THE CLIMATE GROUP

The Office of Tony Blair

BREAKING THE CLIMATE DEADLOCK

TECHNOLOGY FOR A LOW CARBON FUTURE

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E3G

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EXECUTIVE SUMMARY

In recent years the scientific evidence on climate change has become increasingly clear: it is now almost universally accepted that, in order to minimise the risk of irreversible damage to our planet and our livelihoods, we need to strive to keep the average global temperature increase below 2°C. It is also widely recognised that, to achieve this, we will need to peak global emissions before 2020 and then reduce them by 50-85% below 2000 levels, setting interim targets along the way.

Likewise, the political will to act is in place. Heads of government from all parts of the world have declared their willingness to adopt ambitious emissions targets, both individually and collectively, but have wanted to be sure that such goals, while certainly challenging, are practically achievable. This report shows that this is indeed the case. From analysis of the current status of the major abatement solutions, we draw five major conclusions:

1.We know the technologies we need, where to deploy them and the investment required.
To put ourselves on a path to meet our emissions goals, we need to reduce global emissions by 19 Gigatonnes (Gt) in 2020 and energy-related emissions by 48 Gt by 2050. In addition to slowing and eventually halting deforestation, the global roadmap for technology development and deployment must focus on four key sectors:

- Power: Approximately 38% of total savings to 2050. Renewable energy, carbon capture and sequestration (CCS), nuclear power and biomass will all be critical areas.
- Transport: Approximately 26% of total savings to 2050. Key technologies include electric and hydrogen fuel cell vehicles, improved efficiency and current and next generation biofuels.
- Buildings: Approximately 17% of total savings to 2050. Key technologies include improved efficiency in building appliances.
- Industry: Approximately 19% of total savings to 2050. Key technologies include CCS for industrial processes, and industrial motor systems.

The total required annual average investment to scale technology up to the required level is approximately $1 trillion between now and 2050. This is equivalent to 40% of global infrastructure investment or 1.4% of GDP. But much of this investment displaces business as usual spending on high-carbon alternatives and so the incremental cost of additional investment is much smaller. Estimates suggest that a global incremental cost of additional investment of approximately €317bn annually in 2015, rising to €811bn in 2030, is required with an oil price of $60 per barrel. But if the oil price rises to $120 per barrel, this will reduce the cost by €700bn annually – making the incremental additional cost over the period very small or even zero.

2. The technologies required to meet our 2020 goals are already proven, available now and the policies needed to implement them known.
Over 70% of the reductions needed by 2020 can be achieved by investing in three areas: increasing energy efficiency, reducing deforestation and using lower-carbon energy sources, including nuclear and renewables. We also know that by implementing just seven proven policies these reductions can be delivered:

- Renewable energy standards: Regulation to require or feed-in tariffs to stimulate an increased production of energy from renewable sources, in particular wind and solar, could deliver 2.1 Gt of savings.
- Industry efficiency: Improved motors and other efficiency gains could deliver 2.4Gt of savings.
- Building codes: Improving standards for new build and modernising existing building stock could save 1.3 Gt.
- Vehicle efficiency standards: Driving up standards for vehicle efficiency could save 0.4 Gt.
- Fuel carbon content standards: Reducing the carbon content of fuels could lead to 0.3 Gt of savings.
- Appliance standards: Increasing the energy efficiency of white goods and other appliances could reduce emissions by 0.3 Gt.
- Policies to reduce emissions from deforestation and forest degradation (REDD): could deliver close to 9 Gt of reductions.

All seven policies have already been successfully implemented in countries around the world but need scaling up. While cap and trade systems or other means of creating a carbon price can help provide incentives for businesses to invest in low-carbon solutions, in the short term at least, it is these seven policy measures and direct action and investment by governments that will achieve the targets.

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3. Investment now in the technologies of the future order is essential if we are to meet longer-term targets.
Although we have the technologies we need through to 2020, new technologies – many available but not yet commercially proven – will be needed to meet the more challenging long-term goals. Therefore, at the same time as we deploy existing solutions, we must invest in future options, such as carbon capture and storage (CCS), new generation nuclear, concentrated solar power (CSP) and electric vehicles, and the infrastructure, such as smart grids, necessary for them to operate at scale. Instead of locking in high-carbon infrastructure, countries must agree now to speed up the deployment of technologies with potential for long-term carbon reduction. The situation is critical. The status of current technologies shows considerable potential for the future but there is a long way to go before they reach full commercialisation.

For example, without CCS technology, the cost of decarbonisation will be over 70% higher in 2050. Yet there are currently no full-scale CCS plans up and running anywhere in the world, even though the technology is expected to contribute 20% of global emission reductions by 2050. For CCS to reach its full potential we will need to have at least ten full-scale power demonstration plants and a further eight industry demonstration plants up and running by 2015.

Technology will be developed and deployed when the private sector is presented with the right balance of risk and reward. Action is therefore required to create markets for innovation and diffusion that work in a globalised world. This will require not only the acceleration of a comprehensive global carbon market but also the implementation of practical and collaborative technology policies both nationally and internationally. The overall goal must be to aggressively deploy the existing tried and tested options that can deliver mid-term reductions, and to prepare for the long-term development of game-changing technologies.

A long-term global carbon price will be essential to pull technologies through to commercialisation and disseminate them widely. Accelerating the development of national and regional carbon markets, and tools to link these together, must therefore be a priority. Access to the international carbon market will reduce the total cost of abatement by up to 20%.

But alone this is not enough. The reality is that carbon pricing does not address many other market failures along the innovation chain. Overcoming these requires world leaders to develop and implement policies focused specifically on technology development and deployment which are both practical and collaborative. Putting in place strong domestic legislation to decarbonise the power, transport, buildings and industry sectors is an essential starting point.

Looking ahead, governments should adopt a strategic top-down approach to ensure that critical technologies arrive on time and provide investment in disruptive options to allow radical transformation in the future. This is not a policy of picking winners; rather it is to guarantee that there will be enough winners to pick from.

4. Financial support will be needed to enable global deployment of low-carbon technologies but the non-climate benefits are also significant.
More than 30% of global abatement between now and 2030 will be in large emerging economies such as India and China, and developing countries will require significant financial flows to enable them to make the necessary investments. Estimates suggest that this needs to be approximately \$100bn-\$160bn annually between 2010 and 2020. Funding to developing countries could be through both market-based mechanisms, such as the Clean Development Mechanism, or through multilateral financing such as the World Bank Climate Investment Funds.

Yet investment in low-carbon technologies will lead to substantial job creation and growth. Germany created 100,000 jobs in the renewable sector between 2004 and 2006. In the US it is estimated that producing 5% of electricity from wind power by 2020 would add \$60bn in capital investment in rural America, provide \$1.2bn in new income for farmers and rural landowners and create 80,000 new jobs.

In addition, investment must be made in supporting infrastructure such as smart grid technology, which will facilitate the use of new technologies.

Internationally, developed countries should also agree to at least double public research, development and demonstration (RD&D) for low-carbon technologies by 2015 and quadruple it by 2020. This would deliver an additional \$10-\$30bn per annum to push through key technologies. Countries should prioritise international cooperation for strategically important technologies such as CCS, CSP and zero-carbon transport. The Major Economies Forum (MEF) could kick-start this process by agreeing to a global demonstration project for CCS and CSP technology.

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5. Copenhagen can provide the spur for international collaboration that will bring costs down and accelerate diffusion and deployment.

Although many of the policies needed will be implemented nationally or regionally, a strong agreement in Copenhagen will provide the framework for international cooperation to drive long-term change and assist in deploying existing technologies and to provide RD&D opportunities for future technologies. A comprehensive technology mechanism must be put in place, which sets the scale and pace of market and direct finance support, defines the areas where cooperation will take place and establishes an institutional structure to measure, report and verify actions and facilitate joint ventures. This mechanism should:

- Establish a Technology Development Objective to scale up market creation and finance for new technology.
- Agree to the creation of Technology Action Programmes covering market development, global demonstration and orphan areas of research for critical technologies such as CCS.
- Reform and scale up the Clean Development Mechanism to ensure it can support technology diffusion in developing countries.
- Establish a Technology Executive Board under the United Nations Framework Convention on Climate Change (UNFCC) to oversee the creation of global roadmaps and technology action programmes. The board would also contribute to the creation of measurable, reportable and verifiable (MRV) criteria to track technology action and support.
- Establish a protect and share framework for intellectual property rights (IPR), with capacity-building support to strengthen IPR protection in developing countries and provide a clear framework for using the existing flexibilities in national and international law.

Successfully reducing emissions to prevent dangerous climate change is without doubt a huge challenge and will require a revolution in the way we produce and consume energy, travel and design and manage our urban and rural environments. However, the pathway to this revolution is clear and, by means of ambitious international collaboration to develop and deploy low-carbon technologies, well within our grasp. We know what we have to do; this report shows us how.

CHAPTER 1

SIGNPOSTS TO THE FUTURE – AMBITIOUS BUT ACHIEVABLE TECHNOLOGY SOLUTIONS FOR CLIMATE SECURITY

Innovation and technology will be essential to provide the answers to climate change, energy security and economic growth. The solutions are achievable, affordable and realistic but will require concerted effort and international cooperation to be successfully executed. To do this we must have a dual focus, to aggressively deploy existing options to peak and reduce global emissions by 2020, and invest in the technologies of the future to build the capacity to make deep long-term cuts. Copenhagen is the moment for the world to signal this commitment and clearly signpost the path to a sustainable future.

The scientific evidence on climate change is clear: the International Panel on Climate Change's (IPCC) Fourth Assessment Report concludes that to stay below a rise of 2°C we must peak global emissions before 2020 and reduce them globally by 50–85% below 2000 levels by 2050[1]. As shown in figure 1.1, delaying action will require much faster rates of reduction later. If there is a ten-year delay in reducing emissions, then the rate of cuts required increases over a five-year period from 14% to 31%. The UK Committee on Climate Change estimate that the cost of delay from starting on a 550ppm trajectory and then switching to a 450ppm trajectory later would be £25bn for the UK alone[2]. Technology policy must therefore create a critical mass of investment such that we can simultaneously meet both mid-term 2020 goals and the long-term 2050 transformation in our economies.

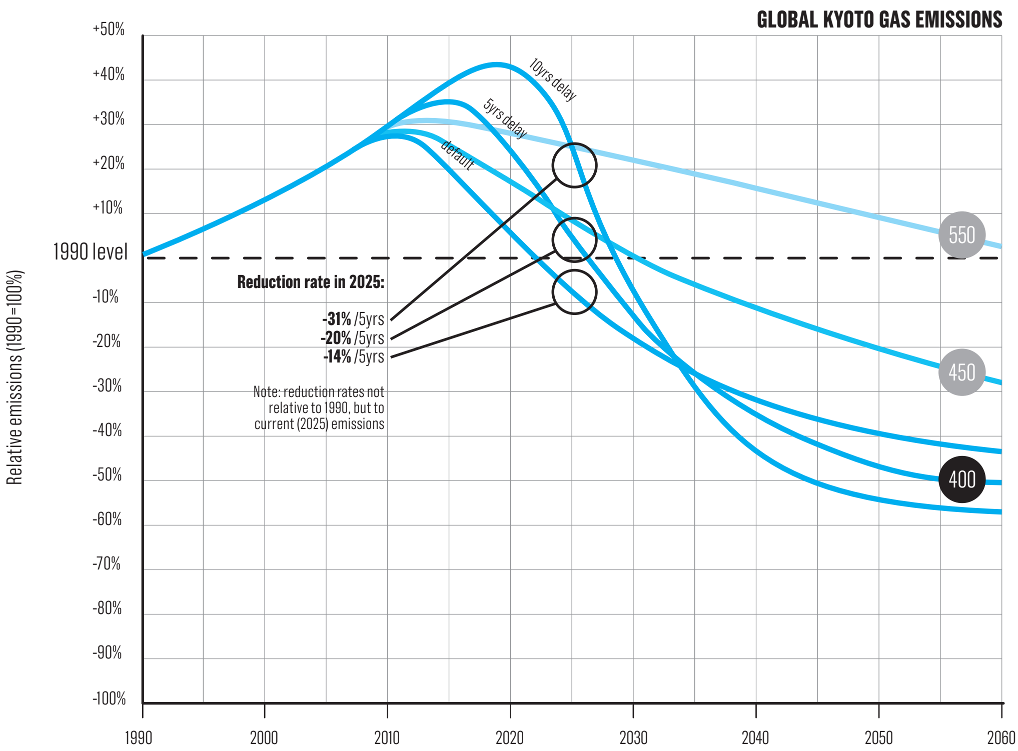

Figure 1.1: Emission reduction rates
Source: Meinshausen, 2005[3]

1 Intergovernmental Panel on Climate Change (2007) Summary for Policymakers. In Climate Change 2007: Fourth Assessment Report, Synthesis Report (AR4). Cambridge University Press, Cambridge,UK, and New York, USA.
2 Committee on Climate Change (CCC) (2008) Building a Low-Carbon Economy: The UK's Contribution to Tackling Climate Change.
3 Meinshausen, M. (2005) On the Risk of Overshoot – Two Degrees. Presented at "Avoiding Dangerous Climate Change", 1-3 February, Met Office, Exeter, UK.

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Creating technology solutions will require a balance of action all the way along the innovation chain. Technologies are at various stages of development, as shown in figure 1.2 below, and so solutions must focus on both near-term commercialisation for those technologies near the market and research, development and demonstration (RD&D) for those further away.

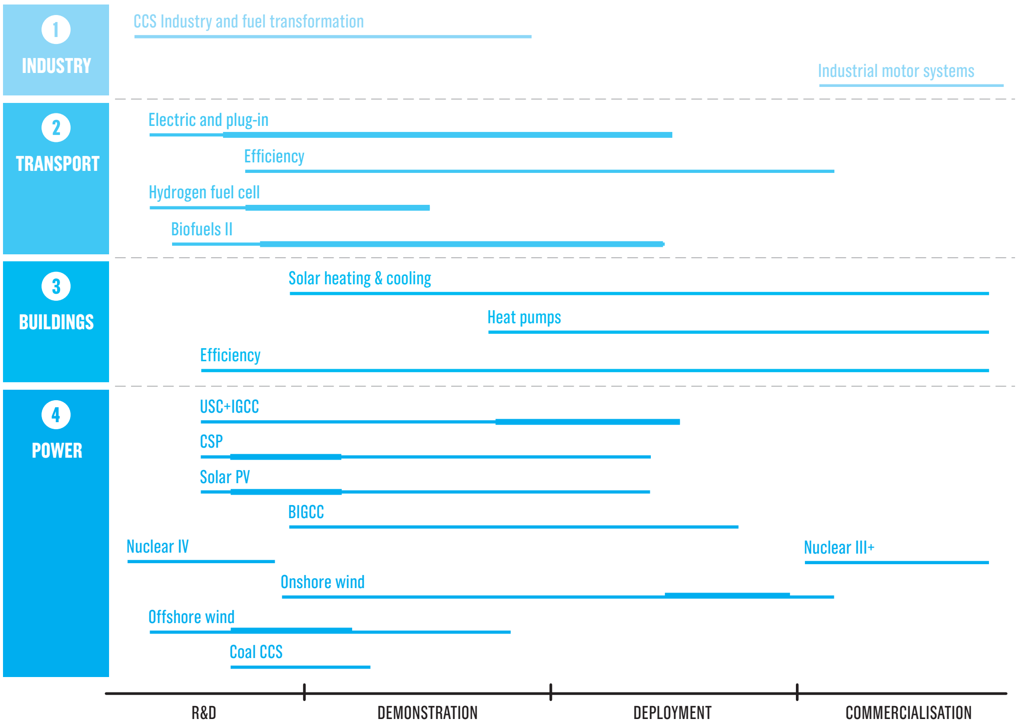

Figure 1.2: Technology development priorities for key technologies
Source: Modified from IEA, 2008[4]

[4] International Energy Agency (2008) Energy Technology Perspectives: Scenarios and Strategies to 2050. OECD/IEA, Paris.

The status of current technologies shows considerable potential for the future but there is a long way to go before they reach full commercialisation (as shown in figure 1.3 below). For example there are currently no full-scale carbon capture and sequestration (CCS) plants up and running anywhere in the world, even though the technology is expected to contribute 20% of global emission reductions by 2050. For CCS to reach its full potential we will need to have at least ten full-scale power demonstration plants and a further eight industry demonstration plants up and running by 2015, and to have invested in the required transport infrastructure for captured CO_2 by 2020. Similarly for concentrated solar power (CSP) there is currently only 436 Megawatts (MW) of installed capacity, which will need to be rapidly expanded to 250 Gigawatts (GW) between 2020 and 2030. In transport, second-generation biofuels will need to move from the test lab to full commercialisation by 2030, and fully electric and hydrogen fuel cell vehicles will need to move from prototypes and limited production models to mass market deployment. Improving buildings efficiency and appliance standards will require mandatory regulation in OECD countries by 2020 and regulation globally by 2030.

TECHNOLOGY	ABATEMENT POTENTIAL BY 2050 ($GTCO_2$)	CURRENT STATUS	TECHNOLOGY NEEDS	DEPLOYMENT NEEDS	TOTAL INVESTMENT NEEDS (2005-2050 BILLION USD)
CCS fossil fuel	4.85	No full scale demonstration plant	RD&D	10 demo plants 2008-2015; full scale demo plants 2015-2030; transport infrastructure developed 2010-2020	1418.5
Nuclear plants (III+IV)	2.8	Total capacity of nuclear power plants 372 GW in 2007	III+ commercialisation; IV R&D	Gen III+ Commercial deployment by 2025; 935 GW by 2050; Gen IV Commercial deployment by 2045; 285 GW by 2050	2032.5
Offshore & onshore wind	2.14	Global cumulative capacity 94 GW in 2007 (mainly onshore)	Offshore RD&D; onshore RDD&D and commercialisation	Offshore competitive by 2030, onshore competitive by 2020. Over 2000 GW capacity by 2050	1640
Biomass IGCC (BIGCC) & co-combustion	1.45	No large scale demonstration	Demonstration and deployment	10 demo plants of 50 MW each 2010-2020. 100 GW Biomass co-combustion and 65 GW BIGCC capacity by 2050	306
PV systems	1.32	World cumulative capacity 6.6 GW 2006	RDD&D	PV competitive by 2020-2030;1150 GW capacity by 2050	1313.5
CSP	1.19	Total capacity 436 MW at the end of 2008	RDD&D	CSP competitive by 2030. 630 GW capacity by 2050	590
Coal IGCC systems	0.69	17 IGCC plants (totaling 4000 MW)	RDD&D	Over 100 GW capacity; competitive by 2030; over 550 GW capacity by 2050.	727.5
Coal ultra-supercritial steam cycles (USC-SC)	0.69	Several large coal plants with USC (400-1000 MV) in Japan and Europe	RDD&D	100 GW capacity; competitive by 2025. Over 550 GW capacity by 2050	717.5
Efficiency in buildings and appliances	7	Efficiency gains 10% to 60% in most major economies	RDD&D and commercialisation	Mandatory dynamic standards by 2020 in OECD and 2030 globally. By 2040 fully commercial.	7100
Heat pumps	0.77	Increasing market share in some OECD countries	Demonstration, deployment & commercialisation	50-70% of buildings in OECD fitted by 2050	2704.5
Solar space and water heating	0.47	Currently deployed but relatively high capital costs	RDD&D and commercialisation	3000 GW capacity by 2050	935
Energy efficiency in transport	6.57	Varied technology development; fuel efficiency standards in some countries	RDD&D and commercialisation	Standards and incentives by 2015 in OECD and 2020 in non-OECD countries. By 2040 fully commercial	9200
Biofuels 2nd Generation	2.16	None used	RDD&D	Full commercialisation by 2030	5584
Electric and plug-in vehicles	2	Limited production (e.g Toyota Prius 500)	RDD&D	Commercialisation between 2020-30 (cumulative 1 million sales of plug-ins)	4310.5
Hydrogen fuel cells	1.79	Prototypes	RD&D	10% of OECD sales by 2030	3892.5
CCS – industry, H2 & fuel transformation	4.28	No full scale demonstration plant	RD&D	8 demo plants 2008-2015; 15 demo plants 2015-2030; transport infrastructure developed 2010-2030	1607.5
Industrial motor systems	1.4	Significant efficiency losses	Commercialisation	Average efficiency gain of 25-30%	4175

Figure 1.3: Summary of key technologies

By 2020 we will need to achieve global emission reductions of approximately 19 Gigatonnes (Gt) of CO_2 equivalent[5]. Analysis by McKinsey suggests that up to half of this will be delivered through reduced emissions from deforestation and degradation and land use change. However, as shown in figure 1.4 below, an additional 9.3 Gt will need to be achieved through the development and deployment of existing and near-market technologies and efficiency improvements across sectors. Reductions in the power sector account for about 20% of the abatement potential. Important technologies such as wind, solar, coal CCS and geothermal will be crucial for reductions in 2020[6]. The roadmap to 2020 also highlights the importance of technologies to improve energy efficiency in transport, buildings and industry. For example in the transport sector, improved vehicle efficiency and use of biofuels will drive short-term savings. In buildings, improvements in efficiency and appliance standards could deliver 1.6 Gt of reductions by 2020. In industry, investment will also need to be made to improve technologies such as motor efficiency systems. It is vital that support for these areas is rapidly increased to provide confidence that we can peak and reduce emissions before 2020, while supporting jobs, growth and energy security.

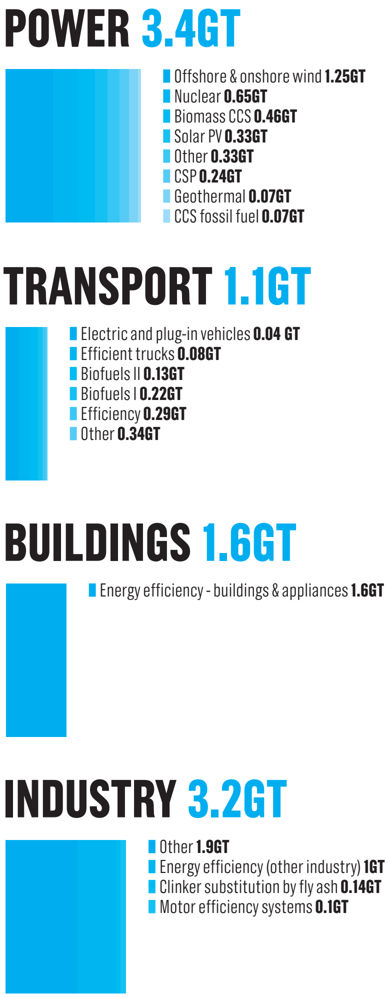

Figure 1.4: Key technology emission reductions to 2020 can deliver 9.3 Gt of CO_2eq
Source: Modified from McKinsey analysis, MAC v2.0, 2009

5 1 Gigatonne is equivalent to 1 billion tonnes. McKinsey (2009) Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve. McKinsey & Company.
6 Project Catalyst analysis 2009.

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But these existing options will not be sufficient to deliver the deep cuts in emissions that will be required by 2050. The International Energy Agency's (IEA) BLUE Map Scenario suggests that 48 Gt of CO_2 savings will be required by 2050[7]. To do this we must also invest now in the research, development and demonstration of new technologies to guarantee that we can meet our long-term goals. The IEA technology roadmaps identify 17 key technologies that will be responsible for approximately 80% of reductions to 2050, equivalent to 42 $GtCO_2$ (see figure 1.5). Delivering these results will require actions today across a range of additional power, transport, buildings and industry technologies to ensure they can be fully commercialised after 2020. In the power sector, accelerated demonstration is required for CCS, as well as next-generation nuclear and concentrated solar power. In transport, we need to invest now in the next generation of biofuels, electric and plug-in vehicles and hydrogen fuel cells. For buildings, heat pumps and solar space and heating technologies are important. Finally for industry, CCS and fuel transformation technologies and improvements in industrial motor systems will have a key role.

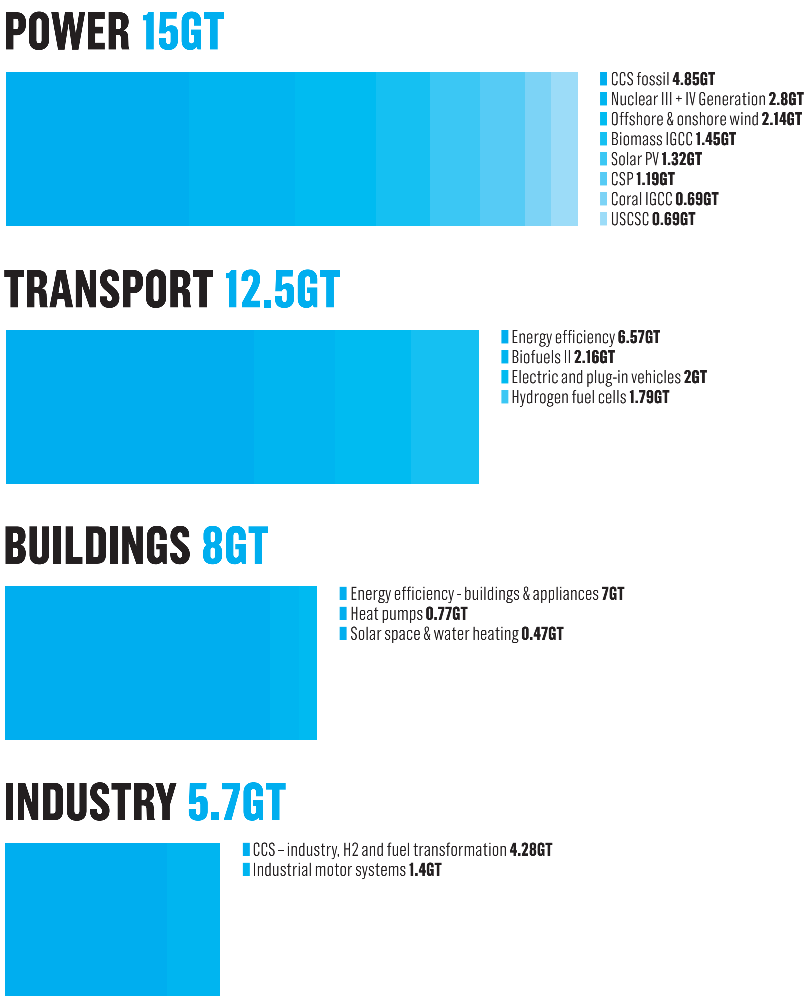

Figure 1.5: Key technology emission reductions to 2050 can deliver 42 Gt of CO_2
Source: IEA (2008)

These reductions cannot be achieved in isolation. Successful transformation of our energy systems will require investments in supporting infrastructure and technologies. For example in the power sector, smart grids and storage technologies will be necessary to achieve all of the possible savings. In transport, infrastructure to support hydrogen fuel cell vehicles or fully electric cars will need to be put in place.

[7] International Energy Agency (2008) Energy Technology Perspectives: Scenarios and Strategies to 2050. OECD/IEA, Paris.

It is clear that there is no single technology that will deliver all the emission abatement we need. Instead we need to focus on a portfolio of technologies across all of the major sectors. These new and existing technologies will need to be deployed and diffused globally in order to avoid high carbon lock-in, as shown in figure 1.6 below. Large emerging economies such as China and India will be crucial, given their projections for rapid domestic growth, but so too will established developed countries in Europe and North America. If developing countries do not participate, the cost of 60 Gt of abatement will rise by 20%[8] and just over half of the overall abatement potential of these key technologies will be captured in non-OECD countries in 2050. For example:

- CCS: 34% in OECD countries; 66% in other developing countries including China and India.
- Onshore and offshore wind: 43% in OECD countries; 57% in other developing countries including China and India.
- Solar (PV and CSP): 46% in OECD countries; 54% in other developing countries including China and India.
- Electric and plug-in vehicles: 49% in OECD countries; 51% in other developing countries including China and India.

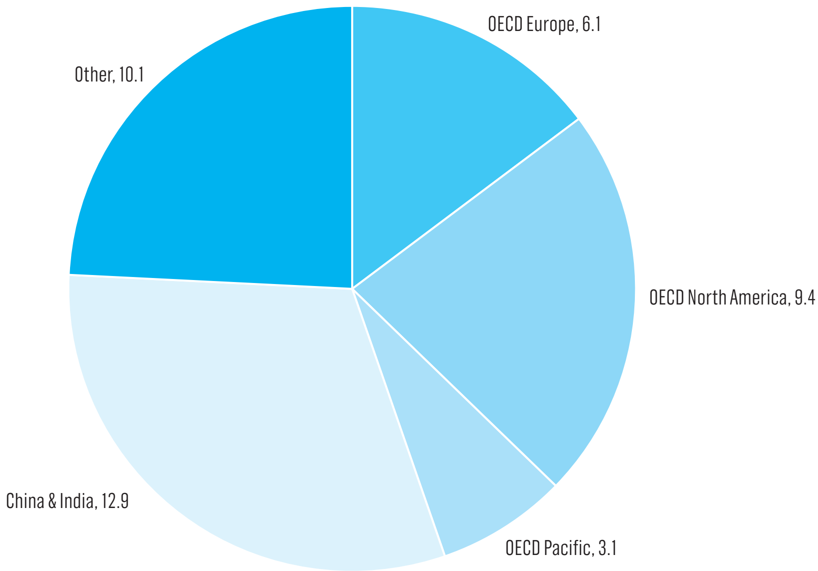

Figure 1.6: Regional energy-related CO_2 reductions in 2050 (17 key technologies ~42 $GtCO_2$ in total)
Source: IEA (2008), BLUE Map Scenario

In each of these sectors there are known technologies at different stages of development. But in addition to supporting these technologies it is also crucial that the right frameworks are established to allow new disruptive technologies to enter the market. The public sector has a crucial role in ensuring that the innovation system works as a whole. Without the right regulatory and physical supporting infrastructure, new technologies will not be commercialised in sufficient time. History is replete with examples of innovations coming on to the market from unexpected quarters. Energy market forecasts in the 1970s did not foresee the rapid development of gas-powered generation through integrated gasification combined cycle (IGCC) plants and it is very possible that similar new energy options will arrive in future. An example of one such promising technology, Biochar, is outlined in box 1.1 below. To allow these technologies to flourish we must create open and competitive markets where new entrants can gain a foothold, and ensure that support is provided in a broad and transparent manner rather than narrowly concentrating on propping up the existing incumbents.

Box 1.1: Potential disruptive technologies - Biochar

Biochar is a charcoal-like material produced by heating biomass with minimal oxygen (pyrolysis). Biochar can be used to enhance the soil carbon sink. Early estimates of its potential to remove carbon from the atmosphere range between about 1 Gt and 9 Gt a year. Biochar systems need to be developed on a meaningful scale to determine better their true sequestration potential.

A wide range of organic feedstock can be used, including forest and crop residues, manure, sewage and green waste. Biomass that currently releases greenhouse gases as it decomposes or is burnt could instead be returned to the soil as mineralised carbon and remain stable for centuries. The pyrolysis process also produces syngas that can be burned to generate electricity, and a crude oil substitute suitable for plastics production. Modern pyrolysis plants can be run on the syngas product alone.

Biochar also offers climate change adaptation value, fertilising the soil and helping it to retain water.

8 Project Catalyst analysis 2009.

The six key areas that can deliver 58% of the technology-related reductions (almost 30% of all reductions) to 2020 are wind power, solar (PV and CSP), nuclear, buildings efficiency, industry efficiency and transport efficiency. Without policies to deliver these technologies, we will not be on track to meet our mid-term targets and economies will be locked into high-carbon growth.

The vast majority of energy efficiency improvements already offer positive economic returns and so will not be affected by the carbon price. To overcome the market failures, such as high transaction costs or principal agent problems that prevent their uptake, governments will need to establish strong regulation with dynamic standards to drive up the performance of buildings, industry and transport systems.

Delivering wind, solar and nuclear improvements will require governments to create the right market conditions for private investment and overcome non-market barriers. Establishing minimum Renewable Portfolio Standards (RPS), requiring increased production of energy from renewable sources, and feed-in tariffs could deliver solar and wind improvements. Governments should also support this with regulation to avoid penalising intermittency and investment to support distributed generation systems. Investment in research, development and demonstration (RD&D) to improve solar and wind technologies will also be needed. Nuclear technology will require insurance and regulatory support in order to accelerate deployment.

To build the capacity to make deep cuts by 2050 the six key technologies that must be accelerated through RD&D by 2020 are CCS in power, CCS in industry, third- and fourth-generation nuclear technology, second-generation biofuels, electric and plug-in vehicles and hydrogen fuel cell vehicles. Together these technologies are expected to contribute 37% of energy-related savings by 2050. It is therefore essential that their development is accelerated to ensure that they can be widely deployed after 2020, including in developing countries.

CCS for both power and industry will require at least ten full-scale power demonstration plants and a further eight industry demonstration plants to be established globally by 2015. It is also essential that by 2020 we have invested in the required transport infrastructure for captured CO_2 to allow widespread usage thereafter. Third-generation nuclear technology will require significant R&D investments and testing in order to be ready for deployment by 2025, with continuing development of fourth-generation systems for deployment in later periods.

We must also invest globally to accelerate second-generation biofuels. This will require both R&D and global demonstration to ensure that they can reach full commercialisation by 2030. The private sector is already investing heavily in full electric and hydrogen fuel cells. However, this development will need to be supported by investment in grid and hydrogen infrastructure and the development of new regulations and standards for these technologies. Electric and plug-in vehicles need to ready for full commercialisation by 2020, and hydrogen fuel cell vehicles are expected to account for 10% of OECD sales by 2030.

If we are to succeed, governments must take two big decisions: first, to get the investment flowing into the technologies of the future; and second, aggressively to deploy existing tried and tested options to improve energy efficiency and deliver mid-term reductions. To achieve this it is vital that countries cooperate to ensure that the right technologies are developed and deployed, at the right scale and speed, in order to manage risks and avoid high-carbon lock-in.

CHAPTER 2 INVESTMENT NEEDS AND RISK MANAGEMENT TO DELIVER TECHNOLOGY SOLUTIONS

The process of global innovation is achieved largely through the private sector and is increasingly international in nature. However, the public sector still has a vital role and in key areas such as energy R&D it accounts for more than 60% of R&D spending in industrialised countries[9]. Government cooperation will be crucial to scale up the current rate of innovation and diffusion. A key consideration for government should be creating the right balance of risk and reward in innovation markets to leverage private sector activity.

Action is therefore required to create markets for innovation and diffusion that work in a globalised world. Markets are tools for delivering outcomes; but, as the recent financial crisis has shown, without the right system of regulation and incentives, a major misallocation of resources can occur. This is especially relevant for climate and adaptation innovations, where we need to meet climate, energy security and economic growth objectives simultaneously. Without national and multilateral action, private companies will not make the necessary investments to meet these goals.

The imperative for technology action is also central to a sustained economic recovery. By creating the global markets for low-carbon and adaptation technology, we will drive growth and job creation. According to the German environment ministry (BMU), Germany had 166,000 jobs related to renewables in 2004 and an estimated 260,000 in 2006[10]. Globally, the wind sector employs about 300,000 people. The US Department of Energy (DOE) estimates that a goal of producing 5% of US electricity from wind by 2020 would add $60 billion in capital investment in rural America, provide $1.2 billion in new income for farmers and rural landowners and create 80,000 new jobs by that year[11]. The solar thermal sector currently employs more than 600,000 people worldwide. Similarly, concentrating solar power (CSP) under the moderate deployment scenario could create about 200,000 jobs by 2020 and more than a million of jobs by 2050[12]. These technologies will also free us from a dependence on imported fossil fuels, ensuring robust energy security.

Developing and delivering these technologies will require a shift in global investment. This shift has three components: first, the overall change in investment patterns for both public and private spending required to deliver the technologies and infrastructure; second, the incremental cost of this additional investment over business and usual investments; and third, the financial flows to developing countries required to support their decarbonisation.

The total global investment costs for these 17 technologies between now and 2050 is significant but manageable. Total annual average investment for R&D, deployment and commercialisation is estimated at close to $1 trillion for both public and private investment. This is equivalent to approximately 40% of global infrastructure investment[13] or 1.4% of world GDP[14]. The incremental cost of additional investment is much smaller and highly dependent on the oil price. McKinsey estimate that a global incremental cost of additional investment of approximately €317bn annually in 2015, rising to €811bn in 2030, is required with an oil price of $60 per barrel. But if the oil price rises to $120 per barrel, McKinsey estimate that this will reduce the incremental additional cost of abatement by €700bn annually – making the cost over the period very small or even zero. Given projections on future demand growth and resource scarcity, there is a high probability of a long-term oil price of $120 per barrel or even higher. The IEA recently expressed its concerns about the possibility of new highs in oil prices by 2010 leading to a potential recession in 2013 mainly driven by the decrease in global oil supply capacity and growing demand[15].

9 Doornbosch, R. and Upton, S. (2006) Do We Have the Right R&D Priorities and Programmes to Support the Energy Technologies of The Future? Round Table on Sustainable Development. OECD, Paris.
10 BMU (2007) Renewables industry provides work for 235,000 people. BMU Press Release, Berlin: 17 September 2007.
11 US Government Accountability OfŠce (GAO) (2004), Wind Power's Contribution to Electric Power Generation and Impact on Farms and Rural Communities. Report to the Ranking Democratic Member, Committee on Agriculture, Nutrition, and Forestry, US Senate, GAO-04-756, Washington, DC.
12 Greenpeace International, SolarPACES and ESTELA (2009) Concentrating Solar Power Global Outlook 2009: Why Renewable Energy Is Hot.
13 OECD estimated that between 2005 and 2030, $71 trillion will be invested in infrastructure. OECD (2006) Infrastructure to 2030: Telecom, Land, Transport, Water and Electricity. OECD, Paris.
14 IMF estimated the global GDP as $72 trillion in 2009 (IMF World Economic Outlook Database, 2009).
15 IEA estimates that investment in oil and gas exploration in 2009 has dropped by 21% from 2008 (equivalent to US$100 billion). See Tanaka, N. (2009) The Impact of the Financial and Economic Crisis on Global Energy Investment. Presented at G8 Energy Ministerial Meeting, Rome, Italy, 24–25 May 2009. OECD/IEA, Paris.

Developing countries will require significant financial flows to enable them to decarbonise and adapt to climate change. Estimates suggest this needs to be approximately \$100bn-\$160bn annually between 2010 and 2020[16]. The balance of action and support between developed and developing countries is still under negotiation. However, the Bali Action Plan clearly establishes a reciprocal relationship between developing countries undertaking enhanced actions to reduce their emissions and developed countries providing finance, technology and capacity-building support. The UK government has called for finance provisions of \$100bn annually for developing countries' mitigation and adaptation by 2020[17]. This could be generated either through market mechanisms such as international offsets and auctioning of countries assigned amount units (AAUs), or through cash mechanisms such as taxation of international bunker fuels or direct transfers. Funding could be delivered to developing countries again by way of both market-based mechanisms such as the Clean Development Mechanism or by multilateral and bilateral financing such as the World Bank Climate Investment Funds or national development agency support. All financing should meet international measurable, reportable and verifiable (MRV) criteria to ensure that the funding is both generated and used appropriately.

However, although the total investment required to develop and deploy technologies is manageable, this does not mean that it will automatically be achieved. Delivering the right low carbon technology options will require both the development of a global carbon market and scaled-up public sector support in key areas. In 2007 the global carbon market was worth \$64bn, more than doubling from \$31bn in 2006, with a traded volume of approximately 3 Gt of CO_2eq[18]. However, this is still far too small to drive the pace and scale of investment that is required to avoid high-carbon lock-in. In order to incentivise the private sector it is vital that the market is expanded and that regional and national systems can be linked together to allow for international trading.

Direct public finance support will also be required in addition to the carbon market, as shown in figure 2.1 below. Market failures along the innovation chain require public spending to drive technologies down their cost curve to a point where the carbon price can take over and accelerate their deployment. This will be especially important in helping technologies cross the 'valley of death' between demonstration and pre-commercial financing. Estimates from the Stern Review and Bosetti et al. suggest a doubling of public energy R&D support to \$20 billion per annum between 2015 and 2025[19] and an increase of up to seven times to \$70 billion by 2050[20]. Considering a wide range of estimates, the European Commission suggested global public support for energy RD&D should at least double by 2012 and quadruple by 2020. The Stern Review also suggests that global public support for deployment should be doubled to around \$66 billion per annum in 2015, rising to \$163 billion by 2025, although part of this financing could be provided through the carbon market.

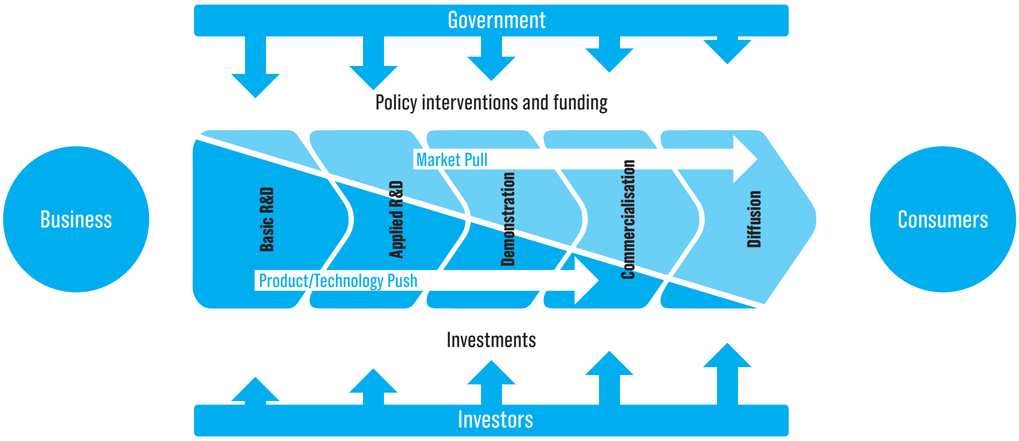

Figure 2.1: Innovation chain

16 Project Catalyst analysis 2009.
17 DECC (2009) The Road to Copenhagen: The UK Government's Case for an Ambitious International Agreement on Climate Change.
18 World Bank (2007) State and Trends of the Carbon Market 2007.World Bank Institute, Washington DC.
19 Stern Review (2006) Stern Review on the Economics of Climate Change. HM Treasury, UK.
20 Bosetti, V., Carraro, C., Massetti, E. and Tavoni, M. (2007) Optimal Energy Investment and R&D Strategies to Stabilise Greenhouse Gas Atmospheric Concentrations. CESifo Working Paper No. 2133. CESifo, Munich.

CHAPTER 2

The balance between push and pull factors for key technologies is outlined in figure 2.2 below. Between now and 2030, RD&D push is required for most technologies to drive them towards innovation. This is especially relevant for CCS, next-generation nuclear and renewable technologies. However, in the short run, pull factors for commercial investment are also required for energy efficiency, electric and hydrogen fuel cell vehicles and heat pumps. Beyond 2030, pull factors are expected to dominate nearly all the technologies.

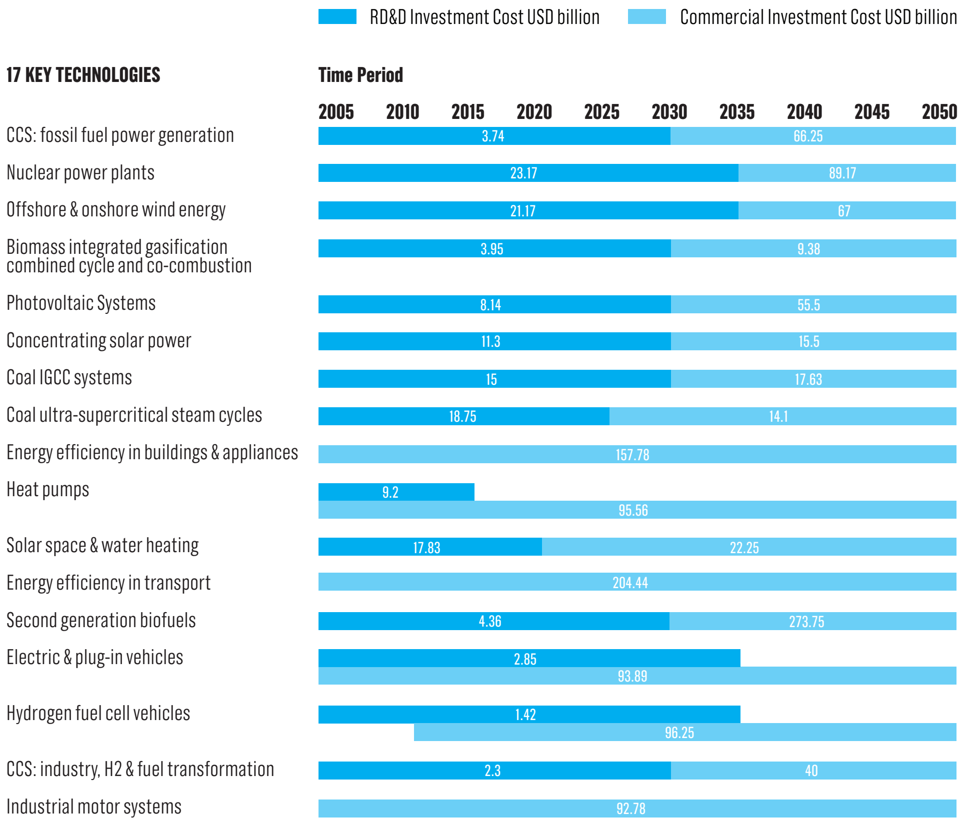

Figure 2.2: Technology roadmaps – annual average investment costs for RD&D and commercialisation of new technologies ($bn)

Governments must also manage the technology and investment risks to delivering climate security. Policy failure may mean that we may not be able to achieve the predicted emissions savings from energy efficiency and forests. From a cost-benefit perspective, many energy efficiency improvements should already provide positive economic returns. However, the fact that they are not being taken up suggests the presence of significant market failures, which will require new regulations to overcome. Energy efficiency improvements are also subject to a 'rebound' effect, whereby the economic savings from improved efficiency may be invested in other carbon intensive activities. For example, a family that insulates their house and moves to a more efficient car may choose to spend the money they save in heating and fuel on an additional flight abroad for a holiday. This rebound effect could significantly undermine current emission pathways as it is extremely hard to model in advance. Similarly, savings from reduced emissions from deforestation and degradation are hard to realise, as described in box 2.1 below.

Box 2.1: Difficulty of achieving carbon savings from forest

McKinsey estimates 12 $GtCO_2e$ can be saved from forestry and agriculture. This consists of both reducing deforestation and forest degradation and then reforesting existing areas and new marginal land. However despite the large abatement potential and apparent low costs, capturing these opportunities will be highly challenging. More than 90% of these areas are located in the developing world and are tightly linked to economic and social circumstances in the regions concerned. The need for local capacity building to realise the savings is high and is often linked to many social issues such as the rights of indigenous people. Overcoming these challenges is potentially difficult, even with current planning. Many tropical forests are located in regions with relatively weak governance systems such as the Congo, potentially making it difficult to implement policies.

Added to this is the difficulty in measuring and monitoring emissions in this sector, such as gaining access to remote areas to assess changes on the ground. This results in a high degree of uncertainty in abatement potential, adding considerable risk to current feasibility and cost estimates.

Similarly, if climate change continues to worsen, suggesting impacts are occurring faster than we previously thought, we will have to deliver innovations sooner than is currently anticipated, including those relevant for adaptation. The IPCC assessments have systematically increased both the threat level and the speed at which climate change is occurring. If this trend continues, then current decarbonisation models will underestimate the scale and speed at which emissions will need to be reduced.

The emission pathways described above make significant assumptions about the early commercialisation of key technologies such as carbon capture and storage, new biofuels, high-penetration renewables, electric vehicles and low-carbon cement and steel production. If some of these key technologies fail or markedly underperform, then more low-carbon technology options will be needed earlier than predicted to keep on track. For example the UK set a goal of reducing emissions by between 76 and 86 million tonnes of carbon in 2010, while the actual reductions are now expected to be 15 million tonnes lower[21]. Underperformance in current policy will require faster action and accelerated use of new technology in the future.

Managing these risks will require investment and cooperation across a portfolio of key technologies. This will provide increased certainty for the private sector to invest and allow for acceleration or corrective action if we move off track.

The pathway for future technologies is clear. We need a global focus on four key sectors: power, transport, buildings and industry. We need to balance mid-term reduction with long-term investment. We need to create a global carbon price to leverage private sector action and provide public support to overcome market failures. The cost is realistic and affordable and will help drive future growth and job creation. The key to success will be finding the political will to make this happen.

[21] Committee on Climate Change (2008) Building a Low-Carbon Economy: The UK's Contribution to Tackling Climate Change.

CHAPTER 3 CRITICAL SECTORS FOR ACTION: POWER, TRANSPORT, BUILDINGS AND INDUSTRY

Technology can be used to manage climate risks. Doing so will provide a massive boost to jobs and growth, free economies from imported fossil fuels and provide the strategic capability for long-term decarbonisation.

Governments should adopt a strategic top-down approach to ensure that critical technologies arrive on time and provide investment in disruptive options to allow radical transformation in the future. This is not a policy of picking winners; rather it is to guarantee that there will be enough winners to pick from. A portfolio approach will ensure that support is spread across a range of different technologies with a balance of push and pull factors along the innovation chain. This will provide the right scale and scope of support so that key technologies can cross gaps in the innovation chain, such as large-scale CCS demonstration that encompasses the range of pre-and post-combustion options and storage scenarios, while avoiding the risk of a myopic focus on only one or two areas. At the same time, strengthening pull factors and regulation will ensure that markets have a strong commercialisation role and avoid the public sector trying to drive widespread deployment.

ACTION IN THE POWER SECTOR

Decarbonising the power sector will be crucial under all emission pathways. It is a major source of emissions in both developed and developing countries and is highly exposed to oil price volatility. International debate on power sector decarbonisation has long been shrouded in scepticism and concerns over costs and potential loss of competitiveness. But the clear economic and security benefits from power sector decarbonisation expose the flaws in this argument and provide a new opportunity to show that bold action will bring large rewards, as shown in box 3.1 below. Future competitiveness will be gained by seizing this moment of change, not propping up outdated industries. Future security will be achieved through transformation, not preservation of the status quo.

Box 3.1 Danish leadership in renewable energy

Denmark is a leading player in the wind energy industry. It has gone from being 99% dependent on foreign oil sources to becoming energy self-sufficient after 30 years of focused energy policy. Danish wind companies account for 40% of the world market, employing approximately 20,000 people, with a combined turnover of €3 billion[22].

Danish support for the renewables industry uses both push and pull measures:

- a tax on the use of fossil fuels
- a spot price environmental premium (€13/MWh) and an additional compensation for balancing costs (€3/MWh) for 20 years are available for new onshore wind farms
- fixed feed-in tariffs exist for solid biomass and biogas under certain conditions, and subsidies are available for CHP plants based on natural gas and waste (biomass, being CO_2 neutral, is exempt from CO_2 duty)
- fiscal support through taxation: a CO_2 tax is levied on electricity production from fossil sources. Renewable energy receives compensation from this, in order to internalise the external costs of fossil fuels. For cooperative operations, no income tax is payable on dividends up to DKK3000 (€400)
- administrative support at the municipal level and active involvement of local utility
- technological development through early government support, starting in the 1980s, focused on creating an indigenous wind energy manufacturing industry.

Between now and 2020, decisive action is required to scale up the deployment and diffusion of a range of technologies. Renewable energy will be a major focus, in particular onshore and offshore wind, solar photovoltaics (PV) and some geothermal energy. Nuclear power and biomass CCS will also be important in the medium term. These technologies already exist and so support is required to create the right regulatory environment for them to operate, close the cost gap with fossil fuel alternatives and invest in the supporting infrastructure such as distributed generation systems, which will allow them to thrive. In the past, climate models have significantly underestimated the speed with which technologies can be brought to market if the right conditions are provided. The IEA estimates during the 1990s of wind penetration by 2020 were actually met in 2004, 16 years ahead of schedule[23]. Decisive action now could achieve similar results.

[22] Ministry of Foreign Affairs of Denmark, 2009.
[23] Riahi, L (2009) Interview: Hans Jørgen Koch Explains Why IRENA Is "50 times More than the IEA". 16 June 2009. online at RenewableEnergyWorld.com.

Significant investment and cooperation must also be made to deliver new technologies that will provide the capacity for long-term decarbonisation. As shown in figure 3.1 below, the carbon intensity of electricity generation must be reduced by more than 80% between now and 2050. Only new technologies can deliver this transformation. Critical areas for this include carbon capture and sequestration (CCS), concentrating solar power (CSP) and third- and fourth-generation nuclear power. CCS in particular will be a vital technology, given the large domestic coal reserves in major economies such as China and the United States. The unabated lifetime emissions from new fossil plants planned in the next 30 years is estimated at 210 billon tonnes of CO_2 which could preclude a 2˚C world[24]. Urgent action to demonstrate CCS technology, including in developing countries, should therefore be an immediate priority for international cooperation. Deployment in China and other major developing countries as well as developed countries will be critical if these technologies are to reach commercialisation[25]. Analysis by McKinsey requires 50 CCS demonstration plants to be up and running globally by 2020 to ensure CCS will take off commercially afterwards, and the IEA estimate that CCS will account for 19% of emission reductions in 2050. Without CCS, the annual cost for emissions halving in 2050 is 71% higher than in the BLUE Map Scenario[26].

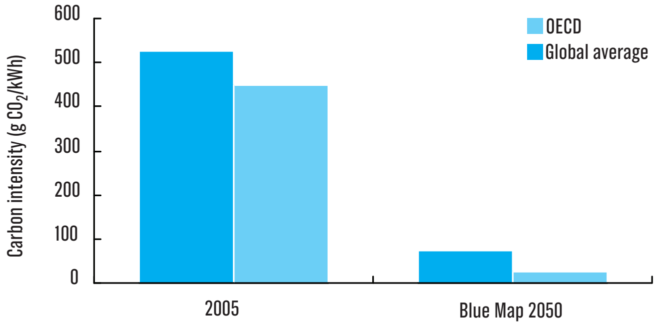

Figure 3.1: Carbon intensity of electricity production
Source: IEA, 2008

However, at a time when there is a global need to scale up the use of power sector technologies, government support for energy RD&D has rapidly declined. Public sector support in G7 countries has declined from a high of over $12bn pa in 1985 to only $10bn pa in 2005, a drop of 50% in real terms[27]. This decline must be reversed and all governments should look to scale up energy RD&D in future.

To enable power sector decarbonisation, action should also be taken to transform supporting infrastructure. Priority areas would be investing in the next generation of smart grids and power storage options. These large, lumpy investments will require significant policy and funding support to achieve and will not happen through private sector action alone. Strong public sector commitment to infrastructure provision would be a credible signal for investors to act more broadly. Political promises are sometimes broken, but tangible assets cannot be ignored.

[24] IEA (2004) World Energy Outlook, OECD/IEA, Paris.
[25] IEA (2008) Energy Technology Perspectives: Scenarios and Strategies to 2050. OECD/IEA, Paris.
[26] IEA (2008) CO2 Capture and Storage: A Key Carbon Abatement Option. OECD/IEA, Paris.
[27] IEA (2008) Energy Technology Perspectives: Scenarios and Strategies to 2050. OECD/IEA, Paris.

CHAPTER 3

ACTION IN TRANSPORT

The transport sector represents a critical area on the path to 2˚C. Emissions in transport are projected to increase by 84% in 2030 under business as usual assumptions. The lack of current commercial options for radical abatement makes this a crucial area for technology development. In the IEA scenarios, 70% of overall additional investment in the BLUE Map Scenario over business as usual is in the transport sector. It is therefore essential that policymakers balance a drive towards energy efficiency improvements in the short run with the development of long-term alternatives.

Efficiency improvements and first- and second-generation biofuels are expected to drive the majority of transport savings between now and 2020. Dynamic standards and regulation to enhance vehicle efficiency will be essential to deliver these benefits. Policy instruments to do this are already employed in many countries domestically and internationally. The CAFE standards for cars and light trucks in the US are one of the best-known examples of environmental standards. The Obama administration has recently announced new and more ambitious targets of a 40% increase in fuel efficiency for Model 2011 cars and light trucks. It is estimated that this could save over 2 million barrels of oil every day -- nearly the entire amount of oil that the US imports from the Persian Gulf[28]. However, even with these increases there is significant potential to push vehicle standards even higher.

We must also invest now in the disruptive new technologies that will provide more radical savings in the long run. Key technologies such as fully electric cars, hydrogen fuel cells, third- and fourth-generation biofuels and efficiency account for more than 25% of overall reductions in 2050. The private sector is already heavily engaged in this area and much of the projected investment consists of increased RD&D in the next 15 years to make these technologies viable. However, the development of these technologies will require significant investments in supporting infrastructure in order to reach full commercialisation. This will include investments in the power sector and grid infrastructure to support electric vehicles, and hydrogen infrastructure and networks for fuel cells. The latter will also require the coordination of fuel infrastructure development at the global level and so the public sector will need to have an active role in shaping and supporting these markets.

The public sector will also have a significant role in driving investment in low-carbon public transport infrastructure. High-speed rail links can reduce demand for air travel, and zero-emission buses and other mass transit systems can cut emissions in major cities.

[28] The White House (2009) From Peril to Progress. The Briefing Room Blog, 26 January 2009.

CHAPTER 3

ACTION IN BUILDINGS

To achieve emission reductions to 2020, a strong focus on energy efficiency in buildings and appliances is required. Large potential savings can be made through improved building regulation and standards; an estimated 75% of abatement in the building sector shows overall net economic benefits. This will be especially important in large emerging economies, which have high rates of new building construction. In developed countries, retrofitting existing buildings, especially to improve insulation and heating systems, can deliver significant improvements. Standards to improve energy efficiency in appliances and air conditioning systems will also be important for mid-term reductions. Some programmes are already in place, such as Top Runner in Japan, and the EU is also in the process of drafting regulations for a number of energy–using products (EuPs) under its Eco-Design Directive. Combined heat and power systems (CHP) are a viable interim measure to reduce emissions from the building sector, but their potential is more limited in the long term as full decarbonisation in the power sector is delivered.

To achieve long-term savings, investment is also required for new heat pump and solar space and heating technologies. Lighting efficiency is improved by two-thirds to three-quarters in the BLUE Map Scenario, reducing energy consumption to around half the baseline level. The IEA suggests this could be reduced even further, depending on the success of commercialising LED lighting (box 3.2). These technologies, in combination with potential improvements in building materials, should encourage the rapid establishment of standards for zero-carbon houses. Making zero-carbon homes realistic and affordable will be essential for making the deep emissions cuts required by 2050.

Box 3.2: Efficiency savings from the use of light emitting diodes (LEDs)

Lighting accounts for 19% of the world's electricity consumption and generates 1.9 Gt of CO_2 annually, according to the International Energy Agency (IEA). Lighting is about to get brighter and much more energy-efficient, as LEDs and smarter control technologies penetrate global markets.

LED chips produce light when electrons jump across a sandwich of two different semi-conducting materials, like a switch. It's a much more efficient process than traditional lighting technologies, has many co-benefits and allows smart controls to easily control the amount of current going into the chip and, thus, the light produced. LED lighting and smart controls are already gaining a foothold in the outdoor market – street lights, parking lots, tunnels, bridges and building security. Initial pilots in the US are showing energy use reductions in the 50–70% range. If outdoor lighting worldwide were to completely take up LED and smart control technologies in that range, the energy savings achieved would be enough to charge up over 60 million plug-in hybrid Priuses annually.

Many barriers remain to market transformation, however, including high cost and current lighting standards. Just as governments are accelerating the use of renewables with feed-in tariffs and other subsidy programmes, LEDs and smart controls, which are much more costly than conventional lamps, also require financial support to jump start the market. China is the first country to establish a large LED programme, having just announced support for 210,000 LED street lamps to be installed in 21 cities.

CHAPTER 3

ACTION IN INDUSTRY

As in the power sector, so too industry can achieve substantial savings up to 2020. There are large potential savings from cross-industrial efficiency including motor systems efficiency, and to a lesser extent from clinker substitution by fly ash.

In the longer term, while energy efficiency and fuel shift remain key areas for reductions, other technologies such as CCS gain importance in the technology mix. CCS in industry accounts for 9% of reductions in 2050 (4.3 $GtCO_2$). However, in order to have CCS commercially available, 15 demonstration plants are needed between 2015 and 2030, and the transport infrastructure must be ready by 2020. Improvements in industrial motor systems are also essential and action is required to deliver 25-30% global efficiency gains by 2050.

Together, action in these four sectors would create a global production and opportunity agenda for the economy, energy security and climate change. The global population has heard and increasingly understands the threats. Now is the time to put forward the solutions. Leaders must confidently take action to create the frameworks for entrepreneurship which will enable this to happen. This will require putting in place strong domestic legislation to decarbonise the power, transport, buildings and industry sectors. Governments should work to provide a balance of push and pull measures such as public financing for RD&D, feed-in tariffs for renewable energy and dynamic standards for energy efficiency. Governments should also invest in supporting infrastructure such as smart grid technology. In general, strong policy action in six key areas could deliver 40% of the required savings up to 2020:

1. Minimum renewable portfolio standards (RPS): Regulation to require an increased production of energy from renewable sources could deliver 2.1 Gt of savings by 2020.
2. Industry efficiency: Could deliver 2.4 Gt of savings by 2020.
3. Building codes: Improving standards for new build and modernising existing building stock could save 1.3 Gt by 2020.
4. Vehicle efficiency standards: Driving up standards for vehicle efficiency could save 0.4 Gt by 2020.
5. Fuel carbon content standards: Reducing the carbon content of fuels could lead to 0.3 Gt of savings by 2020.
6. Appliance standards: Increasing the energy efficiency of white goods and other appliances could reduce emissions by 0.3 Gt by 2020.

In addition, governments should agree to at least double public RD&D for low-carbon technologies by 2015 and quadruple them by 2020; and to aggressively expand national, regional and international carbon markets to support diffusion. They should also prioritise international cooperation for strategically important technologies such as CCS, CSP and zero-carbon transport. Mechanisms for achieving this are described in the next chapter.

Finally, leaders must make Copenhagen the moment for international cooperation to drive long-term change. No other forum has the reach or legitimacy, and no other forum can provide the strong link between technology, emissions reductions and adaptation. World leaders must therefore take decisive action to ensure that the Copenhagen agreement includes a strong technology cooperation mechanism to assist in deploying existing technologies and providing research, development and demonstration for future technologies.

CHAPTER 4 ACTIVATING THE SOLUTIONS – WHAT NEEDS TO BE DELIVERED IN COPENHAGEN?

The Copenhagen agreement must represent sufficient ambition on global emission reductions and finance to be on track to stay below 2˚C in the medium term, and build the institutional framework for long-term change. It must signal that those companies that want to operate and prosper in a low-carbon economy will have a leg up, and those that don't will be left behind. For technology this means setting the scale and pace of market and direct finance support, defining the areas where cooperation will take place and establishing an institutional structure to measure, report and verify actions and facilitate joint ventures.

However, it will be important to remember that there will not be a single route to decarbonisation and, reflecting the different structures of their economies, developed and developing countries will not necessarily follow the same course. The old idea that all technology will be 'developed' in the North and 'transferred' to the South is dead. The only way to beat the ticking clock of climate change is to cooperate on those vital areas that will open the path to future commitments. But for this to work we must be clear that this cooperation is not charity. All sides must bring something to the table, and all sides must be willing to share success with others.

The Copenhagen agreement should include a Technology Development Objective to scale up market creation and finance for new technology. In the past debates have focused on either delivering emissions reductions or on developing new technology. It is now clear that we must do both. Therefore, alongside emissions targets the Technology Development Objective should have an equal emphasis on innovation. The Objective must deliver sufficient technology diffusion to be on track for mid-term targets in 2020 and sufficient investment in technology development to deliver long-term reductions. The Objective should also give a mandate to create a global roadmap and Technology Action Programmes for cooperation on strategic technologies.

The Technology Action Programmes should define three clear areas where international cooperation is necessary for specific technologies:

- Market development: This is necessary to create global markets for new technologies. It can take the form of cooperation to generate a sufficient global price to make a technology viable, such as electric cars, or the creation of niche markets for technology development, such as zero-carbon buildings. Global cooperation to coordinate regulations and standards between countries will be crucial for achieving this.
- Global demonstration programmes: This is relevant for large-scale, high risk technologies, often with complex transmission and storage needs, such as carbon capture and sequestration (CCS) and concentrated solar power (CSP). The size and complexity of these technologies make it difficult for the private sector to independently finance demonstration. The success of these technologies also relies on geological or other location-specific factors, which mean that demonstration needs to occur in a number of countries to achieve full commercialisation. Global cooperation is therefore necessary to fully prove the technology and allow it to become commercial.
- Orphan areas of research: This is relevant to important technologies where there is currently a lack of demand, for example owing to a lack of ability to pay, such as drought-resistant crops for least-developed country farmers, or because incumbents in highly concentrated markets are resistant to investing in new technology, such as in steel and cement. Global cooperation in publicly funded research and development projects or the creation of prizes or advance purchase commitments is necessary to overcome these barriers.

CHAPTER 4

The success of different technologies will require different types of cooperation, as outlined in figure 4.1 below. For example concentrated solar power (CSP) requires both market development to create niche areas where it can gain a foothold and a global demonstration programme to drive it along the innovation chain.

	MARKET DEVELOPMENT	GLOBAL DEMONSTRATION PROGRAMME	ORPHAN AREA OF RESEARCH
POWER SECTOR			
CCS	●	●	
Offshore wind	●	●	
Onshore wind	●		
Nuclear III/IV		●	
Solar PV	●		
CSP	●	●	
Biomass	●		
Power storage		●	●
Smart grids		●	●
BUILDINGS SECTOR			
Efficiency	●		
Heat pumps	●		
Solar heating + cooling	●		
Zero carbon building	●		●
TRANSPORT SECTOR			
Electric & plug-in vehicles	●		
Hydrogen fuel cells	●		
Biofuels	●		
INDUSTRY SECTOR			
CCS & fuel transformation		●	
Industrial motor systems	●		

Figure 4.1: Types of international cooperation required for key technologies

An example of a Technology Action Programme for CCS is outlined in box 4.1 below.

Box 4.1: Example of a Technology Action Programme for carbon capture and sequestration (CCS)

EU heads of government, G8 energy ministers, the International Energy Agency and the Carbon Sequestration Leadership Forum (CSLF) have all called for broad commercial deployment of CCS by 2020.

In June 2008, G8 energy ministers agreed to collaborate to launch 20 large CCS demonstration projects worldwide by 2010 to help accelerate commercial CCS deployment in developed and developing countries by 2020. By implementing this commitment at the July 2009 Summit in L'Aquila, Italy, G8 leaders could inject significant momentum into the Copenhagen climate negotiations. Furthermore, the Major Economies Forum (MEF), which is due to take place around the G8 summit in July, provides a new opportunity for dialogue and breakthroughs. A major movement in the MEF towards technology building, as outlined in the Bali Action Plan, would build trust with developing countries in the lead-up to Copenhagen.

Existing but separate commitments by MEF countries partly fulfil the energy ministers' recommendation. In December 2008 EU heads of government agreed public funding for up to 12 CCS demonstration plants by 2015. Significant funding for CCS demonstrations has also been announced by the US, Canada, Norway and Australia. The G8/MEF now needs to align these efforts globally.

However, outstanding requests from coal-intensive developing countries for financial and technical assistance with CCS demonstrations remain unfunded. These early stage demonstration projects will carry extra capital costs of around €400 million per 400MW in developed countries, in addition to the €500 billion cost of the basic power plant. Costs in developing countries are likely to be 30-50% lower.

The G8/MEF should further implement the energy ministers' call for international action to partner, build capacity and share information with emerging economies, where coal is an essential part of any readily available route out of poverty for hundreds of millions of people. In addition to the 20 projects target, financial support should be offered for at least three further CCS demonstrations in China, India, Indonesia and South Africa.

The July G8/MEF Summit should launch a leader-led process to deliver a CCS Technology Action Programme (TAP) identifying all the core elements in commercialising CCS globally. By November, leaders from a group of key countries could agree on those core elements and be ready to begin implementing them.

- The Leaders' Initiative would commit to jointly support three CCS demonstrations in developing countries, and reiterate earlier commitment for delivering 20 full-scale CCS demonstration plants in developed countries.
- The initiative should include a financing package, agreements on knowledge sharing and capacity building and agreement to explore options for including CCS inside Copenhagen sectoral and technology mechanisms, with the aim of developing a joint proposal.
- A working party could report to the UN General Assembly in September, or to the Ministerial session of the CSLF in London in mid-October.
- A CCS TAP in November, with a report to the leaders, would be a major step along the critical pathway.
- Framework agreements with the developing countries should be announced at Copenhagen, and work would continue into 2010 once the major elements have been agreed.

This initiative can build on (and fully fund) the 2005 Near-Zero Emissions Coal (NZEC) CCS cooperation between the UK, the EU and China. It would also build on recent Memoranda of Understandings on low-carbon technologies between Italy and China, Italy and the UK, and Italy and the US.
Commitments could be administered through the Asia Pacific Partnership on Clean Development and Climate (APP), which has a fossil fuels programme chaired by Canada and Australia. Alternatively, developing country partnerships could be coordinated by the Global CCS Institute (GCCSI).

A Technology Executive Board under the UNFCCC should be established to oversee the creation of global roadmaps and Technology Action Programmes. The board would be responsible for reporting back progress to the UNFCCC Conference of the Parties (COP) and initiating corrective action if the programmes are off track. To monitor progress, the board would also contribute to establishing measurable, reportable and verifiable (MRV) criteria for technology assistance and action.

The Copenhagen agreement must also set the framework to help catalyse joint ventures. Public–private and private–private joint ventures will be essential to deliver the right technology in the right places. This should build on the extensive private sector experience of these relationships to accelerate the pace and scale of activity with developing countries by providing model templates for licensing and joint ventures, which can be tailored to specific circumstances. Copenhagen should both reform and expand the Clean Development Mechanism (CDM) and act as a springboard for the growth of domestic and regional carbon markets. A reformed CDM could help drive private investment in developing countries and accelerate the diffusion of commercial technologies.

The sensitive issue of intellectual property rights (IPR) should be handled through a 'protect and share' framework. This would provide financing for developing countries to strengthen their domestic IPR protection systems in return for government-to-government guarantees that investors' rights will be protected. Countries that do not protect IPR would risk having their access to future funds blocked. The framework would also allow for the use of existing flexibilities in the WTO Trade Related Aspects of Intellectual Property Rights (TRIPS) Agreement and national law to accelerate the sharing of technology. Public investment in global technology demonstration programmes must leverage increased knowledge sharing to accelerate further deployment. The protect and share agreement should provide templates to help structure public–private joint ventures to ensure that public returns are generated for public investment.

Box 4.2: Use of IPR flexibilities

Thanks to TRIPS flexibilities, the price of anti-retrovirals, which are used in the treatment of HIV/AIDS patients, has dramatically reduced[29]. In low- and middle-income countries, the average prices of most first-line medicines decreased by 30-64% from 2004 to 2007, making the treatment available more widely except in most eastern European and Latin American countries[30].

These flexibilities also exist in national law. For example, compulsory licensing (CL) occurs often between private sector firms, and it has been used quite frequently in the US and Canada; courts in the US have approved considerable numbers of CL requests[31]. Recently, the US Supreme Court approved a new standard over patent infringements in certain cases. This implied, as in the case between Paice and Toyota over patents that involved a hybrid vehicle improvement, that a permanent injunction would not likely issue; instead, the court would establish damages in the form of a reasonable royalty[32].

Although the private sector should provide the bulk of technology-related investment, significant public financing will also be required. This will be necessary both to support the areas of international cooperation and to build developing countries' own capacity to adapt and utilise technology. Rather than trying to centralise all funding through multilateral instruments, Copenhagen should establish measurable, reportable and verifiable (MRV) criteria for both bilateral and multilateral financing to be 'counted' towards developed countries meeting UNFCCC commitments. Bilateral financing will be crucial to build on the existing technology partnerships and actions and to create the innovative spaces where new modes of collaboration can be achieved. But new multilateral financing will be necessary to capture the global public-good aspects of climate technology and build capacity in least developed countries. It should be provided either by existing multilateral institutions, such as the Climate Investment Funds of the World Bank, or by a new dedicated technology fund under the UNFCCC.

Box 4.3: Example of ongoing cooperation that could contribute towards meeting UNFCCC commitments – the Asia-Pacific Partnership

A number of existing technology cooperation initiatives offer possible templates for the future and could contribute towards meeting UNFCCC commitments through the use of appropriate measurable, reportable and verifiable (MRV) criteria. The Asia Pacific Partnership (APP), for example, brings together governments and industries from Australia, Canada, China, India, Japan, Korea, and the US. The purpose of this non-legally binding initiative is the development, diffusion, deployment and transfer of existing, emerging and longer-term cost-effective, cleaner, more efficient technologies and practices. Since its inception in 2006, APP has established a number of working groups dealing with a range of energy- and carbon-intensive industries including cement, aluminium, steel and power generation. The unique membership of the group illustrates the potential for productive collaboration among developed and developing countries. By providing a robust set of MRV criteria under the UNFCCC, support provided through the APP could be 'counted' towards countries meeting their commitments. Such a system would avoid trying to centralise all support in a single UN mechanism and encourage the development of new, creative partnership arrangements.

If Copenhagen delivers the right technology objective with the right modes of cooperation and the right institutional structures, this will provide the basis to achieve the next decades' worth of emission reductions, avoid carbon lock-in and build the right infrastructure for the future.

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CHAPTER 4

SUMMARY OF KEY ACTIONS FOR COPENHAGEN

1. Establish a Technology Development Objective to scale up market creation and finance for new technology.
2. Agree to the creation of Technology Action Programmes covering market development, global demonstration and orphan areas of research for critical technologies such as CCS.
3. Reform and scale up the Clean Development Mechanism to ensure it can support technology diffusion in developing countries.
4. Establish a Technology Executive Board under the UNFCCC to oversee the creation of global roadmaps and Technology Action Programmes. The board would also contribute to the creation of MRV criteria to track technology action and support.
5. Establish a protect and share framework for IPR, with capacity-building support to strengthen IPR protection in developing countries and provide a clear means of using the existing flexibilities in national and international law.

ANNEX

CARBON CAPTURE AND SEQUESTRATION (CCS): FOSSIL FUEL FACT SHEET

Current technology status

- CCS involves three main steps: capture, transportation and storage of CO_2. These steps have been used and validated on a small scale, but not yet incorporated into large power plants.
- There are currently no full-scale CCS demonstration plants in the world.

Abatement potential

- CCS emission reductions are projected to account for 4.85 $GtCO_2$ emissions savings (10% of overall energy-related emissions savings) in 2050.
- Without CCS the cost of decarbonisation increases by 70%.
- However, given the need for further RD&D, these savings are only expected to be made at scale after 2020.

Investment need

- Between now and 2030, $3.74bn per annum is required (total investment covering both public and private sector) for R&D, demonstration and deployment in order to push technology towards commercial scale. Between 2030 and 2050, commercial investment of $66bn per annum is required to diffuse the technology globally.
- The bulk of the cost of CCS projects is associated with CO_2 capture (depending on the technology used, it can account for more than half of the overall cost per tonne CO_2 avoided). In addition to that, fitting coal or gas power plants with CCS implies an energy penalty. Some studies estimate that adding CCS to a power plant would need roughly 10-40% more energy than a plant of equivalent output.

Deployment pathways

- Ten demonstration plants are needed between 2008 and 2015. This would be followed by an additional 20 full-scale demonstration plants between 2015 and 2030 for commercialisation. Full-scale deployment of CCS requires a significant effort in demonstration and the development of a suitable infrastructure. Infrastructure for the transportation of CO_2 will need to be developed between 2010 and 2020.
- 66% of the emissions savings will be captured in developing countries including China and India, while 34% will be in OECD countries.
- Governments and private sector should plug the financial gaps in early CCS projects to enable widespread deployment of CCS after 2020.
- To avoid lock-in to high-carbon infrastructure, new power plants should include capture/storage readiness considerations in their plans by 2015.
- RD&D is needed to reduce capture cost, improve overall system efficiencies and ensure storage integrity and monitoring.
- Develop and enable legal and regulatory frameworks for CCS at the national and international levels, including long-term liability regimes.
- Integrate CCS into Emissions Trading Scheme (ETS) and post-Kyoto instruments
- Share best practice and lessons internationally and jointly fund large plants in developing countries by multilateral lending institutions, industry and governments.

ANNEX

ONSHORE AND OFFSHORE WIND FACT SHEET

Current technology status

- Global wind power installed capacity in 2007 was 94 GW (predominantly onshore). Since 2001, installed wind capacity worldwide has grown by 20-30% a year. The bulk of the capacity is installed in IEA member countries led by Germany, US and Spain. Wind provided 156 TWh electricity in 2006, just under 1% of global electricity supply.
- Compared to onshore wind technology, offshore wind power technology is less mature and currently about 50% more expensive, although it offers more potential in the future owing to the larger scale of offshore installations.
- Although wind power is increasingly commercial, much RD&D remains to be done if wind is to deliver its full potential to provide ample zero-emission electricity supply. Offshore wind is in a pre-commercial development phase, but deployment is progressing. It requires substantial R&D and demonstration support, while onshore wind needs mainly further demonstration, deployment and commercialisation.
- Government support for RD&D of wind technology, which has led to significant cost reductions, has played a critical role in the sector. Over the period 1974 to 2006, government RD&D budgets for wind power in IEA countries were about US$3.9bn.

Abatement potential

- Wind technologies can reduce 1.25 $GtCO_2eq$ in 2020 (36% of power sector emission reduction).
- In 2050, emission savings from wind technologies are projected to increase to 2.14 $GtCO_2$ (4.5% of overall energy-related emissions reduction or about 12% of emissions savings in power sector).

Investment need

- Between now and 2035, R&D, demonstration and deployment investment of $21bn per annum is required (total investment covering both public and private sector) to drive the technology to full commercial potential. Between 2035 and 2050, commercial investment of $67bn per annum is required to diffuse the technology globally.

Deployment pathways

- 900 GW capacity needs to be installed by 2025 to make onshore competitive by 2020 and offshore by 2030. Over 2000 GW capacity needs to be installed by 2050. By 2050, global cumulative installed capacity increases by a factor of 21 (more than 2010 GW), and wind constitutes 12% of global electricity production.
- The IEA BLUE Map Scenario envisages that 57% of abatement potential of this technology will be captured in developing countries including India and China, while 43% will be in the OECD countries.
- Continued RD&D is needed to provide further reductions in cost and uncertainty to fully capture the potential. OECD private and public investment in RD&D should be in the region of $300 million per annum.
- Stable, predictable policy support to encourage investment is needed.
- Low–cost, long-range transmission systems need to be in place. Lead times for the planning and construction of new transmission should be reduced. New infrastructure should be developed to meet the needs of large wind plants in the planning stage. Cost of grid connectivity could be shared across the power sector.
- Investment in power storage technology will be important to manage intermittency issues.

ANNEX

CONCENTRATING SOLAR POWER (CSP) FACT SHEET

Current technology status

- Concentrated solar power (CSP) uses direct sunlight, concentrating it several times to reach higher temperatures. The heat is then used to operate a conventional power cycle such as a steam turbine.
- It is best suited for areas with high direct solar radiation such as arid and semi-arid areas. These areas are widespread across the globe, but not universal.
- CSP has the potential to deliver power on demand, e.g. by storing heat in various forms. It can also work in tandem by burning fossil fuel in hybrid power plants to produce electricity on a continuous basis.
- Total installed capacity of CSP was just 436 MW at the end of 2008. However, the industry has been expanding rapidly and projects under construction at the moment, mostly in Spain, will add 18 GW to the installed capacity by 2017.
- CSP electricity is much cheaper than photovoltaics (PV), although it is not yet competitive with fossil fuel or wind power. Therefore, it needs technology improvements through further R&D, demonstration and deployment to become fully competitive.

Abatement potential

- CSP can reduce 0.24 $GtCO_2eq$ by 2020 (7% of emissions reduction in power sector).
- In 2050, CSP's share in emissions reduction increases to 1.19 $GtCO_2$ (6.5% of power sector emissions reduction).

Investment need

- Between now and 2030, R&D, demonstration and deployment investment of $11.3bn per annum is required (total investment covering both public and private sector) to drive the technology to full commercial potential. Between 2030 and 2050, commercial investment of $15.5bn per annum is required to diffuse the technology globally.
- Plants under construction are expected to generate electricity at a cost of between $125/MWh and $225/MWh, mostly depending on the location. The industry considers that learning and economies of scale could achieve cost competitiveness in the next ten to 15 years. Future costs may lie in the range of $35–$62 per MWh.

Deployment pathways

- 250 GW capacity needs to be installed between 2020 and 2030 to make CSP commercially competitive; 630 GW capacity needs to be installed by 2050.
- The IEA BLUE Map Scenario envisages that 63% of abatement potential of this technology will be captured in developing countries including India and China, while 37% will be in the OECD countries.
- There is considerable scope to reduce costs on all elements of CSP through RD&D. However, this potential will be reached only if there is an active marketplace that can support technology learning. Cost reductions from current levels would come from increased volume production, plant scale-up and technological advances.
- Key supporting infrastructure such as low-cost, long-range transmission systems also need to be provided in order to economically connect CSP plants to the grid.

ANNEX

SOLAR PHOTOVOLTAIC (PV) FACT SHEET

Current technology status

- Solar PV systems directly convert solar energy into electricity. PV systems can be grid-connected or stand alone (off-grid). Off-grid PV systems are particularly important in remote areas and developing countries. These constitute 10% of the total PV market.
- The solar PV market has grown exponentially in the last 15 years and is expected to accelerate further in the next few years. Total world cumulative capacity was 6.6 GW in 2006. Total cumulative PV capacity in selected IEA countries (5.7 GW) has increased by a factor of eight since 2000.
- Germany, Japan and the United States account for approximately 70% of global cumulative capacity, and 63% of global PV manufacturing.
- Solar PV needs technology improvements through further R&D, demonstration and deployment to become fully competitive.

Abatement potential

- Solar PV can reduce 0.33 $GtCO_2eq$ by 2020 (around 10% of power sector emissions reduction).
- In 2050, solar PV's share in emissions reduction increases to 1.32 $GtCO_2$ (about 7% of power sector emissions reduction).

Investment need

- According to the IEA BLUE Map Scenario, in order to achieve full solar PV abatement potential, R&D, demonstration and deployment investment of $8.1bn per year between 2005 and 2030 is required. Between 2030 and 2050, commercial investment of $55.5bn per year is needed.
- The investment costs of PV systems are still high. This represents the most important barrier to PV deployment. Total PV system costs were around $5.5–$6.25/W by the end of 2006 (2005 prices). The IEA roadmap estimates that the investment cost could be reduced to $1.9/W in 2030 and $1.1/W by 2050. In addition, PV electricity generation costs could be as low as $0.05 per kWh by 2050 in good solar irradiation regions.

Deployment pathways

- PV needs to be competitive with retail electricity by 2020–2030. This will require installation of at least 150 GW capacity in 2030 and 1150 GW capacity by 2050. This is equivalent to 6% of total world electricity generation (i.e. 2584 TWh).
- The IEA BLUE Map Scenario envisages that 54% of abatement potential of this technology will be captured in the OECD countries, while 46% will be in developing countries including India and China.
- Sustained and effective incentives are needed in the next five to ten years to overcome the pre-competitive stage of PV systems and to achieve exponential market growth.
- Sufficient public and private R&D funding should be guaranteed for the development of next-generation solar PV technologies.
- Technology transfer issues for, particularly off-grid, application in developing countries must be tackled.
- Standardised solutions should be developed with the construction industry for the integration of solar PV in buildings.
- Development of storage technology to overcome intermittency issues.

ANNEX

HEAT PUMPS FACT SHEET

Current technology status

- Heat pumps are most suitable for use in cooling, space heating, hot water and industrial heat. They include a wide range of products that facilitate heat exchange between air, water, soil or bedrock and water or buildings.
- Heat pumps have been gaining more market share in some OECD countries. For example, in Sweden, about 48% of all electrically heated homes have heat pumps. Heating-only pumps have a significant market share in a number of countries, notably Sweden, Switzerland, the United States, Germany, France, Austria and Canada.
- Heat pumps are considerably more expensive than boilers (by a factor of about three compared to a gas boiler), although running costs are much lower, which altogether bring significant economic benefits to households. For example, electric heat pumps can reduce primary energy consumption for heating by as much as 50% compared to fossil fuel-fired boilers.
- Even though many are available on the market, some heat pump technologies still face some technical barriers, which have resulted in lack of confidence in the technology, hence, limited deployment. In order to capture their full market and abatement potential, further demonstration, deployment and commercialisation are needed.

Abatement potential

- Heat pumps can reduce 0.77 GtCO_2 in 2050 (1.6% of overall energy-related emissions reduction).

Investment need

- Between now and 2015, R&D, demonstration and deployment investment of about $9bn per annum is required (total investment covering both public and private sector) to drive the technology to full commercial potential. Between now and 2050, commercial investment of about $96bn per annum is required to diffuse the technology globally.

Deployment pathways

- Further RD&D is essential to improve technical and economic performance of heat pumps by 2020. Their cost-effectiveness, energy efficiency and carbon footprint can be improved by 50% between 2020 and 2030. 50-70% of buildings in OECD will need to be fitted with heat-pumping technologies by 2050.
- Half of the emissions savings from heat pumps are expected to be captured in developing countries and the other half in OECD countries.
- Further RD&D is needed to develop more energy-efficient, sustainable and cost-effective heat pumping technologies.
- Actions on policies are required to ensure all building codes promote energy conservation and efficiency measures.
- Most countries should have policies that recognise the benefits of heat pumps.

ANNEX

ENERGY EFFICIENCY IN BUILDINGS AND APPLIANCES FACT SHEET

Current technology status

- Energy efficiency in buildings and appliances encompasses a variety of products and measures such as the building envelope, hot water systems, lighting and large and small appliances utilised in households and offices.
- In developed countries, energy efficiency policies for major appliances have achieved gains of 10% to 60%. Similarly, many new lighting solutions are so cost-effective that retrofitting the existing lighting systems makes economic sense. Some lighting technologies such as LED are considered to offer high potential for further technical improvements. Given the diversity of underlying technologies, support is needed at all stages of the innovation chain to capture efficiency and abatement benefits.

Abatement potential

- Energy efficiency in buildings and appliances can reduce 1.6 $GtCO_2eq$ in 2020 (that is the total abatement potential in buildings or about 8% of all abatement potential in 2020).
- Its share in emissions reduction will rise to 7 $GtCO_2$ in 2050 (about 15% of overall energy-related emissions reduction).

Investment need

- Between now and 2050, commercial investment of about $158bn per annum is required to diffuse the technologies globally.

Deployment pathways

- New technologies will need to be developed and deployed for even higher energy efficiency by 2020.
- The IEA BLUE Map Scenario envisages that 53% of abatement potential of this technology will be captured in developing countries including India and China, while 47% will be in the OECD countries.
- Mandatory minimum efficiency standards for mass-produced appliances will need to be implemented by 2020 in OECD and worldwide by 2030, with continuous tightening. International standards need to be reviewed regularly to ensure adequate vigour.
- Building codes could request the cold countries to meet 'passive house' levels by 2015, and globally from 2030.
- Policy will need to shift towards Best Available Technology (BAT) in lighting efficiency from 2025.
- International collaboration is needed to facilitate the rapid exchange of BAT in the buildings sector to ensure rapid uptake worldwide.
- Energy efficiency improvement in buildings and appliances must be monitored.
- Assuming the market pull policies suggested above are fully implemented, technologies will be already commercial by 2040.

ELECTRIC AND PLUG-IN HYBRID VEHICLES FACT SHEET

Current technology status

- Plug-in hybrid vehicles combine the vehicle efficiency advantages of hybridisation with the opportunity to travel part-time on electricity provided by the grid. Electric vehicles, on the other hand, do not have an internal combustion engine at all, hence rely on energy storage or battery charging from the grid more than hybrids.
- There is currently quite limited production of electric and plug-in vehicles, although car manufacturers are increasingly investing in the area. For example, Toyota has recently launched its first fully hybrid plug-in car and about 500 have been manufactured for sale. To achieve the level of deployment and commercialisation needed, further R&D, demonstration and deployment support is required.

Abatement potential

- Electric and plug-in vehicles can reduce 0.04 $GtCO_2eq$ in 2020 (3.6% of abatement potential in transport sector).
- In 2050, their share in emissions reduction increases to 2 $GtCO_2$ (about 4% of overall energy-related emissions reduction or about 16% of emissions savings in transport).

Investment need

- Between now and 2035, R&D and demonstration of about $3bn per annum is required (total investment covering both public and private sector) to drive the technology to deployment. Between now and 2050, additional investment of about $94bn per annum is required for further deployment.

Deployment pathways

- RD&D is estimated to reduce the cost of batteries to $300/kWhr from their current $1000/kWhr. Plug-in trials will need to reach 10,000 vehicles worldwide by 2010. Additional cost reductions can be achieved through R&D and learning between 2010 and 2020. Semi-commercial deployment of plug-in hybrids will need to increase to a 5% share of sales in IEA countries by 2020. Between 2020 and 2030, plug-in vehicles need to be commercialised with a cumulative sale of approximately 1 million. Deployment of pure electric vehicles will need to begin by 2030. This will be followed up by rapid market expansion of plug-ins and increased market share of pure electric vehicles out to 2050.
- 51% of the emissions savings will be captured in developing countries including China and India, while 49% will be in the OECD countries.
- The energy storage system is the primary area where further progress in needed. Despite slow progress, there now appears to be tremendous potential for important breakthroughs.
- Governments need to redouble efforts to identify emerging, promising energy storage technologies and support research to bring these technologies to market, particularly in the form of public–private partnerships.
- The power of international networks should be tapped to maximise information sharing and learning.
- RD&D programmes should complement each other and provide assistance to innovative companies.

ANNEX

HYDROGEN FUEL CELL VEHICLES FACT SHEET

Current technology status

- Fuel cell vehicles are based on converting hydrogen into electricity.
- Hydrogen fuel cell vehicle costs are currently very high, with a few manufacturers in 2007 offering very limited production runs at prices of $100,000. On the other hand, Honda began the first commercial production of a hydrogen fuel cell vehicle (FCX Clarity) in 2008, and plans to produce 200 vehicles over the next three years available for lease only initially in the US and Japan.
- Hydrogen fuel cell vehicles still need substantial R&D and demonstration support in order to push the technology towards deployment.

Abatement potential

- Hydrogen fuel cell vehicles are not expected to be commercial by 2020. However, in 2050, their share in emissions reduction increases to 1.8 $GtCO_2$ (about 4% of overall energy-related emissions reduction or about 14% of emissions savings in transport).

Investment need

- Between now and 2035, R&D and demonstration investment of about $1.4bn per annum is required (total investment covering both public and private sector) to drive the technology to deployment. Between 2010 and 2050, additional investment of about $96bn per annum is required to deploy the technology globally.

Deployment pathways

- By 2020 RD&D is estimated to reduce the cost of fuel cell system to $300/kW (compared to around $500/kW now), as well as the cost of energy storage by 50%. Further cost reductions are expected through RD&D and learning, thanks to about 10,000 trial vehicles worldwide. This means semi-commercial deployment of hydrogen fuel cell vehicles can begin in 2020, with sales share increasing to 10% in OECD by 2030 and cumulative sales up to 1 million vehicles. Continued cost reduction is estimated to bring the cost down by a factor of six by 2050.
- 56% of the emissions savings will be captured in the OECD countries, while 44% will be in developing countries including China and India.
- The 2020 targets of cost reduction are quite ambitious and will require a doubling of RD&D efforts with greater attention to energy storage options.
- A global roadmap for fuel cell vehicle deployment should be in place by 2015, also addressing fuel infrastructure investment needs and system expansion issues.
- International collaboration is needed to coordinate research on key technical components and fuel infrastructure development. Ongoing work on international standard setting, safety testing, etc. needs to continue apace.

ANNEX

SECOND-GENERATION BIOFUELS FACT SHEET

Current technology status

- Second-generation biofuels are produced using wood-like feedstocks such as wood, straw and grass, and are therefore less likely to put pressure on food security than first-generation biofuels, which used food crops as feedstock.
- Currently, second-generation biofuels are not used on the commercial scale. For full commercialisation in the next couple of decades, substantial R&D, demonstration and deployment efforts are needed.

Abatement potential by 2050

- Second-generation biofuels account for 0.13 $GtCO_2eq$ emissions reduction in 2020 (about 12% of abatement potential in transport sector).
- In 2050, the share of second-generation biofuels increases to 2.16 $GtCO_2$ (4.5% of overall energy-related emissions reduction or 17% of emissions reduction in the transport sector).

Investment need

- Between now and 2030, R&D, demonstration and deployment investment of about $4.4bn per annum is required (total investment covering both public and private sector) to drive the technology to full commercial potential. Commercial investment needed between 2030 and 2050 grows substantially to about $274bn per annum in order to scale up the technology globally.

Deployment pathways

- RD&D will reduce the cost of biofuels to $0.60/litre gasoline equivalent. Initial large-scale plants need to be constructed by 2010–15 in order to start deploying the technology by 2012. By 2030 it needs to be fully commercialised. In this period, the cumulative sales are expected to reach 1000 Mtoe (million tonne of oil equivalent).
- 54% of emissions savings will be captured in developing countries, while OECD countries account for 46% of the savings.
- Significant scale-up is needed to demonstrate the technology globally.
- Even though some of the second-generation biofuel technologies are close to deployment phase, basic R&D is crucial in some areas.
- Better international coordination of demonstration projects, deployment policies, biofuels trade is needed as well as continuous collaboration in basic research.

ANNEX

CARBON CAPTURE AND SEQUESTRATION (CCS) INDUSTRY FACT SHEET

Current technology status

- CCS technologies will be crucial in carbon-intensive sectors such as steel and cement as well as hydrogen and biomass plants. However, as is the case with CCS in the fossil fuel power sector, different components of CCS have not yet been integrated into a large industrial plant. Substantial RD&D is needed to deploy it at the scale and speed needed.

Abatement potential by 2050

- CCS in industry accounts for 4.28 $GtCO_2$ emissions savings in 2050 (9% of overall energy-related emissions reduction).

Investment need

- Between now and 2030, R&D, demonstration and deployment investment of about $2.3bn per annum is required (total investment covering both public and private sector) to drive the technology to full commercial potential. Between 2030 and 2050, commercial investment of about $40bn per annum is required to diffuse the technology globally.

Deployment pathways

- Eight demonstration plants are needed between 2008 and 2015. This would be followed by another 15 full-scale demonstration plants between 2015 and 2030 for commercialisation. Infrastructure for the transport of CO_2 will need to be developed between 2010 and 2020. The majority of carbon-intensive industries such as iron and cement will need to be equipped with CCS by 2050.
- 53% of the emissions savings will be captured in developing countries including China and India, while 47% will be in OECD countries.
- Further RD&D is needed to reduce capture cost, improve overall system efficiencies and ensure storage integrity and monitoring.
- Legal and regulatory frameworks for CCS at the national and international levels need to be developed and enabled, including long-term liability regimes.
- CCS should be integrated into ETS and post-Kyoto instruments.
- Best practice and lessons should be shared internationally and multilateral lending institutions, industry and governments should jointly fund large plants in developing countries.

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