set alongside the minimum standard, which would include financial and other incentives (i.e., subsidies, tax credits, etc.) for builders and owners who install and use these technologies; and 3) a long-term state of the art standard is established at the same time, to provide an innovation horizon for manufacturers and owners (EURIMA 2006, p. 12).

With the three-tiered standard, government policy ensures minimum (but vital) efficiency improvement in all new buildings, provides incentives for the adoption of best-available technology, and also gives a signal of the long-term political importance of energy efficiency in the building sector. While new building standards are imperative, the efficiency of the current building stock must be addressed as well. Stringent standards for renovations and retrofits should be developed in concert with standards for new construction. To induce and expedite investment in highly efficient renovations, financial and additional incentives (tax credits, for example) will likely be necessary.

Building codes themselves only capture part of the potential to reduce emissions in the building sector. Over half of the reduction potential from the building sector identified by McKinsey stem from changes in equipment (McKinsey 2009, pp. 106-107). Thus, efficiency standards for appliances and other equipment should accompany building codes. The Top Runner Program developed by the Japanese government is an effective model, with reductions achieved through required continuous improvements in product energy efficiency; the most efficient product in a category is set as the efficiency standard, which is then revised periodically encouraging improvement.

Building codes themselves only capture part of the potential to reduce emissions in the building sector. Over half of the reduction potential from the building sector stem from changes in equipment.

The success of building codes and efficiency standards depends heavily on local conditions, enforcement, and compliance. A stringent code or standard in a country with no expertise or capacity to enforce fails to create real reductions in greenhouse gas emissions. Moreover, to be effective in the long term, codes and standards must be updated regularly to reflect product, design, and material advances.

Beyond existing energy efficient products, the continued research and development of integrated buildings systems can further reduce the energy needs of the building stock. Integrated systems research investigates the interaction of building design and components and equipment, such as appliances, lighting, and air and heat flow (USGBC p. 4) with the eventual goal of research being the creation of net-zero energy buildings (NSTC 2008, p. 6), in which consumption and production of energy balance each other out.

3.6.2
Information and education

Lack of information and education notably impedes reductions of greenhouse gas emissions in the building sector, particularly in developing countries (see Box 7). While certain firms readily promote their own GHG-reducing products, public investment in education and the dissemination of information is integral to wider-scale use of energy-efficient design and technologies.

Information campaigns can be sponsored by governments to inform citizens of new products and programs that promote efficiency in the building sector. To be effective, such campaigns must be tailored to match the intended outcome of the program (lower greenhouse gas emissions, for example) with the desires of each specific audience (lower electricity bills). Such campaigns are especially important in developing countries, where a lack of information is a serious barrier and aversions to new products and techniques run high (UNEP 2007, pp. 44–45).

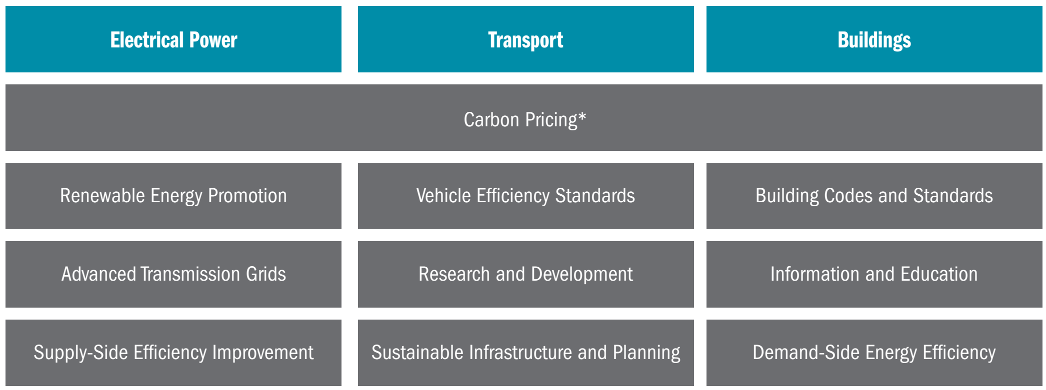
Public investment could be used to support the development of curricula at engineering, architecture, and technical schools; it could also establish training for government officials and mid-career professionals. These students, workers and professionals need exposure to current products, materials, and designs to build better housings and structures that will reduce greenhouse gas emissions from this sector (WEST 2008, pp. 6–9). Additionally, research on the impact of buildings on local environments could lead to evidence-based policies that incorporate the role the built environment plays in land use and transportation policy. Better zoning and density can reduce the need for new land for building development while mixed-use development can cut the demand for transportation (USGBC 2008, p. 5).

To be effective in the long-term, codes and standards must be updated regularly to reflect product, design, and material advances.

BOX 7. Policy packages for developing countries

The policy strategy outlined here can be effective in nearly every setting. However, a UNEP report sheds particular light on the unique difficulties faced by developing countries in the building sector (UNEP 2007, pp. 65-68). Research demonstrates that a basket of measures introduced simultaneously is most likely to achieve meaningful results in the developing country context. One possible integrated policy would combine a regulatory mechanism (building standards) with capacity building and training along with demonstration projects (funded by the government) and financial incentives for adoption. Without implementation and enforcement, many policies to promote building efficiency will fail—especially in many developing countries. As many developing countries face financial and capacity limitations to develop and enforce building codes and other policies, developed countries could facilitate building investment in developing countries by directing funds toward training, enforcement, and financial incentives.

Figure 4. Policy portfolio for green transformation



*Other sectors subject to carbon pricing: industrial emissions; via offsets: agriculture, forestry

3.7
Remaining sectors

The remaining eight sectors for which McKinsey has calculated investment needs collectively comprise 20 percent of the global investment need in 2030. This remainder of capital investment in GHG abatement is divided into the following sectors (ordered from highest to lowest investment need in 2030): forestry (5 percent), iron and steel (4 percent), other industry (3 percent),[11] chemicals (3 percent), petroleum and gas (2 percent), waste (1 percent), cement (1 percent), and agriculture (0 percent). Agricultural abatement costs are extremely low, averaging $1.50 per ton of CO_2e abated, and require no significant capital investments (McKinsey 2009, p. 127). Though the scope of this study is focused on the three sectors requiring 80 percent of investment by 2030, it bears noting that the other sectors will also require increasing investment in GHG abatement, totaling $139.5 billion annually starting in 2011 and rising to $247.5 billion annually in 2026–2030.

[11] "Other industry" is an aggregate of industries not separately listed.

4 Conclusion

Responding to the worst economic crisis in decades, a number of countries have adopted ambitious fiscal stimulus measures with the potential to mobilize significant levels of investment in low-carbon technologies. Yet when measured against estimated investment needs, these short-term funding efforts—which are often based on deficit spending and hence fiscally unsustainable—are manifestly insufficient to trigger the vast transformation of energy systems called for to avoid irreversible impacts from climate change.

Transitioning to a low-carbon economy will require unprecedented and sustained levels of investment, with estimated annual capital requirements between \$500 billion and \$800 billion. The greater part of this investment—up to 86 percent—will need to come from the private sector through equity and debt. Public policy, meanwhile, can play an important role where private investment currently lacks the necessary incentives and regulatory framework, and public funding can help bring the newest technologies closer to market readiness, provide needed infrastructure upgrades, and temporarily fill gaps in private investment due to the financial crisis.

In North America, annual capital investment levels will need to reach \$104 billion annually in just a few years' time, while estimated annual investment needs in Europe will be \$81 billion during the same period (2011–2015). China will need to increase annual investment the most dramatically, to \$86 billion annually in the near term, eventually reaching \$315 billion by 2030.

Eighty percent of this (mainly private) investment will need to flow into three key sectors: energy generation, transportation and buildings. A successful transformation process will also depend on the ability to channel financial flows into strategic technologies within each sector. In the power sector, improved renewable energy generation, grid infrastructure, electricity storage and energy efficiency will be decisive. For transportation, key investments should fund hybrid and electric vehicles, public transportation and transit planning, and improved vehicle efficiency. Investment in the building sector, finally, should be focused on building design and the retrofitting of existing structures, improved energy efficiency, and urban planning aimed at creating transit-oriented development.

Ensuring sufficient private capital flows into these key technologies will hinge on the underlying regulatory framework and targeted policy measures. Governments have a vital supportive role in providing the appropriate enabling environment, including stable, long-term institutional and regulatory frameworks that make private investment flows viable. Policymakers can apply a number of measures to promote private investment in clean technology and direct funds where they are needed over the long run.

In particular, the required transformation will call for:

- **A price on carbon.** A strong and consistent price signal for carbon emissions must be provided through carbon markets or a carbon tax, to ensure that investments flow into low-carbon technologies. Revenue from carbon taxes or allowance auctioning will also be a key source of funding for the public investment needs described in this study.

- **Incentives for renewables.** Policies are needed to incentivize private investment for the deployment of renewable energy sources, such as feed-in tariffs, renewable portfolio standards, or a combination of both.

- **Efficiency standards.** Robust energy-efficiency standards are needed to promote innovation in all three sectors, through combined heat-and-power generation in the energy sector, vehicle emission standards in the transport sector, and efficiency standards for buildings and household appliances.

- **Public funding where markets fail.** Public funding will be required in many areas, including education, research & development, planning, and technology deployment. Public investment is particularly required in public transportation, advanced power storage technologies, grid infrastructures, and urban planning.

Given the urgency of achieving bold emissions-reduction targets, these measures need to be adopted in a focused, coordinated manner and without delay. Though critical, near-term investment needs and policies have already been identified, it will ultimately remain a question of political will whether the necessary policy framework can be adopted and implemented to spur green investment and the associated economic transformation.

A successful transformation process will depend on the ability to channel financial flows into strategic technologies within each sector. Governments have a vital supportive role in providing the appropriate enabling environment, including stable, long-term institutional and regulatory frameworks that make private investment flows viable.

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