# EXECUTIVE SUMMARY

## Introduction

Climate change is a major challenge. Secure, reliable and affordable energy supplies are needed for economic growth, but increases in the associated carbon dioxide ($CO_2$) emissions are the cause of major concern.

About 69% of all $CO_2$ emissions, and 60% of all greenhouse gas emissions, are energy-related. Recent IEA analysis in *Energy Technology Perspectives 2008* (ETP) projects that the $CO_2$ emissions attributable to the energy sector will increase by 130% by 2050 in the absence of new policies or supply constraints, largely as a result of increased fossil fuel usage. The 2007 Intergovernmental Panel on Climate Change (IPCC) *4th Assessment Report* indicates that such a rise in emissions could lead to a temperature increase in the range of 4-7°C, with major impacts on the environment and human activity. It is widely agreed that a halving of energy-related $CO_2$ emissions is needed by 2050 to limit the expected temperature increase to less than 3 degrees. To achieve this will take an energy technology revolution involving increased energy efficiency, increased renewable energies and nuclear power, and the decarbonisation of power generation from fossil fuels.

The only technology available to mitigate greenhouse gas (GHG) emissions from large-scale fossil fuel usage is $CO_2$ capture and storage (CCS). The ETP scenarios demonstrate that CCS will need to contribute nearly one-fifth of the necessary emissions reductions to reduce global GHG emissions by 50% by 2050 at a reasonable cost. CCS is therefore essential to the achievement of deep emission cuts.

Most of the major world economies recognise this, and have CCS technology development programmes designed to achieve commercial deployment. In fact, at the 2008 Hokkaido Toyako summit, the G8 countries endorsed the IEA's recommendation that 20 large-scale CCS demonstration projects need to be committed by 2010, with a view to beginning broad deployment by 2020. Ministers specifically asked for an assessment by the IEA in 2010 of the implementation of these recommendations, as well as an assessment of progress towards accelerated deployment and commercialisation.

Current spending and activity levels are nowhere near enough to achieve these deployment goals. CCS technology demonstration has been held back for a number of reasons. In particular, CCS technology costs have increased significantly in the last 5 years. In the absence of suitable financial mechanisms to support CCS, including significant public and private funding for near-term demonstrations and longer-term integration of CCS into GHG regulatory and incentive schemes, high costs have precluded the initiation of large-scale CCS projects.

The regulatory framework necessary to support CCS projects also needs to be further developed. Despite important progress, especially in relation to international marine protection treaties, no country has yet developed the comprehensive, detailed legal and regulatory framework that is necessary effectively to govern the use of CCS. CCS is also poorly understood by the general public. As a result, there is a general lack of public support for CCS as compared to several other GHG mitigation options.

This report attempts to address some of these issues by collecting the best global information about the cost and performance of $CO_2$ capture, transport and storage technologies throughout the CCS project chain. Chapters 1-4 contain this information, and use it to conduct a scenario analysis of the role of CCS in climate change mitigation. Chapter 5 discusses the financial incentive mechanisms that governments can use to provide both short- and long-term incentives for CCS. This chapter also contains an expansion and update of the 2007 IEA publication *Legal Aspects of $CO_2$ Storage: Updates and Recommendations* and examines the current state of public awareness and acceptance of the relevant technologies. Chapter 6 includes a review of the status of CCS policies, research and demonstration programmes, and $CO_2$ storage prospects for several regions and countries. Chapter 7 concludes with a proposed CCS roadmap that includes the necessary technical, political, financial and international collaboration activities to enable CCS to make the contribution it needs to make to global GHG mitigation in the coming decades.

## General Findings

Given appropriate emission reduction incentives, CCS offers a viable and competitive route to mitigate $CO_2$ emissions. In a scenario that aims at emissions stabilisation based on options with costs up to USD 50/t $CO_2$ (ACT Map[1]), 5.1 Gigatonnes (Gt) per year of $CO_2$ would be captured and stored by 2050, which is 14% of the total needed for global temperature stabilisation. In the ETP BLUE Map scenario, which cuts global $CO_2$ emissions in half and which considers emission abatement options with a cost of up to USD 200/t $CO_2$, CCS accounts for 19% of total emissions reductions in 2050. In this scenario, 10.4 Gt of $CO_2$ per year would be captured and stored in 2050. Without CCS, the annual cost for emissions halving in 2050 is USD 1.28 trillion per year higher than in the BLUE Map scenario. This is an increase of about 71%. About half of all CCS would be in power generation and half would be in industrial processes (cement, iron and steel and chemicals) and the fuel transformation sector.

Overall, on the basis of current economics, the financial consequences of CCS range from a potential benefit of USD 50/t $CO_2$ mitigated (through the use of $CO_2$ for enhanced oil recovery) to a potential cost of USD 100/t $CO_2$ mitigated.

$CO_2$ capture leads to an increase in capital and operating expenses, combined with a decrease in plant energy efficiency. In terms of cost per tonne of $CO_2$ captured, costs are USD 40-55/t for coal-fired plants, and USD 50-90 for gas-fired plants. In terms of cost per tonne of $CO_2$ abated, the figures for coal-fired plants in 2010 are around USD 60-75, dropping to USD 50-65/t $CO_2$ in 2030; and for gas-fired plants, USD 60-110 in 2010, dropping to USD 55-90 in 2030.

## $CO_2$ Transport and Storage

$CO_2$ transportation costs depend on the volumes that need to be transported and the distances involved. Regional "hub and spoke" network structures would be the most efficient way of connecting many emitting nodes to large storage sites. However, putting in place a safe, efficient $CO_2$ transportation system will raise very significant cost and infrastructure challenges.

*1. In ETP, the ACT scenarios envisage bringing global $CO_2$ emissions in 2050 back to 2005 levels, while the BLUE scenarios envisage halving those emissions.*

With the recent development of a more robust methodology for storage capacity estimates, governments urgently need to conduct detailed evaluations of their national $CO_2$ storage capacity, working in partnership with bordering nations who share the same storage space. In the medium term, depleted oil and gas reserves, unmineable coal seams, and deep saline formations are the best options for $CO_2$ storage. Deep saline formations appear to offer the potential to store several hundreds of years' worth of $CO_2$ emissions. This must be validated, and site selection criteria must be developed and shared internationally to identify the most appropriate storage sites. Wider international collaboration and consensus are critically needed to ensure the viability, availability and permanence of $CO_2$ storage.

## CCS Demonstration

The next 10 years will be critical for CCS development. By 2020, the implementation of at least 20 full-scale CCS projects in a variety of power and industrial sector settings, including coal-fired power plant retrofits, will considerably reduce the uncertainties related to the cost and reliability of CCS technologies. Several industrial-size demonstration CCS projects have been announced in Europe, North America and Australia, along with cooperative programmes in non-OECD countries. But many of these projects appear to be making slow progress. If these demonstration projects do not materialise in the near future, it will be impossible for CCS to make a meaningful contribution to GHG mitigation efforts by 2030.

CCS and clean coal technologies should be developed in tandem. As a first priority, R&D should focus on improving fossil plant efficiency, along with research on the integrity of storage methods. Better $CO_2$ capture technologies also need to be developed and to be integrated with power plant designs. Governments should also ensure that new power plants either include CCS or are CCS ready, with engineering designs that provide for later carbon capture retrofit, together with identified routes to $CO_2$ storage sites.

Demonstration projects should leverage and expand on existing $CO_2$-Enhanced Oil Recovery (EOR) activities, as they can generate revenues to offset costs. Over 200 additional billion barrels of oil can be recovered using enhanced oil recovery. This will provide a $CO_2$ storage potential of 70-100 Gt at low or even negative cost. However, there is a shrinking window of opportunity for most oil fields to apply $CO_2$-EOR and the oil and gas sectors should cooperate to maximise these opportunities. The development of $CO_2$-EOR can also jump-start the transport infrastructure required for full CCS deployment in some regions.

## Financial and Regulatory Incentives

Investment in CCS will only occur if there are suitable financial incentives and/or regulatory mandates. Various financial and regulatory options exist for encouraging CCS. The most appropriate approach will vary from country to country. It is clear that market-based solutions alone will be insufficient to finance critical early demonstration projects. Governments must lead by providing sufficient direct financing or financial incentives for CCS demonstration. Private sector finance is also critical. In the area of financing $CO_2$ transport, governments can help to encourage the development of the enabling infrastructure, and can help optimise the linkage of major emission nodes and storage sites. In addition, the medium- and longer-term viability of CCS, particularly in developing nations, will be enhanced by inclusion of CCS in the Kyoto Protocol Clean Development Mechanism. Finally, the financial and insurance industry must be engaged to develop tailored products to address long-term liability issues.

## Development of Legal and Regulatory Frameworks

Governments are making important progress toward the establishment of legal and regulatory frameworks governing CCS, including the recently proposed European Union framework. But much additional work is needed to fill important gaps. Significant national and sub-national effort is needed to address $CO_2$ transport, $CO_2$ storage site selection and monitoring requirements, liability for $CO_2$ leakage, and property rights, among other things. International marine environment protection instruments have led the way in clarifying the legal status of offshore $CO_2$ storage, and the permitting approaches and technical guidance being developed by the London Protocol provide important precedents that other regional and national authorities can adapt in their own contexts.

## Public Awareness and Acceptance

The current level of public awareness of the potential for CCS to be an important GHG mitigation solution is generally low, and public opinion tends to be indifferent or unfavourable as a result. In many countries, public acceptance of CCS will be closely linked to the development of regulatory frameworks to manage risks to public health and safety. Governments in some countries have begun strong public education efforts. But little is known about successful strategies that can be learned from these early efforts. Governments need to share lessons internationally from these programmes, and adapt their future awareness efforts in the light of these conclusions.

## International Co-operation

Given the scale of investment required for CCS RD&D, and the projected growth of fossil-fuel usage in non-OECD countries, international co-operation is clearly needed to accelerate CCS deployment. In particular, more must be done to develop a co-ordinated, complementary set of early CCS demonstration projects around the world, using different technologies and geologic settings for $CO_2$ storage. This will serve to maximise the benefit from initial investments and target gaps in knowledge. Organisations such as the IEA (and its Implementing Agreements) and the Carbon Sequestration Leadership Forum have created networks to share best practices and lessons learned relating to CCS technologies, site selection, monitoring and verification, and the development of legal and regulatory frameworks. However, these networks must be expanded to include broader and more meaningful participation from emerging economies and the Middle East if CCS is to achieve its full global potential as a $CO_2$ abatement solution.

## CCS Roadmaps

International co-operation can be enhanced through the development and implementation of a global CCS roadmap. Building on the CCS roadmaps in ETP 2008 and other roadmap activities on a national and international level, we have deepened the analysis to include a more extensive set of short, medium and long term milestones needed for CCS to achieve global commercialisation by 2030. The way forward for CCS urgently needs to be co-ordinated amongst major stakeholders. The G8/IEA/CSLF *Near-Term Opportunities for CCS* recommendations are a first step in that direction. The roadmap developed for this publication outlines one potential way forward to further enhance dialogue amongst government and industry stakeholders which would aim to lead to the implementation of a more co-ordinated global strategy on CCS.