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The Global Status of CCS: 2012 is the fourth edition of the Global CCS Institute’s key publication on the progress and challenges facing carbon capture and storage (CCS). These reports provide a comprehensive overview of the state of development of CCS projects and technologies, and of actions taken to facilitate the demonstration of those technologies at a large scale.

The Global Status of CCS: 2012 covers developments from late 2011, until the beginning of September 2012. It draws on the results of the Institute's annual project survey, completed by lead proponents of major CCS projects around the world. Survey results were supplemented by interviews with personnel from many of these projects, and by research undertaken by Institute staff.

The assistance of project proponents in completing survey questionnaires and taking part in interviews is particularly acknowledged. The Institute is grateful for the high degree of cooperation received.

The Institute also acknowledges Edlyn Gurney and many of its staff who were instrumental in authoring, reviewing and designing the report.
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EXECUTIVE SUMMARY

ACTION IS NEEDED NOW TO ENSURE CCS CAN PLAY A VITAL ROLE IN TACKLING CLIMATE CHANGE

Addressing climate change requires broad-scale action within the global community. Effective action is needed now to decarbonise energy consumption during this century; no single technology, or even class of technologies, can achieve this outcome.

To achieve greenhouse gas (GHG) emission reduction targets limiting a global average temperature rise to no more than 2°C, the International Energy Agency (IEA) estimates that energy-related emissions must reduce very substantially. Large-scale investments in several technologies are required in order to meet this target, with carbon capture and storage (CCS) contributing 7 Gt of the required 42 Gt emission reduction in a least cost scenario. If CCS were to be excluded as a technology option in the electricity sector, the IEA states that investment costs over the period to 2050 would increase by 40 per cent.

CCS is a vital component of a portfolio of low-carbon technologies, as it is able to reduce carbon dioxide (CO₂) emissions substantially from both the energy sector and other industries.

The Global CCS Institute’s Global Status of CCS: 2012 report identifies the status of CCS, the developments that have occurred in the past year, and the challenges that must be addressed in order for climate change to be managed effectively and efficiently.

CCS IS ALREADY CONTRIBUTING, BUT PROGRESS MUST BE ACCELERATED

CCS is used in a number of industries today, and already plays an important role in tackling climate change. Around the world, eight large-scale CCS projects are storing about 23 million tonnes of CO₂ each year. With a further eight projects currently under construction (including two in the electricity generation sector), that figure will increase to over 36 million tonnes of CO₂ a year by 2015. This is approximately 70 per cent of the IEA’s target for mitigation activities by CCS by 2015.

To maintain the path to the 2°C target, the number of operational projects must increase to around 130 by 2020, from the 16 currently in operation or under construction. Such an outcome looks very unlikely as only 51 of the 59 remaining projects captured in the Global CCS Institute’s annual project survey plan to be operational by 2020, and inevitably some of these will not proceed. This situation should send a strong message to governments on the adverse impact of delays to climate change legislation. The lack of progress continues to undermine private sector investment in CCS activities, which then impedes technology development. Since CCS is the only technology available for complete decarbonisation of industrial sectors such as iron, steel and cement manufacture, the risk of not being able to limit temperature rises to just 2°C becomes even greater.

The window of opportunity identified by the IEA means that action is needed now to extend broad-scale climate policy to support the required technologies. Like all emerging technologies, substantial, timely and stable policy support – including a carbon-price signal – is required for CCS to be viably demonstrated and deployed. This will drive industry confidence and investment, ensuring continuing innovation, and ultimately reducing capital and operating costs.

SLOW PROGRESS BUT IMPORTANT DEVELOPMENTS

It is clear a very substantial increase in new projects needs to occur if the IEA scenario for CCS is to be met.

Since the Global Status of CCS: 2011 report, the net number of large-scale integrated projects (LSIPs) increased by one to a total of 75. During the year, eight previously-identified LSIPs were cancelled, put on hold or restructured for diverse reasons, ranging from insufficient revenues for carbon sales to inadequate storage regulations. These were offset by nine new projects, and of these, five are in China, where the progress of CCS continues to be strong.

Currently, at least 19 developing countries are engaged in CCS-related activities, mostly at the early stage. To achieve global emission reduction targets, 70 per cent of CCS deployment will need to occur in non-OECD countries by 2050.
Most of the newly-identified LSIPs are investigating enhanced oil recovery (EOR). As an additional source of revenue, CO₂ EOR has become a strong driver supporting projects, particularly in North America, China and the Middle East. Nevertheless, current assessments on the potential of EOR and depleted oil and gas fields strongly suggest that deep saline formations will provide the bulk of storage in the long term. Strong near-term potential for CCS exists in industries with the lowest additional cost of capture (natural gas extraction, fertiliser, synfuels and ethanol production).

**ENCOURAGING POLICY SUPPORT BUT MORE REQUIRED**

It is vital that there be more progress towards reducing emissions via policy settings that will achieve large-scale emission reductions. It is important therefore to recognise progress in a number of countries including the United Kingdom and China, as well as the inclusion of CCS in the United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM). The radical technological change required to decarbonise the energy system means that countries cannot rely on a carbon price alone. Governments must ensure that the necessary regulatory infrastructure is in place, and as the IEA has noted, “policy packages should be regularly reviewed to maintain coherence over time”.

The inclusion of CCS in the CDM marks an exciting new era for the global deployment of CCS as a major mitigation option. It encourages the institutional arrangements needed to support projects, and also enhances confidence due to its international recognition.

There has been some progress in rebalancing climate policy settings for carbon pricing, and enhanced support for all low-carbon technologies within the UK, specifically. Australia also introduced a carbon tax in 2012, which will shift to an emissions trading scheme in 2015.

The UK Government is taking a leading role with the first comprehensive policy to drive CCS deployment beyond demonstration projects. Support for CCS, as well as other low-carbon technologies, is being enabled through the reform of electricity market arrangements. This policy package should be closely watched for its impact and the potential for application elsewhere.

The inclusion of CCS in China’s 12th Five-Year Plan is very encouraging. The plan is focused on building clean energy and this is underlined by the fact that five of the nine newly-identified LSIPs are in China.

Full ratification of the amendments to the Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR Convention) is important for those countries planning to transport and store CO₂ offshore. Challenges remain in the adoption of amendments to the London Protocol to allow for the export of CO₂ streams for storage in sub-seabed geological formations.

CO₂ EOR can be considered a CCS project if it can demonstrate that permanent storage of injected anthropogenic CO₂ is associated with EOR operations. Policy and regulations must encourage the transition of CO₂ EOR to dedicated storage, and should provide clear guidance on least-cost monitoring and reporting requirements.

International standards for CCS are being developed and this will support effective and efficient operations across all CCS activities. These standards are likely to take several years to develop, so in the interim it will be important to avoid overly conservative requirements being imposed on CCS projects.

**BARRIERS MUST BE OVERCOME TO REALISE THE BENEFITS OF CCS**

Like many emerging technologies, CCS faces barriers which discourage new projects from emerging and prevent existing projects moving to construction and operation.

Funding for CCS demonstration projects, while still considerable, is increasingly vulnerable and the level of funding support still available will service fewer projects than initially anticipated. The relatively higher-cost CCS projects (for example in the power, steel and cement sectors) require strong government support continuing into the operational phase. There are significant issues with debt availability to support CCS in the current challenging economic climate. CCS is also often not treated equivalently to other low-carbon technologies in policy settings and government support. In order to achieve emission reductions in the most efficient and effective way, governments should ensure that CCS is not disadvantaged.
Storage site selection and characterisation is a lengthy and costly process so this must begin at initial project stage. Indeed the majority of perceived risk in CCS projects is often associated with storage. Public understanding of CCS remains low. Early stakeholder engagement is therefore important and this must include addressing perceptions of storage.

REDUCING THE COST OF TECHNOLOGY THROUGH DEMONSTRATION PROJECTS IS VITAL
In Norway and Canada, two projects highlight the benefits of public and private sector support in advancing cost-effective technologies. The opening of the US$1 billion Technology Centre Mongstad (TCM) in Norway, an industrial-scale test centre for carbon capture, marks an important milestone in research, development and demonstration (RD&D) efforts and should demonstrate the potential for CCS costs to be significantly reduced over time.

In Canada, Shell's Quest project announced it will capture and store more than one million tonnes of CO₂ per year produced at the Athabasca Oil Sands Project. The knowledge generated by both of these projects will drive innovation around the world.

Commercial-scale demonstration of capture requires application at increasing scales with integration into an industrial process or power station, and it is noteworthy that power generation has yet to be demonstrated at scale. Southern Company's post-combustion Plant Barry in the US recently became the world's largest integrated CCS project at a coal-fired power plant. Advances in oxyfuel combustion have also been realised through the commissioning of two pilot-scale oxyfuel combustion demonstration projects, CIUDEN in Spain and Callide in Australia.

Two large-scale demonstration power generation projects are currently in construction and scheduled to begin operation in 2014: Kemper County in the US and Boundary Dam in Canada. These early commercial-scale demonstration projects will identify any construction and operating problems through ‘learning by doing’.

CCS in the iron and steel and cement manufacturing industries remains a challenge, and considerable work is still needed to encourage capture demonstrations and CCS technology developments.

ACCELERATION OF CCS DEPENDS ON COLLABORATION AND KNOWLEDGE SHARING
Sharing information and lessons learnt from CCS projects has great benefits, helping stakeholders address difficult and time-consuming challenges such as building the business case for CCS projects and improving understanding of the technology. For example, there is limited CO₂ pipeline operation experience outside the US, Canada and Norway, and transfer of this knowledge to other countries would assist in accelerating the deployment of CCS.

Knowledge and expertise must be shared through open networks such as those run by the Global CCS Institute.

RECOMMENDATIONS FOR DECISION MAKERS:
Climate change legislation must not be delayed. Timely and stable policy support is required to deal with the barriers to implementation of CCS. This will drive industry confidence, encouraging more innovation, and ultimately reducing capital and operating costs.

To achieve emission reductions in the most efficient and effective way governments should ensure that CCS is not disadvantaged. They must review their policies to ensure that CCS can play a full part in the portfolio of low-carbon technologies.

Funding for CCS demonstration projects by governments and industry should be accelerated to develop the technology and bring down costs through innovation.

Sharing expertise and learning from CCS projects around the world must be encouraged to ensure that progress is made as quickly as possible. Creating a business case and managing the technology is a complex and difficult process, so capturing and using lessons from other projects is vital. This knowledge must be shared with developing countries where 70 per cent of CCS deployment must occur by 2050.

For more information on the global status of CCS go to: www.globalccsinstitute.com
1

INTRODUCTION

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KEY MESSAGES

› Widespread action is needed to mitigate the effects of climate change.
› CCS is an essential element in a portfolio of climate change mitigation technologies.
› CCS in the electricity sector reduces total investment needs for abatement technologies by almost 30 per cent.
› CCS is critical to decarbonising emissions in the industrial sector.

1.1 THE CLIMATE CHANGE CHALLENGE

As the effects of climate change become better understood and human-induced CO₂ concentrations in the atmosphere are globally accepted as the major cause, substantial reductions in CO₂ emissions from power production and other high CO₂ emitting industries will be required to manage the risks of climate change through a greater uptake of near-zero emission technologies.

Monitoring has shown that the amount of CO₂ in the atmosphere is increasing, with atmospheric concentrations now approaching 400 ppm (Figure 1) compared to pre-industrial levels of 280 ppm (IPCC 2007a). This elevated level of CO₂ concentration enhances the greenhouse effect, leading to global warming. This rise in temperature causes the climate to change, sea levels to rise, and ocean and land environments to be affected.

FIGURE 1 Global CO₂ emissions

Source: Conway and Tans (2012), NOAA/ESRL.
During the 20th century, the global average temperature increased by around 0.74°C, with the rate of increase accelerating over the period (IPCC 2007a). The IPCC estimated that by 2100, the increase in global average temperature could range between 1.1–6.4°C depending on the level of greenhouse gas (GHG) emissions during this century. More recent estimates suggest that the world is on a path towards the 6°C level, given currently enacted legislation to reduce emissions (IEA 2011a).

A changing climate will inevitably lead to increased vulnerability to, and severity and frequency of, climate events which could lead to an increased risk of disasters occurring such as heat waves, species extinction, rising sea levels, and flood events.

Developing countries are likely to be the most affected by such adverse impacts of climate change, which will mostly be abrupt and irreversible in nature. The Intergovernmental Panel on Climate Change (IPCC) cites a sobering statistic that between 1970 and 2008, 95 per cent of all natural disaster-related deaths occurred in developing countries (IPCC 2012).

Recent analysis suggests that temperature increases and climate change affect not only the level of economic output, but also the rate of economic growth. It has been estimated that, for certain developing countries, a 1°C rise in temperature in a given year reduces economic growth by 1.3 percentage points, on average (Dell et al. 2012). Further, higher temperatures have wide-ranging effects, reducing not only agricultural output but also industrial production and influencing political stability.

When fossil fuels burn, large amounts of CO₂ are released into the atmosphere. CO₂ is also released from the ground together with natural gas during natural gas production. Industrial processes, such as refining oil, or producing iron, steel, cement, and ammonia, also release large amounts of CO₂. Other major sources of CO₂ include emissions from cars, trucks, ships, and aeroplanes, and emissions from domestic sources – such as heating. In addition, land clearing has reduced the ability of the Earth to absorb excess CO₂ as there is less plant life to assist in natural regulation. All of these activities contribute to increasing the concentration of CO₂ in the atmosphere.

Energy-related CO₂ emissions account for nearly 60 per cent of total global anthropogenic GHG emissions. In 2011, CO₂ emissions from the combustion of fossil fuels reached a record 31.6 Gt (IEA 2012a). Primary energy consumption continues to rise (Figure 2) and fossil fuels have provided the major share of the incremental growth over the past decade, accounting for more than 80 per cent of the increase in energy consumption (IEA 2012b).
The largest global source of fossil fuel emissions comes from coal-fired power plants, with around 9 Gt of CO₂ emitted in 2011. Coal is the most abundant fossil-fuel resource worldwide. Recoverable reserves can be found in 70 countries or more, with sufficient reserves for 150 years of generation at current global consumption rates. Between 2000 and 2009, growth in coal consumption far exceeded the combined increase of all non-fossil energy sources (IEA 2012b). Despite the very strong growth in non-fossil energy generation, its share of total generation has declined.

As climate change is driven by the stock of GHGs in the atmosphere, even if all anthropogenic CO₂ emissions were to cease tomorrow, climate change has already begun and effects will still be seen long into the future. The global challenge is to enact policies that result in emissions peaking in the near future and rapidly reducing thereafter (Figure 3). In December 2010, the 16th session of the Conference of the Parties (COP 16) to the UNFCCC approved a non-legally binding commitment to cap global average temperature rises to 2°C. A 2°C rise will still result in rising sea levels, and increased frequency of extreme weather events, including increased drought and flooding (Stern 2009). Limiting the increase in the stock of CO₂ in the atmosphere to 1000 Gt this century will give a 50 per cent chance of limiting to 2°C (Meinshausen, et al. 2009). Achieving this constraint on carbon emissions requires energy-related CO₂ emissions to fall to zero by 2075 (IEA 2012b).
FIGURE 3 CO₂ concentration, temperature and sea level changes after emissions are reduced

<table>
<thead>
<tr>
<th>Magnitude of response</th>
<th>Time taken to reach equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions peak:</td>
<td>Sea-level rise due to ice melting:</td>
</tr>
<tr>
<td>0 to 100 years</td>
<td>several millennia</td>
</tr>
<tr>
<td></td>
<td>Sea-level rise due to thermal expansion:</td>
</tr>
<tr>
<td></td>
<td>centuries to millennia</td>
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<tr>
<td></td>
<td>Temperature stabilisation:</td>
</tr>
<tr>
<td></td>
<td>a few centuries</td>
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<tr>
<td></td>
<td>CO₂ stabilisation:</td>
</tr>
<tr>
<td></td>
<td>100 to 300 years</td>
</tr>
<tr>
<td></td>
<td>CO₂ emissions</td>
</tr>
</tbody>
</table>

Source: IPCC (2001). Note that the vertical axis on this graph is qualitative and separate lines cannot be compared with each other as they relate to different units (changes in CO₂ emissions, CO₂ concentration, temperature, and sea level).

The total costs over time of avoiding the global average temperature rising beyond 2°C is estimated to be around 3–4 per cent of a single year’s value of global economic output (IPCC 2007b, Stern 2008). This would delay the increase in global prosperity by around a year over the medium to long term (Figure 4). The total benefits of managing the risks of climate change are estimated to be well in excess of this cost (Stern 2007).

FIGURE 4 Modest economic impact from taking action


Reducing GHG emissions requires fundamental changes to society, including the way electricity is generated, industrial systems operate, and how people and goods travel. These changes include developing more renewable energy sources, switching to less carbon-intensive fuels and generally being more energy efficient. These alternative energy generation technologies include solar thermal, biomass, geothermal, wind, and tidal. However, as fossil fuels are expected to continue to be widely used in the coming decades, something must be done to reduce the emissions resulting from their use.

CCS can make an essential contribution to the overall GHG reduction effort by reducing the emission of CO₂ from industries and power stations that use fossil fuels (see box). Most of the technologies needed for CCS are already being used extensively in a variety of industries, but are yet to be widely applied to power generation and industry at a commercial scale. There are also industries, such as iron and steel manufacturing, and cement production, where CCS is often the only solution for substantial emission reductions.
CCS is the long-term isolation of fossil fuel CO₂ emissions from the atmosphere through capturing and storing the CO₂ deep in the subsurface of the Earth.

CCS is made up of three key stages.

1. **Capture**: Carbon capture is the separation of CO₂ from the other gases produced when fossil fuels are burnt for power generation and when CO₂ is produced in other industrial processes.

2. **Transport**: Once separated, the CO₂ is compressed and transported to a suitable site for geologic storage.

3. **Storage**: At its storage site, CO₂ is injected into deep underground rock formations, often at depths of 1 km or more.

1: Capturing the CO₂

Capturing CO₂ emissions from industrial processes is easiest at large plants where for example CO₂-rich flue gas can be processed at the facility.

The separation of CO₂ is already performed in a number of standard industrial processes. For example, in natural gas production, CO₂ is separated from the natural gas during processing. Similarly, in industrial plants that produce ammonia or hydrogen, CO₂ is removed as part of the process.

As the largest contribution to CO₂ emissions is from the burning of fossil fuel, particularly in producing electricity, three main processes are being developed to capture CO₂ from power plants that use coal or gas. These are:

- post-combustion capture;
- pre-combustion capture; and
- oxyfuel combustion capture.

In other industries, such as in steel mills and cement plants, capture processes have not yet been developed at a large scale, but in each case an existing capture method could be tailored to suit the particular production process. For instance, collection of CO₂ from cement plants uses post-combustion capture, and collection from modified steel manufacturing processes uses a type of oxyfuel combustion.

2: Transporting the CO₂

Once separated, the CO₂ is compressed to make it easier to transport and store. It is then transported to a suitable storage site. Today, CO₂ is already being transported by pipeline, by ship, and by road tanker – primarily for use in industry or to recover more oil and gas from oil and gas fields. The scale of transportation required for widespread deployment of CCS is far more significant than at present, and will involve the transportation of CO₂ in a dense phase.

3: Storing the CO₂

The final stage of the CCS process sees the CO₂ injected into deep underground rock formations, often at depths of 1 km or more (Figure 5). At this depth, the temperature and pressure keep the CO₂ as a dense fluid. The CO₂ slowly moves through the porous rock, filling the tiny spaces known as pore space.

Appropriate storage sites include depleted oil fields, depleted gas fields, or rock formations which contain water with a high level of salinity (saline formations). These storage sites generally have an impermeable rock (also known as a ‘seal’ or ‘cap rock’) above them. The seal and other geologic features prevent the CO₂ from returning to the surface.

These types of sites have securely contained fluids and gases for millions of years, and with careful selection, they can securely store CO₂ for just as long.

Once injected, a range of sensing and monitoring technologies are used to monitor the CO₂’s movement and changes within the rock formations. Monitoring, reporting and verification processes are important for the project performance management and to assure the public and regulators that the CO₂ is safely stored.

Finding appropriate storage sites requires the collection of a great deal of data, and takes significant time and effort. Many economies around the world have active programs to identify storage sites for CO₂, including the US, Canada, China, South Africa, Australia and Europe.
FIGURE 5 Geologic storage options for CO₂

Geological Storage Options for CO₂
1. Depleted oil and gas reservoirs
2. Use of CO₂ in enhanced oil recovery
3. Deep unused saline water-saturated reservoir rocks
4. Deep unmineable coal seams
5. Use of CO₂ in enhanced coal bed methane recovery
6. Other suggested options (basalts, oil shales, cavities)
THE ROLE OF CCS

CCS has a key role amongst a portfolio of emission reductions technologies. The IEA (2012b) has developed scenarios to examine pathways to achieve energy emission reductions under a range of assumptions. Central to the changes required to cut energy-related CO₂ emissions in half by 2050 are three key strategies:

- creation of a smarter, more flexible, decentralised energy system;
- improved energy efficiency; and
- transformation of electricity generation.

The first two items directly target decoupling of energy consumption and economic activity in seeking to use a wider variety of energy providers and to do so in both technologically and behaviourally more efficient ways. But it is the decarbonisation of the electricity system by 2050 that is the most important technological change required, and here CCS has a fundamental role, together with renewable and nuclear technologies.

CCS is the only technology currently available or on the horizon (later this century) that can decarbonise sectors such as cement, or iron and steel. The IEA notes that emission reductions in these sectors need to commence shortly, but complete decarbonisation will require increased penetration of the use of electricity into these sectors (as well as transport), reinforcing the importance of the technological transformation of electricity generation in the first place.

In order to decarbonise electricity generation by 2050, as well as making significant progress in decarbonising industrial emissions, the IEA identified the portfolio of low-carbon technologies required to achieve this at least cost (Figure 6). In the absence of countries implementing further climate change policies, energy-related emissions could nearly double from 31.5 Gt in 2009 to 58 Gt by 2050. Reducing energy-related emissions to 16 Gt by 2050 requires large investments in CCS and in renewable and nuclear technologies, as well as significant, but achievable, improvements in energy efficiency.

**FIGURE 6 Energy-related CO₂ emission reductions by technology**

![Energy-related CO₂ emission reductions by technology](image_url)

Source: IEA (2012b).

Note: Percentages represent share of cumulative emissions reductions to 2050. Percentages in brackets represent share of emissions reductions in the year 2050.
The scenario that incurs the lowest overall cost identifies CCS accounting for 14 per cent of the total 850 Gt reduction in energy-related CO₂ emissions by 2050. The total amount of CO₂ sequestered by CCS technologies through to 2050 in this scenario is around 123 Gt, with 70 per cent captured from the power sector and 30 per cent from industrial applications such as gas processing, fertiliser production and cement manufacture. However, as electricity generation must be decarbonised by 2050, the growth of CCS in this sector slows towards the end of this period, whereas CCS activities continue to increase in the industrial sector (Figure 7). Overall, the role of CCS grows over time as the required reduction in total CO₂ emission increases, requiring increasing action in the industrial sector.

FIGURE 7 CO₂ capture by sector and region

By 2050, the role of CCS in decarbonising energy emissions is evenly split between capturing emissions in the power sector and in industry. Although the deployment of CCS occurs in Organisation for Economic Co-operation and Development (OECD) member countries initially, it is non-OECD countries where CCS has a larger role. This is because these countries experience higher rates of economic growth with development over the long term and as industrial activities in particular increase at a much faster rate in those countries. By 2050, in the scenarios modelled by the IEA, non-OECD countries should account for 70 per cent of CO₂ captured and stored securely.

If CCS were to be excluded as a technology option in the electricity sector, the IEA states that investment costs over the period would increase by 40 per cent, or approximately US$3 trillion, because they will draw on relatively more expensive abatement options to provide electricity. Minimising the resources required to reduce emissions makes it easier and more affordable for all countries to undertake the task, including developing economies. Importantly, it means more resources for other key social and economic tasks such as improving health outcomes, developing skills, and reducing poverty.

As CCS is currently the only technology available to support the complete decarbonisation of the production of industrial products such as iron and steel or cement, if it were not available to these sectors then it is unclear whether industrial use of energy could be completely decarbonised at all.
1.3

SCOPE OF REPORT

It is clear that CCS as a low-carbon technology can significantly reduce CO₂ emissions and help mitigate climate change. The Global CCS Institute’s mission is to accelerate the demonstration and deployment of CCS globally, to bring forward the technology’s potential. This annual *Global Status of CCS* report provides a comprehensive reference source on the status of CCS and measures progress that has occurred in CCS over the past year. This includes showcasing project, policy and other developments as well as highlighting challenges still to be addressed.

To accelerate and monitor the development of CCS, many aspects must be addressed – from the policy environment through to technical challenges. This report covers these key aspects across separate chapters while making the link and dependencies across these areas apparent.

The results from the Global CCS Institute’s annual project survey are featured in Chapter 2. The Institute undertakes the most comprehensive annual global survey of CCS projects with the aim of providing a global overview of CCS projects which are intended to demonstrate the technology at a large scale. A critical mass of these large-scale projects is needed in the short term to demonstrate the integrated application of CCS technologies.

Chapter 3 analyses the business case for a project, one in which the necessary strategic and financial information is presented to make and monitor a decision about whether the investment should proceed. This information includes many factors – from government support to the confidence in the technology.

Key developments in the area of policy, legislation and regulation are presented in Chapter 4. It is of high importance that national policy settings in all key countries are conducive to CCS demonstration. Developing countries have additional challenges when implementing CCS and are separately addressed in Chapter 5.

Chapters 6, 7 and 8 then discuss the progress and challenges that have been made in capture, transport, and storage respectively. Chapter 9 discusses the use of CO₂ EOR. This chapter presents the role CO₂ EOR may play in CCS, along with some of the technical and legal aspects of CO₂ in EOR relative to carbon storage, and describes the economic, commercial, and regulatory landscape influencing these operations.

Finally, in Chapter 10 (on public engagement), interesting trends in the annual project survey data are identified and reflected, focusing on best practice outcomes emerging from early demonstration projects and applied social research.
2.1 An overview of large-scale integrated CCS projects 16
2.2 Key project developments in 2012 20
2.3 Regional developments 22
2.4 Detailed project breakdown 29
2.5 Demonstration of large-scale integrated CCS projects 38
The Global CCS Institute identified 75 large-scale integrated CCS projects globally, as at September 2012, a net increase of one project since the release of the *Global Status of CCS: 2011* report.

Nine newly-identified projects were added to the listings and another eight projects were removed due to being cancelled, put on hold, or restructured. The reasons for cancellation or being put on hold are diverse and range from insufficient revenues for carbon sales to inadequate storage regulations.

More than half of all newly-identified large-scale integrated projects are located in China. All newly-identified projects are investigating EOR options, at least as an additional source of revenue.

In general, moderate progress was made by projects this year, with those at the more advanced planning stages making the most progress. There have been two additional projects identified as under construction, in the US and in Canada.

The first peak in large-scale projects coming online that was expected to occur in 2015–16 has shifted over the past two years and is now projected to start from 2018–20.

The Global CCS Institute’s monitoring and analytic efforts are focused on LSIPs, as projects at this scale constitute a reliable indicator of the demonstration of CCS technology globally, and have the critical mass needed to achieve substantial reductions in CO₂ emissions.

This chapter provides an overview of the current status of LSIPs globally, as well as key developments that have occurred since the release of the *Global Status of CCS: 2011* report, released in October 2011. This analysis is based on the Global CCS Institute’s annual survey undertaken from March to June 2012, and includes comparisons with the Global CCS Institute’s 2011, 2010, and 2009 *Global Status of CCS* reports (Global CCS Institute 2011a, 2011b, and WorleyParsons et al. 2009). The projects survey process is described at Appendix A and a detailed explanation of the stages in the asset lifecycle of a project is included at Appendix B.

LSIPs are defined as projects involving the capture, transport and storage of CO₂ at a scale of:

- at least 800,000 tonnes of CO₂ annually for a coal-based power plant; or
- at least 400,000 tonnes of CO₂ annually for other emission-intensive industrial facilities (including natural gas-based power generation).

The thresholds listed above correspond to the minimum volumes of CO₂ typically emitted by commercial-scale power plants and other industrial facilities. Projects at this scale must store anthropogenic CO₂ permanently in geologic storage sites to qualify as LSIPs, and projects that involve EOR using anthropogenic CO₂ can also satisfy this definition. Since there is currently no clear standard or regulatory guidance on monitoring requirements involving CO₂ storage associated with EOR, criteria regarding monitoring expectations for CO₂ EOR are not included in the current LSIP definition. Generally, CO₂ EOR projects will undertake some monitoring and the monitoring methods will be site-specific.

This definition of LSIPs will be regularly reviewed and adapted as CCS matures; as clear CCS legislation, regulation, and standards emerge; and as discussions progress on project boundaries, lifecycle analysis, and acceptable use of CO₂.

Additionally, there are many projects around the world of a smaller scale (or which focus on only part of the CCS chain) that are important for research and development (R&D), for demonstrating individual elements of CCS and building local capacity. A sample of such projects that were included in the Institute’s project survey this year is provided at Appendix A.
2.1

AN OVERVIEW OF LARGE-SCALE INTEGRATED CCS PROJECTS

The Global CCS Institute has identified 75 LSIPs as at September 2012. 16 of these are currently operating or in construction (‘Execute’), with a combined capture capacity of around 36 million tonnes per annum (Mtpa) of CO2. A further 59 LSIPs are in the planning stages of development (‘Identify’, ‘Evaluate’, and ‘Define’), with an additional potential capture capacity of more than 110 Mtpa (Figure 8). A map of the LSIPs is displayed at Figure 9, where the projects are identified by a reference number that corresponds to the detailed project listing in Appendix C.

There has been a net increase of one LSIP since the release of the Global Status of CCS: 2011 report. Nine new projects were identified while eight were cancelled, put on hold or restructured. An overview of these key project developments is provided in Section 2.2.

FIGURE 8 LSIPs by asset lifecycle and region/country

<table>
<thead>
<tr>
<th>Region/Country</th>
<th>Identify</th>
<th>Evaluate</th>
<th>Define</th>
<th>Execute</th>
<th>Operate</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>0</td>
<td>7</td>
<td>9</td>
<td>4</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>Europe</td>
<td>4</td>
<td>8</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Australia and New Zealand</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Canada</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>China</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Middle East</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Other Asia</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Africa</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>24</td>
<td>21</td>
<td>8</td>
<td>8</td>
<td>75</td>
</tr>
</tbody>
</table>
FIGURE 9 World map of LSIPs

Industry sector
- Power generation
- Synthetic natural gas
- Natural gas processing
- Iron and steel production
- Coal-to-liquids (CTL)
- Chemical production
- Oil refinery
- Enhanced oil recovery (EOR)
- Depleted oil and gas reservoirs
- Deep saline formations
- Various options considered/not specified

LSIPs: GLOBAL
- Hydrogen production
- Natural gas processing

Storage types
- Various options considered/not specified

See North American map for detail
See Europe map for detail
See China map for detail
During the past three years, there has been a slow but steady increase in LSIPs entering construction, as demonstrated in Figure 10. There are now eight LSIPs under construction around the world. These provide examples of viable business cases for CCS technology given specific circumstances. In particular:

- all but one of those LSIPs are found in North America (four in the US and three in Canada), where project proponents benefit from an established CO₂-based EOR market and the availability of substantial public funding;
- only two projects are in the power generation sector (Boundary Dam in Canada and Kemper County in the US), and both include the sale of CO₂ for EOR;
- two have been identified as having started construction since the previous status report (Air Products Steam Methane Reformer EOR Project in the US and Quest in Canada); and
- three include the sequestration of CO₂ in deep saline formations (the Gorgon Carbon Dioxide Injection Project in Australia, Archer Daniels Midland’s (ADM’s) Illinois Industrial CCS (ICCS) project in the US and Quest in Canada).

FIGURE 10 LSIPs by asset lifecycle and year

The Global CCS Institute estimates that up to five additional LSIPs could reach a final investment decision (FID) by the end of 2012 – three of which are located in North America, one in Europe, and one in the Middle East. These are:

- Texas Clean Energy Project in the US;
- NRG Energy Parish Project in the US;
- Alberta Carbon Trunk Line (ACTL) with North West Sturgeon Refinery CO₂ Stream in Canada;
- Rotterdam Opslag en Afgav Demonstratieproject (ROAD) in the Netherlands; and
- Emirates Steel Industries in the United Arab Emirates.

Table 1 lists the 16 LSIPs in the Operate and Execute stages. These projects have a combined capture and storage capacity of approximately 36 Mtpa, equivalent to the emissions of more than seven million cars per year and roughly equivalent to the current annual emissions of Singapore or New Zealand (United Nations Statistics Division 2012). This highlights the significant contribution that CCS can already bring as part of a portfolio of CO₂ abatement technologies.
### TABLE 1 LSIPs in the Operate and Execute stages (‘Active’)

<table>
<thead>
<tr>
<th>NAME</th>
<th>COUNTRY</th>
<th>CAPTURE TYPE</th>
<th>VOLUME CO₂ (MTPA)</th>
<th>STORAGE TYPE</th>
<th>DATE OF OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operate stage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Val Verde Gas Plants</td>
<td>United States</td>
<td>Pre-combustion (gas processing)</td>
<td>1.3 Mtpa</td>
<td>EOR</td>
<td>1972</td>
</tr>
<tr>
<td>Enid Fertilizer CO₂-EOR Project</td>
<td>United States</td>
<td>Pre-combustion (fertiliser)</td>
<td>0.68 Mtpa</td>
<td>EOR</td>
<td>1982</td>
</tr>
<tr>
<td>Shute Creek Gas Processing Facility</td>
<td>United States</td>
<td>Pre-combustion (gas processing)</td>
<td>7Mtpa</td>
<td>EOR</td>
<td>1986</td>
</tr>
<tr>
<td>Sleipner CO₂ Injection</td>
<td>Norway</td>
<td>Pre-combustion (gas processing)</td>
<td>1 Mtpa (+0.2 Mtpa in construction)</td>
<td>Deep saline formation</td>
<td>1996</td>
</tr>
<tr>
<td>Great Plains Synfuel Plant and Weyburn–Midale Project</td>
<td>United States/Canada</td>
<td>Pre-combustion (synfuels)</td>
<td>3 Mtpa</td>
<td>EOR</td>
<td>2000</td>
</tr>
<tr>
<td>In Salah CO₂ Injection</td>
<td>Algeria</td>
<td>Pre-combustion (gas processing)</td>
<td>1 Mtpa</td>
<td>Deep saline formation</td>
<td>2004</td>
</tr>
<tr>
<td>Snøhvit CO₂ Injection</td>
<td>Norway</td>
<td>Pre-combustion (gas processing)</td>
<td>0.7 Mtpa</td>
<td>Deep saline formation</td>
<td>2008</td>
</tr>
<tr>
<td>Century Plant</td>
<td>United States</td>
<td>Pre-combustion (gas processing)</td>
<td>5 Mtpa (+ 3.5 Mtpa in construction)</td>
<td>EOR</td>
<td>2010</td>
</tr>
<tr>
<td><strong>Execute stage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Products Steam Methane Reformer EOR Project</td>
<td>United States</td>
<td>Post-combustion (hydrogen production)</td>
<td>1 Mtpa</td>
<td>EOR</td>
<td>2012</td>
</tr>
<tr>
<td>Lost Cabin Gas Plant</td>
<td>United States</td>
<td>Pre-combustion (gas processing)</td>
<td>1 Mtpa</td>
<td>EOR</td>
<td>2012</td>
</tr>
<tr>
<td>Illinois Industrial CCS Project</td>
<td>United States</td>
<td>Industrial separation (ethanol)</td>
<td>1 Mtpa</td>
<td>Deep saline formation</td>
<td>2013</td>
</tr>
<tr>
<td>ACTL with Agrium CO₂ Stream</td>
<td>Canada</td>
<td>Pre-combustion (fertiliser)</td>
<td>0.59 Mtpa</td>
<td>EOR</td>
<td>2014</td>
</tr>
<tr>
<td>Boundary Dam Integrated CCS Demonstration Project</td>
<td>Canada</td>
<td>Post-combustion (power generation)</td>
<td>1 Mtpa</td>
<td>EOR</td>
<td>2014</td>
</tr>
<tr>
<td>Kemper County IGCC Project</td>
<td>United States</td>
<td>Pre-combustion (power generation)</td>
<td>3.5 Mtpa</td>
<td>EOR</td>
<td>2014</td>
</tr>
<tr>
<td>Gorgon Carbon Dioxide Injection Project</td>
<td>Australia</td>
<td>Pre-combustion (gas processing)</td>
<td>3.4–4.1 Mtpa</td>
<td>Deep saline formation</td>
<td>2015</td>
</tr>
<tr>
<td>Quest</td>
<td>Canada</td>
<td>Pre-combustion (hydrogen production)</td>
<td>1.08 Mtpa</td>
<td>Deep saline formation</td>
<td>2015</td>
</tr>
</tbody>
</table>
2.2

KEY PROJECT DEVELOPMENTS IN 2012

Since the publication of the *Global Status of CCS: 2011* report, there have been significant changes in the number of LSIPs; eight projects from various countries were removed from the Global CCS Institute’s LSIP listing and nine new LSIPs were identified. All newly-identified projects are considering the use of CO₂ for EOR either as a primary or a secondary storage option.

Changes to LSIP listing in 2012

Figure 11 outlines changes in the numbers of LSIPs that have occurred since the release of the *Global Status of CCS: 2010* report. A detailed list of all major changes made to the LSIP listing since 2011 is provided in Appendix A.

FIGURE 11 Changes in LSIPs from 2010 to 2012

Newly-identified LSIPs

Five new early-stage LSIPs were identified in China since 2011, three of which are in the power generation industry. While pre-combustion capture is currently the most frequently-used technology in China, investments in the testing of oxyfuel combustion capture are increasing. All proponents of large-scale CCS projects in China are investigating EOR options, at least as an additional source of revenue.

Newly identified LSIPs in China are listed below.

- **Daqing Carbon Dioxide Capture and Storage Project** (Identify stage) – a super-critical coal-fired power plant that would capture around 1 Mtpa of CO₂ through oxyfuel combustion, developed by the China Datang Group in partnership with Alstom.
- **Dongying Carbon Dioxide Capture and Storage Project** (Identify stage) – a new build coal-fired power generation plant with a planned capture capacity of 1 Mtpa of CO₂, also developed by the China Datang Group.
- **Shanxi International Energy Group CCUS Project** (Identify stage) – a new, super-critical coal-fired power plant with oxyfuel combustion being developed in partnership with Air Products, with a capture capacity of more than 2 Mtpa of CO₂.
- **Jilin Oil Field EOR Project (Phase 2)** (Identify stage) – EOR operations at the Jilin oil field, where around 200,000 tpa of CO₂ from a natural gas processing plant are currently being injected, are scheduled to be expanded to more than 800,000 tpa from 2015.
- **Shen Hua Ningxia Coal to Liquid Plant Project** (Identify stage) – a new build coal-to-liquids (CTL) facility developed that would capture around 2 Mtpa of CO₂, it is one of three LSIPs developed by the Shenhua Group.
A further four new LSIPs were identified in other countries, all in the power generation industry.

- **Caledonia Clean Energy Project** (UK, Identify stage) – a new build integrated gasification combined cycle (IGCC) power plant proposed by Summit Power that would capture up to 90 per cent of the plant’s CO₂ emissions, possibly for use in EOR in the North Sea. The project will be proposed for funding under the UK’s £1 billion CCS competition.
- **Sargas Green Power Plant Malta** (Malta, Identify stage) – a new build fluidised bed boiler power plant that would capture around 1.2 Mtpa of CO₂ from two 180 MWe modules for use in EOR.
- **Industrikrift Möre AS Norway** (Norway, Identify stage) – a new build natural gas-based power plant planned to capture more than 1.4 Mtpa from 2016.
- **NRG Energy Parish CCS Project** (US, Define stage) – retrofit of post-combustion CO₂ capture from a 240 MWe process stream at a sub-critical coal-fired power plant, planned to capture around 1.5 Mtpa of CO₂ for use in EOR by mid-2015.

**Projects removed from LSIP listing**

Eight projects at various stages of development were removed from the LSIP listing since 2011.

- **Longannet Project** (UK, Define stage) – cancelled in October 2011, following an announcement by the UK Department of Energy and Climate Change that it would not fund the construction of the CO₂ capture facilities.
- **Vattenfall Jänschwalde** (Germany, Define stage) – cancelled in December 2011, citing the lack of government support and the absence of a clear legal framework.
- **Sweeny IGCC Power Project** (US, Evaluate stage) – cancelled in April 2012 following the split of ConocoPhillips Company and Phillips 66 Company.
- **Project Pioneer** (Canada, Define stage) – cancelled in April 2012 citing the insufficient price of emissions reductions and revenue from carbon sales.
- **Coolimba Power Project** (Australia, Identify stage) – removed in May 2012 after the proponent confirmed it had reprioritised its investments.
- **Good Spring IGCC** (US, Identify stage) – EmberClear announced the project was restructured as a natural gas combined cycle (NGCC) plant in May 2012, with CCS plans at the site being put on hold.
- **Peel Energy CCS Project** (UK, Evaluate stage) – Ayrshire Power withdrew its planning application for the new Hunterston power plant in June 2012, thereby putting the project on hold.
- **Browse Reservoir CO₂ Geosequestration Project** (Australia, Evaluate stage) – removed August 2012 after the proponent had confirmed that it had put the project on hold.

Additional details on some of these projects are provided in Section 2.3.

**Project progress**

Moderate progress was made by LSIPs this year, with projects at the Define stage advancing the most. Of the 24 LSIPs that were at the Define stage last year, nine indicated their front end engineering design (FEED) study was 76–100 per cent complete in the Institute’s annual survey, with a further two indicating a 50–75 per cent completion. In a positive development, two of these LSIPs, both in the hydrogen production industry, moved to the Execute stage.

- **Construction of Air Products’ new build hydrogen plant in Texas started in August 2011 and the plant is expected to become operational by the end of 2012. Around 1 Mtpa of CO₂ will be captured and used in EOR.**
- **On 5 September 2012, Shell Canada announced it would go ahead with its Quest project in Alberta. This followed the formal approval of the project by the Energy Resources Conservation Board (ERCB) in July 2012. More than 1 Mtpa of CO₂ will be captured from hydrogen manufacturing units at the Scotford Upgrader near Edmonton, and transported by underground pipeline for injection into a 2 km deep saline formation. In October 2011, the project’s storage development plan was awarded the world’s first certificate of fitness for safe CO₂ storage by Det Norske Veritas (DNV).**

Five additional projects currently in the Define stage could reach FID by end of 2012 or early 2013. Notable developments that occurred in the past year for three of these projects are listed below.

- **A storage permit was obtained in March 2012 for the ROAD project in the Netherlands. This was the first CO₂ storage permit of this kind applied for under the European Union’s CCS Directive, and is an encouraging precedent for other projects that included the planned storage of CO₂ offshore in the North Sea.**
- **Progress on Summit Power’s Texas Clean Energy Project in the US has been steady since a long-term CO₂ sales agreement was signed with Whiting Petroleum Corporation last year. A Record of Decision (ROD) was issued by the US Department of**
Energy (DOE) regarding the funds allocated to the Texas Clean Energy Project in October 2011. This ROD formally allows public funds previously allocated to the project to be spent beyond engineering and design studies. In addition, all key permits and off-take agreements are now in place and both the Engineering, Procurement and Construction (EPC) and the Operation and Maintenance (O/M) contracts have been signed. The recently announced introduction of major new project participants and signing of a memorandum of understanding (MoU) with Sinopec Energy and the Export-Import Bank of China to advance and help assure the financing for the project supports the view that this project may reach final investment decision (FID) by the end of 2012.

- In Abu Dhabi, Emirates Steel Industries' CCS project is set to become the Gulf's first large-scale project in operation after Abu Dhabi National Oil Company (ADNOC) and Masdar signed a formal agreement in January 2012, concluding three years of negotiations. In May 2012, ADNOC also announced it was investigating offshore CO2 EOR options, which could lead to further storage opportunities for Abu Dhabi's CCS projects in development.

Further to this, two projects that were at the Evaluate stage last year made significant progress and moved up to the Define stage of the asset lifecycle.

- 2Co Energy's Don Valley Power Project in the UK progressed following the appointment of legal and financial advisers to assist with the delivery of the project, which is expected to be commissioned in 2016. FEED studies have now been completed and a capture technology provider has been selected (Linde Gas). The project, which has attracted investment from Samsung C&T and the BOC Group, has a strong chance of reaching FID in 2013, especially as it was announced to be the front runner in the European Union’s NER300 funding competition in July 2012.

- Swan Hills Synfuels A ‘In Situ Coal Gasification/Power Generation Project’ in Canada, with a detailed FEED study under way and a capture technology provider selected. Negotiations for the CO2 off-take agreements are at the advanced stages and the project could reach FID by the end of 2013.

For the 34 remaining projects that were at the Evaluate or Identify stages last year, overall progress has been more limited. Around 15 of these projects were more than halfway through pre-feasibility studies last year; three are now cancelled, with the remaining projects reporting no significant progress, or in some cases a regression.

### 2.3 REGIONAL DEVELOPMENTS

#### North America

**Canada**

Canada continues a robust large-scale CCS demonstration program (Figure 12), which includes:

- the Great Plains/Weyburn–Midale project, which continues to inject around 3 Mtpa of CO2 for EOR;
- three LSIPs that are in construction (Execute stage), SaskPower’s Boundary Dam project, Enhance Energy’s Alberta Carbon Trunk Line (ACTL) with Agrium and Shell’s Quest; and
- two projects (Enhance Energy’s ACTL with Northwest Sturgeon Refinery and Swan Hills Synfuels) that may be in a position to progress to a FID in 2012-13.

Following the formal approval issued by the ERCB regarding Shell’s Quest project in July 2012, Shell Canada announced on 5 September 2012 that it would go ahead with the project. The project is scheduled to come online in 2015 and will capture more than 1 Mtpa of CO2 for injection into an onshore deep saline formation. Meanwhile, in April 2012, TransAlta announced the cancellation of its Project Pioneer, noting that while costs and technology performance were as expected, the potential revenue from CO2 sales and offset credits were insufficient to justify the project at the current time.

At the pilot scale, Husky Energy Inc. announced in May 2012 that it had started operations at its ethanol plant in Lloydminster, Alberta. Around 90,000 tpa of CO2 will be captured at the plant and transported by truck to enhance recovery in Husky’s heavy oil projects.
Industry sector Storage type

- Power generation
- Natural gas processing
- Synthetic natural gas
- Fertiliser production
- Hydrogen production
- Coal-to-liquids (CTL)
- Chemical production
- Oil refinery

- Deep saline formations
- Enhanced oil recovery (EDR)
- Various options considered/not specified

FIGURE 12 North America map of LSIPs
In April 2012 the formation of the Canadian Oil Sands Innovation Alliance was announced. This group of 12 major oil sands developers has the objective of mitigating the environmental impact of oil sands projects and has identified GHG emission reductions as one of the four main areas of focus for the Alliance, with CCS expected to play an important role. In Alberta, the Regulatory Framework Assessment project, which aims to develop world class regulations for all elements of CCS, is expected to report its recommendations to the Alberta Minister of Energy by the end of 2012.

**UNITED STATES**

The US continues to be the country with the largest number of LSIPs, with 24 active and planned projects (Figure 12). The US also has the largest number of active projects, with four projects in operation and four in construction (Execute stage). In addition, the US has the most advanced portfolio of projects. All of the 16 US projects in planning are either at the Evaluate or Define stage, and their continued progress over past years is largely driven by domestic demand for CO₂ for use in EOR. One LSIP, the Good Spring IGCC project in Pennsylvania (Identify stage) was removed from the Institute’s LSIP listings in June 2012 after its proponent, EmberClear Corporation, announced the project was restructured from a coal-based IGCC to a natural gas-based combined cycle plant (NGCC) without CCS.

The US DOE is providing financial assistance to five power and three industrial LSIPs (see section 3.3). This includes funding to three of the projects which are under construction. The Air Products Steam Methane Reformer EOR Project; the Illinois-ICCS project; and the Kemper County IGCC Project are expected to begin operations in 2012, 2013, and 2014 respectively.

In addition, the DOE is continuing to support nine large-volume (≥1 Mt) CO₂ injection tests under seven Regional Carbon Sequestration Partnerships. The Southeast Regional Carbon Sequestration Partnership (SECARB) began injection in Mississippi in 2009, and the Midwest Geologic Sequestration Consortium (MGSC) began injection in Illinois in November 2011. The majority of current US LSIPs include the planned use of the captured CO₂ for EOR, which is reflective of the improved economics of utilisation coupled with storage. The DOE’s integrated coal program technology roadmap is based on continuous technology development, designed to reduce the cost of capture and establish the safety and efficacy of CO₂ storage.

**China**

China continues to take a systematic approach to the deployment of CCS, focusing on research and development followed by the roll out of pilot projects and demonstration projects. Seven of these projects have been included in the Institute’s 2012 annual survey and are listed at Appendix A. Progress has been made with the successful demonstration of smaller-scale pilot projects. As evidenced by the growing number of planned LSIPs, government and industry recognise the importance of CCS for the country’s energy future (Figure 13). The growing number of proposals involving CO₂ utilisation and EOR highlight the commercial challenges faced by projects and the importance of establishing a business case for CCS. Cross-sectoral collaboration also remains a challenge for CCS project developers, particularly for power generators that do not have access to a suitable CO₂ storage site.

Material changes since the release of the *Global Status of CCS: 2011* report include the identification of five new LSIPs, as discussed previously in this chapter. There are now 11 LSIPs in China which are all in the early development stages (nine in Identify and two in Evaluate). Most of these projects involve major state-owned power, oil, or coal companies, as well as a wide array of international partners.

China Datang Corporation is a large state-owned power generation enterprise whose project, the Datang Daqing Oxyfuel Combustion CCS Demo, was added to the Institute’s LSIP listing in December 2011. Datang Heilongjiang Power Generation Co Ltd (a subsidiary of China Datang Corporation) is developing this new-build super-critical coal-fired power plant near Daqing city in Heilongjiang province. Around 1 Mtpa of CO₂ is planned to be captured through oxyfuel combustion from one of two 350 MWe cogeneration of heat and power units at the plant. Options for the storage of CO₂ include deep saline formations and the use of CO₂ for EOR in nearby oil fields.

In addition to the Daqing CCS project, Datang intends to build a 1000 MW coal-fired power plant in Shandong province. In November 2011 Alstom signed an agreement with Datang for Alstom to develop the CCS facilities, including feasibility studies. This project plans to capture 1 Mtpa of CO₂ from 2020.

In another newly identified LSIP this year, the Shanxi International Energy Group (SIEG) intends to build a 350 MW oxyfuel combustion power plant with CO₂ capture, utilisation, and storage facilities. Air Products has been awarded a contract from SIEG to perform a feasibility study and detailed cost estimates this year. The project plans include the capture of 2 Mtpa CO₂ using Air Products’ oxyfuel CO₂ purification technology.

The China National Petroleum Company (CNPC) continues demonstration of small-scale operations. CNPC’s project has seen the pilot plant of the Jilin oil field successfully inject around 200,000 tpa of CO₂ from a natural gas processing facility for EOR by the end of 2011. The planned next phase is to expand capacity to 0.8–1 Mtpa by 2015 (WorleyParsons 2012).
FIGURE 13 China map of LSIPs

LSIPs: CHINA

Industry sector

- Power generation
- Natural gas processing
- Coal-to-liquids (CTL)
- Chemical production

Storage type

- Deep saline formations
- Enhanced oil recovery (EOR)
- Depleted oil and gas reservoirs
- Various options considered/not specified

Power generation
Natural gas processing
Coal-to-liquids (CTL)
Chemical production

Deep saline formations
Enhanced oil recovery (EOR)
Depleted oil and gas reservoirs
Various options considered/not specified

Map of China showing LSIPs with different markers for industry sectors and storage types.
Europe

There have been many developments in Europe since 2011 which clearly illustrate the role governments and other public bodies can play in influencing the progress of technology (Figure 14).

In the UK, there was broad and strong political support for CCS, the transposition of the European Union’s (EU) CCS Directive, and the re-launch of its £1 billion CCS competition, even though two projects were cancelled (Longannet and Peel Energy). In Germany, the transposition of the CCS Directive was much delayed, resulting in a draft law with more restrictive conditions and financial support more limited to research activities. As a result, one of Europe’s most advanced CCS demonstration projects, Vattenfall’s Jänschwalde project, was cancelled and withdrawn from the EU’s New Enterants’ Reserve 300 (NER300) funding program.

In April 2012, the UK re-launched its CCS competition – a ‘CCS Commercialisation Programme’ – with £1 billion of funding to support upfront costs and additional support through ‘low carbon contracts for difference’. The competition closed to bids in July 2012 and it is widely expected that the five projects remaining in the NER300 program have placed bids. The new competition was open to both solid and gas-fired electricity generators and industrial CO₂ emitters. Storage is to be offshore and the plants are to be commercial scale and operational by 2020. A further £125 million would be available for a CCS research and innovation program.

For other European countries involved in CCS activities, the main focus of interest has continued to be the ECs NER300 program. There are still 10 candidate projects in this competition and the release by the Commission of a Working Document setting out the ‘current order of selection’ and a reserve list in July 2012 fuelled increased discussion around this program. The first project on the list is the Don Valley IGCC project (UK) followed by the Bełchatów CCS project (Poland). Both of these projects could expect to receive NER300 co-funding, subject to the availability of sufficient other funds to cover the remaining 50 per cent of the costs of the CCS part of their project and the confirmation of co-funding by their Member State. A third project, the Air Liquide industrial application Green Hydrogen CCS project (the Netherlands), may also be funded. A final decision on project funding will be taken towards the end of 2012. In the meantime, the Commission continues to strongly advocate CCS as an important part of its low-carbon economy future.

The NER300 program has been impacted by the low carbon price over recent months during the period when the European Investment Bank (EIB) tendered the first 200 million allowance units to fund the program. As a result, less money has been raised than expected. Funding is presently estimated to be between €1.3–1.5 billion, a portion of which will also be spent on innovative renewable energy projects.

Two major LSIPs outside the NER300 program, the ROAD project in the Netherlands and the OXYCFB 300 Compostilla project in Spain have made progress. The ROAD project received a positive opinion by the European Commission concerning its planned storage site (the first such opinion applied for under the CCS Directive), while the Compostilla project made progress in developing its geologic storage sites in the Duero Basin, both in the area of Sahagún for the commercial storage site and at the underground laboratory site of Hontomín.

Furthermore, there have been significant technological developments, including the opening of the TCM in May 2012. There has been a marked increase in interest in the possible application of CCS to a number of bio-energy projects that could lead to the development of carbon-negative projects in the future, in particular in the Baltic region and Romania.

Despite the progress made, the EC policy objective of having up to 12 commercial-scale demonstration plants operating in Europe by 2015 is no longer achievable, with 4–5 projects operating in the next 5–6 years being a more realistic scenario.
FIGURE 14 Europe map of LSIPs

LSIPs: EUROPE

Industry sector
- Power generation
- Natural gas processing
- Hydrogen production
- Iron and steel production

Storage type
- Deep saline formations
- Enhanced oil recovery (EOR)
- Depleted oil and gas reservoirs
- Various options considered/not specified

Europe map highlighting LSIPs with markers for different industry sectors and storage types.
Middle East and North Africa (MENA)

The Middle East has some of the highest per capita emissions of CO₂ in the world. In addition, the region has a number of natural advantages including excellent storage potential and many opportunities for EOR. However, only the United Arab Emirates (UAE) is actively pursuing an interest in CCS.

When announced in 2007, the Masdar CCS Network in Abu Dhabi was the most ambitious CCS project in the world. The project scope was for a fully-integrated network designed to capture approximately 6 Mtpa of CO₂ from five industrial-scale emitters, and transport it through a pipeline network for delivery to the Abu Dhabi National Oil Company (ADNOC) for use in EOR.

The project was expected to capture and store CO₂ from five industrial-scale emitters:

- Emirates Steel Industries (ESI) – capture of 0.8 Mtpa of CO₂ from a dehydration and compression unit at an existing steel plant;
- Emirates Aluminium (EMAL) – capture of 2 Mtpa of CO₂ from an existing natural gas-based power plant at an aluminium smelter complex; and
- Hydrogen Power Abu Dhabi (HPAD) – new build hydrogen combined cycle power plant designed to capture 1.7 Mtpa of CO₂ (90 per cent of the plant's emissions).

The Masdar CCS Network is expected to further consider incorporating CCS on its Taweelah Asia Power Co project and the Habshan gas separation plant, however, in the near future will concentrate efforts on the ESI project.

In North Africa, the In Salah project, operational since 2004, continues to inject around 1 Mtpa of CO₂ and play an important role in the research and development of storage monitoring techniques.

Australia and New Zealand

Progress of CCS projects in Australia continues to be dependent on the availability of government funding and there has been measured progress for four Australian LSIPs over the past 12 months.

- In February 2012, the CarbonNet Project received AU$100 million in funding, with AU$70 million as part of the Australian Government’s CCS Flagships program and AU$30 million from the Victorian State Government. The project, which is investigating the potential for capturing CO₂ from electricity generation and new coal-based industries in the Latrobe Valley and storing it within Victoria’s geologic basins, is currently at the Evaluate stage. Extensive research and development is currently being undertaken, including modelling and testing of potential CO₂ storage sites.
- The South West CO₂ Geosequestration (formerly Collie) Hub in Western Australia is currently in the Evaluate stage, focusing on pre-competitive data acquisition. A drilling program to collect data from a 2.9 km deep well in the investigation area was completed in March 2012. In addition, an unincorporated joint venture (UJV) agreement has been finalised by the South West Hub industry partners. The UJV will lead the commercial deployment of the project when it transitions from the pre-competitive data acquisition phase to CO₂ transport and trial injection.
- The Gorgon Project is an AU$43 billion offshore gas development in the Indian Ocean and includes the Gorgon CO₂ Injection Project, which is expected to be operational in 2015. More than 3.4 Mtpa of the separated CO₂ will be injected and stored in the Dupuy Formation over the anticipated 40 year life of the project. This project will be the world’s largest initiative for geologic storage of CO₂.
- The Surat Basin CCS Project (formerly Wandoan) in Central Queensland is currently being restructured. This power generation project with post-combustion capture is scheduled to come online in 2020 and is designed to capture around 1 Mtpa of CO₂ that would be stored in an onshore deep sandstone formation. CO₂ injection testing at the targeted storage site could begin in 2013.

In addition to this, the pilot-scale Callide Oxyfuel Project, an international low-emissions coal demonstration project at the Callide Power Station in Biloela (Queensland), achieved operation of its first boiler in full oxyfiring mode in March 2012. The project has entered an 18-24 month campaign of process testing, which aims to capture 90 per cent of the CO₂ emissions from coal combustion.

Two Western Australian LSIPs were removed from the LSIP listings this year after their respective proponents confirmed that the projects were not being progressed further. The Coolimba Power Project (Identify stage) is considered definitely cancelled after the proponent confirmed no further investment would be made into the project. The Browse Reservoir CO₂ Geosequestration Project (Evaluate) was classified as on hold. While Browse Joint Venture has undertaken geosequestration evaluation studies for the proposed James Price Point development in line with the Browse Retention Lease conditions, these studies have concluded that geosequestration is not currently commercially viable. Geosequestration will be maintained as a potential option for managing carbon from the Browse LNG Development should it become economically and technically viable during the life of the project.

In New Zealand, Solid Energy's Southland Coal to Fertiliser Project includes the capture of around 1 Mtpa of CO₂, that would be stored in onshore deep saline formations. The project could commence operations in 2018.
2.4

DETAILED PROJECT BREAKDOWN

Geographic distribution of LSIPs

The US has the largest number of CCS projects in both the active and planning stages, with half of active LSIPs and more than a quarter of all planned LSIPs (Figure 15). Because LSIPs that were cancelled or put on hold during the past three years have mostly not been followed by the development of new projects, there are now no LSIPs at the earliest stage of development planning (Identify) stage in the US.

Conversely, China has more than doubled its number of planned LSIPs from five to 11 in just two years, and has now overtaken Canada in potential capture capacity (Figure 16). All but two of the Chinese LSIPs, however, are in the Identify stage, particularly for their storage components.

Although the total number of LSIPs in Europe remained the same between 2010–12, six projects which were quite advanced in development planning (Evaluate and Define) have been cancelled or put on hold since 2010 and replaced with new, earlier stage projects.

FIGURE 15 LSIPs by region and year

<table>
<thead>
<tr>
<th>Region</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
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<tr>
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<tr>
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</tr>
<tr>
<td>Canada</td>
<td>10</td>
<td>15</td>
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<tr>
<td>Australia and New Zealand</td>
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<td>Middle East</td>
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<tr>
<td>Other Asia</td>
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<td>3</td>
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</tr>
<tr>
<td>Africa</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Number of LSIPs

2012 | 2011 | 2010
There has been little change in the distribution of LSIPs across industries during the past three years, as demonstrated in Figure 17.

The largest number of projects in the planning stages of development continues to be in the power generation industry, with 40 LSIPs totalling more than 70 Mt in potential CO₂ capture capacity. In addition, only two large-scale power generation projects with CCS are currently being constructed around the world. Three power generation LSIPs could reach FID in 2012–13, two of which are located in the US (Texas), and one in Europe. The paucity of commercial-scale power generation projects with CCS progressing through to construction is likely to continue in the coming years as all cancelled projects in 2011–12 were power projects, with more than half of them being at the most advanced stage of planning development (Define stage). Further to this, national energy and climate change policy frameworks have increasingly favoured natural gas-based rather than coal-based power generation, while low natural gas prices continued to support the business case for natural gas-based power generation.

Planned applications of CCS have slightly increased in the synthetic natural gas, fertiliser, and hydrogen production sectors, while there remains a paucity of CCS projects in other high-emitting industries such as iron and steel production or oil refining. In particular, LSIP cancellations that occurred in these industries over the past three years have not been compensated by new project announcements, and there is still no commercial-scale CCS project being planned in the cement industry, which now represents around 8 per cent of all anthropogenic CO₂ emissions globally (Olivier et al. 2011).
FIGURE 17 LSIPs by industry sector and year

Number of projects

2012 2011 2010

- Power generation
- Natural gas processing
- Synthetic natural gas
- Fertiliser production
- Hydrogen production
- Coal-to-liquids (CTL)
- Chemical production
- Iron and steel production
- Oil refining
- Cement production
- Pulp and paper
- Other

Number of projects
FIGURE 18 Volume of CO₂ captured by industry sector and year

Power generation
- 2012
- 2011
- 2010

Natural gas processing
- 2012
- 2011
- 2010

Other industries
- 2012
- 2011
- 2010

FIGURE 19 LSIPs by industry sector and project structure

Power generation
- New build construction
- Retrofit to existing plant
- Retrofit to plant in construction

Natural gas processing
- New build construction
- Retrofit to existing plant
- Retrofit to plant in construction

Other industries
- New build construction
- Retrofit to existing plant
- New unit at existing plant

Volume of CO₂ (Mtpa)

Number of projects
Figure 18 shows the potential volume of CO₂ captured by industry sector and by survey year, demonstrating an overall decrease in planned capture capacity. In particular, this figure highlights the marked decrease in CO₂ capture capacity in the power generation sector since 2010. While the net number of power generation projects has remained constant since 2010, a number of projects with a large CO₂ capture capacity have been cancelled or put on hold and replaced with smaller projects.

Figure 19 shows the current distribution of LSIPs by industry sector and project structure (new build vs. retrofit). Projects involving the retrofit of CCS technology at an existing plant are progressively being replaced by new-build applications as efficiency and GHG emission regulations become more stringent, particularly for power generation projects. Out of the 17 new LSIPs identified since 2010, only four (less than one-quarter) are retrofit constructions. In contrast, well over one-third of the LSIPs that were cancelled or put on hold since 2010 were retrofit projects.

Distribution of LSIPs by capture technology

The project announcements and cancellations that occurred during the past year have caused a slight shift in the distribution of LSIPs across capture technologies in some regions.

Pre-combustion capture is still the most frequently chosen CO₂ capture technology in North America, with 75 per cent of all projects in both the US and Canada (Figure 20). However, the share of pre-combustion capture has decreased in the US since last year (88 per cent), due to the cancellation of two pre-combustion LSIPs and the announcement of one new post-combustion LSIP.

In 2011, an overwhelming majority (83 per cent) of projects in China included pre-combustion capture. Due to five new LSIPs being announced this year, China’s portfolio of capture technologies in planning has become significantly more balanced, with 40 per cent of projects including pre-combustion capture and the remaining 60 per cent split between all capture technologies.

There has been little change in the distribution of capture technologies in other regions, with pre-combustion being the most widely proposed capture technology in Canada as well as Australia and New Zealand, while post-combustion capture remains the preferred option in Europe, representing 52 per cent of all CCS projects.

**FIGURE 20 LSIPs by capture type and region**

![Graph showing distribution of LSIPs by capture type and region](image-url)
While pre-combustion is still the most frequently chosen capture technology by LSIPs in development planning, with 44 per cent of all planned projects, its share has significantly decreased since last year (55 per cent) as new projects with oxyfuel combustion or industrial separation capture were announced. Post-combustion capture remains the second most frequently chosen technology with around 31 per cent of all planned projects.

In the power generation sector, post-combustion capture is the most widely chosen option, with 45 per cent of all power projects, up by 5 per cent since last year (Figure 21). Pre-combustion capture comes second (33 per cent), followed by oxyfuel combustion capture (14 per cent).

Further details regarding the maturity levels of CO₂ capture technologies can be found in Chapter 6 of this report.

**FIGURE 21 LSIPs by capture type and industry**

![Bar chart showing LSIPs by capture type and industry](chart.png)

**Distribution of LSIPs by transport type**

Pipelines continue to be the primary method chosen for transporting the high quantities of CO₂ associated with CCS. Pipeline transport has been identified in 92 per cent of all LSIPs, with only four projects stating that transportation will occur via shipping. The majority of pipelines are identified as being onshore with offshore pipelines being more common in Europe than in any other region.

Most pipeline projects involve privately owned and operated transportation infrastructure, though 22 per cent of projects with a pipeline transport system use or will use other entities' infrastructure for the carriage of CO₂.

Further details regarding the transport of CO₂ can be found in Chapter 7 of this report.
Distribution of LSIPs by storage type

More than half of all LSIPs include the use of CO₂ for EOR as a primary storage type, this is up 5 per cent since 2011. There has been little change to the regional distribution of projects by storage type during the past three years. EOR is still the primary regional storage option for a vast majority of LSIPs in North America and Asia, and for all LSIPs in the Middle East. In particular, all LSIPs in China include the planned use of CO₂ for EOR either as a primary or as a secondary option (Figure 22).

In contrast, most current LSIPs in Australia and New Zealand include the planned storage of CO₂ in onshore deep saline formations or non-potable aquifers. In Europe, deep saline formations and depleted oil and gas reservoirs are still largely prevalent and represent more than 70 per cent of projects. However, offshore storage options (including EOR) are progressively gaining pace, as two of the three LSIPs newly-identified in Europe in 2012 include the planned used of CO₂ for EOR.

Due to the long lead time and uncertainty associated with the characterisation of a potential storage site, there is an increasing effort to diversity storage options. In the 2012 project survey, 23 projects (30 per cent) indicated they were considering more than one type of storage or utilisation, compared to 17 projects (23 per cent) in the 2011 survey.

Further details regarding the storage of CO₂ can be found in Chapter 8.

FIGURE 22 Volume of CO₂ potentially stored by primary storage type and region
While a number of LSIPs have continued to make notable progress on their capture component, results from the 2012 project survey indicate that the discrepancy in the advancement of the storage component between projects with EOR and those with dedicated geologic storage (deep saline formations or depleted oil and gas fields) has persisted in the past year (Figure 23). For projects whose capture component is in the Define stage, over two-thirds of those with EOR have signed a commercial agreement for the off-take of CO₂ or are in advanced negotiations with potential EOR customers, while only one-third of those with dedicated geologic storage have the same level of storage definition and are undertaking the detailed characterisation of their primary storage target/s.

**FIGURE 23 Comparison of capture and storage progress**

![Comparison of capture and storage progress](image)

Around two-thirds of the 16 LSIPs in operation or construction include the use of CO₂ for EOR. Further to this, four of the five projects that could reach FID by the end of 2012 include EOR. In contrast, three-quarters of the projects that were removed from the LSIP listing this year included dedicated geologic storage.

While EOR continues to be an important step in demonstrating CCS technology at a commercial scale, providing a partial cost offset to develop CO₂ capture facilities, there is a need for consistent and comprehensive policy settings that provide an incentive to invest in CCS at the macro level, including the use of dedicated geologic storage. This is particularly important as EOR (or even depleted oil and gas fields) is unlikely to provide the storage capacity necessary for CCS to be a major contributor to CO₂ abatement in the long term (IPCC 2007b, Dooley and Friedman 2005).
Portfolio distribution of LSIPs

A portfolio distribution mapping the key industries, technologies and regions of LSIPs to the previous discussion in this chapter is provided in Table 2 below. Many of the salient points have been made previously, including the geographical dominance of a few regions, the dominance of power generation projects and pipeline systems within these regions, and geographical differences in the type of storage options being pursued.

### TABLE 2 Portfolio distribution of LSIPs

<table>
<thead>
<tr>
<th>Capture</th>
<th>Power</th>
<th>NORTH AMERICA</th>
<th>EUROPE</th>
<th>ASIA</th>
<th>AUSTRALIA - NEW ZEALAND</th>
<th>MENA</th>
<th>SUB-TOTAL</th>
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<tbody>
<tr>
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<td></td>
<td>7</td>
<td>3</td>
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<td>19</td>
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<td>1</td>
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<table>
<thead>
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<th>Storage</th>
<th>Geologic</th>
<th>NORTH AMERICA</th>
<th>EUROPE</th>
<th>ASIA</th>
<th>AUSTRALIA - NEW ZEALAND</th>
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<td>4</td>
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<tr>
<td>Onshore depleted oil and gas reservoirs</td>
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<td></td>
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<td>Enhanced oil recovery</td>
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<td>Enhanced gas recovery</td>
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<td>Various storage options being considered</td>
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**KEY:**
- ≥ 10 projects
- 3–9 projects
- 1–2 projects
- No projects
### DEMONSTRATION OF LARGE-SCALE INTEGRATED CCS PROJECTS

Figure 24 shows the potential volume of CO₂ that could be stored in any given year by current LSIPs and how this capacity is distributed across stages of the asset lifecycle, based on responses to the 2012 project survey. Total volumes recorded by projects in the 2011 and 2010 surveys are also provided for reference. For projects at the Define, Evaluate and Identify stages, the volumes shown do not correspond to the actual volumes of CO₂ that will be stored by LSIPs, but to the total capacity of all LSIPs currently in planning, as only the projects that are best-in-class will reach FID.

The first peak of new LSIPs coming online that was expected to occur in 2015–16 (based on annual project survey responses in 2009 and 2010) has shifted and is now projected to start from 2018–20. This is partly due to the fact that six LSIPs at the Define stage and eight LSIPs at the Evaluate stage have been cancelled or put on hold since 2010, and were replaced with less mature projects. Additionally, a number of project proponents have reassessed their project’s development schedule since 2010, due to:

- delayed outcomes from competitive public funding programs leading proponents to slow down or shelve their project’s activity until further information is available, including the amounts likely to be awarded to individual projects;
- uncertainties around short to medium-term policy developments, particularly with respect to projected CO₂ prices, hindering the confidence necessary for companies to invest in capital-intensive low-carbon technologies such as CCS;
- more generally, the aftermath of the global financial crisis (GFC), with reduced credit volumes available and tighter lending conditions, leading companies to reprioritise their investments away from LSIPs CCS projects, while remaining involved in smaller-scale demonstrations or research initiatives.

The total volume of CO₂ potentially captured and stored by all LSIPs has also slightly decreased during the past three years, as very large projects that have been cancelled or put on hold were replaced with smaller projects, while some others (particularly hubs) have reassessed their capture capacity to a more modest scale.

**FIGURE 24 Volume of CO₂ potentially stored by LSIPs (Mtpa CO₂)**
The rate at which the next generation of CCS projects currently in development is moving forward into construction is considerably lower than was generally expected in 2008 and 2009, when many clean energy or CCS-specific public funding programs were announced. Government action is needed for CO₂ emissions to be priced at a level that is consistent with the social costs likely to be incurred if low-carbon technologies are not widely adopted. Further to this, there is a need – through a set of comprehensive, consistent, and stable regulatory and policy frameworks – for CCS to be explicitly and consistently supported as part of a portfolio of carbon abatement technologies.

In the absence of the above, CCS demonstration is strictly dependent on private initiative or one-off public funding programs that provide large sums to few LSIPs. This in turn increases the difficulty of obtaining the balanced set of early-mover CCS projects that is needed across a range of industries and technologies in order to reduce the costs associated with CCS, as well as to provide guidance for legislators as to how best to adjust prevailing policy and regulatory frameworks. The ongoing uncertainty over long-term climate policy is having a significant impact in shaping current investment decisions and is likely to push out the CCS demonstration phase further into the 2020s. A more concerted approach, supported by strong political action, is required for CCS technology to achieve its substantial mitigation potential as part of a portfolio of carbon abatement technologies.
3

BUSINESS CASE

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3.2 CCS costs and competitiveness 44
3.3 Commercial gaps for LSIPs and other CCS projects 46
3.4 Financing and risk 51
3.5 Outlook 55
Building the business case for CCS projects is difficult and time-consuming.

There is strong near-term potential for CCS, with the most economic propositions being natural gas extraction, fertiliser, synfuel, and ethanol production.

Higher cost CCS projects (power, steel, and concrete) require strong government support, including during the operational phase, due to low or absent carbon pricing arrangements.

CCS is a competitive technology for power sector emissions reduction when compared to other low-carbon technologies.

Many projects target additional revenues from CO₂ utilisation to close the commercial gap.

There are significant issues with debt availability to support CCS in a post-GFC world.

3.1 INTRODUCTION

The business case for a project provides the strategic, financial, commercial, technical, operational and other information and analysis necessary to make a FID about whether an investment or project should be implemented. It also provides justification for the project/investment in terms of its alignment with the objectives of the organisation. In the context of CCS and government support programs for CCS demonstration projects, these objectives can include:

- technology development and commercialisation opportunities;
- market leadership;
- achieving a commercial return;
- satisfying expected regulatory changes; and
- protecting value of the existing portfolio.

The business case also provides the basis for managing and controlling the delivery of the project on time, within budget, and to the agreed quality standards and timeframes.

Developing a business case requires significant efforts and work streams running in parallel, and is a difficult and complex undertaking. A wide range of technical, commercial, financial, and operational considerations must be considered and captured within the business case for a project (Figure 25).
FIGURE 25 Complexity of the business case

**Technical factors**
- Capture process
- Capture integration
- Capture rate
- Pipeline technical specification
- Storage characterisation

**Commercial factors**
- Project cost
- Grant eligibility
- Financing strategy
- Resourcing plan
- Project and contractual structure
- Public engagement
- Storage liability issues
- Project permitting
- Environmental approvals
- Regulatory approvals
- Risk management plan

**Operational factors**
- Capture performance (e.g. capture rate, operating cost, energy penalty (if relevant))
- Transport performance (leakages, operating cost)
- Storage performance (MMV)
- Outages and chain risk
- Closure arrangements

**Financial factors**
- Delivering an adequate net present value/internal rate of return
- Sizing and timing of debt and equity contributions
- Financial covenants
- Project accounts
- Project reserves
- Financial structuring
For many CCS projects these complexities are magnified from the need to integrate the elements of the CCS chain (CO₂ capture, compression, transport, injection and storage). Despite the lack of carbon pricing arrangements and other complexities faced, 16 LSIPs around the world have successfully constructed their business cases and made positive FIDs. These projects are predominantly in gas processing, synfuels, ethanol and fertiliser production where capture costs are lower and integrating capture technology is better understood (Table 3). In contrast, carbon capture project development in sectors such as power, steel and cement production faces significantly higher costs.

### TABLE 3 Comparison of production cost increases with the addition of CO₂ capture

<table>
<thead>
<tr>
<th>POWER GENERATION</th>
<th>HIGHER COST CO₂ CAPTURE FROM INDUSTRIAL SOURCES</th>
<th>LOWER COST CO₂ CAPTURE FROM INDUSTRIAL SOURCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-combustion</td>
<td>Oxyfuel</td>
<td>IGCC</td>
</tr>
<tr>
<td>Percentage increase in cost of production with CCS (first-of-a-kind)</td>
<td>61-76</td>
<td>53-65</td>
</tr>
</tbody>
</table>


As pointed out in Chapter 1, by 2050, the role of CCS in decarbonising energy emissions is evenly split between capturing emissions in the power sector and industrial sector, meaning that demonstration projects are needed now to support significant commercial deployment prior to 2050. If CCS were to be excluded as a technology option in the electricity sector, the IEA (2012b) states that investment costs would increase by 40 per cent, or approximately US$3 trillion, over the period to draw on relatively more expensive abatement options to provide electricity.

CCS, as a range of technologies applicable to a number of power and industrial applications, is currently considered to be in a pre-commercial stage in many of those applications and only at the pilot stage for several of them (such as iron and steel or cement applications).

Governments around the world are seeking to advance the development of CCS applications, particularly in the high-cost, low CO₂ concentration power generation sector as well as iron and steel and cement production, through support for demonstration projects. Improved understanding of the cost and performance of large-scale CCS plants is a key motivation for these demonstration projects.
3.2

CCS COSTS AND COMPETITIVENESS

Adding CCS to any process increases capital costs as well as ongoing operating and maintenance costs. Inevitably, this increases the cost of the product resulting from that process, whether electricity or industrial outputs. Such cost increases arise from the role of CCS in significantly reducing CO₂ emissions compared with what would otherwise be the case. Placing these cost increases in context, alternative methods of reducing or avoiding CO₂ emissions are also generally more expensive than traditional electricity generation or industrial production processes. While there is often a focus on the additional costs of CCS, the appropriate comparison is with alternative means of significantly mitigating CO₂ emissions, and on this basis CCS is a cost-competitive technology.

When applied to electricity generation, CCS has four main impacts on the cost structure for any project seeking to meet a given level of electricity demand:

- additional capital expenditure associated with the CO₂ capture and compression plants;
- additional fuel costs for the energy used in the capture process;
- additional capital expenditure to build a larger power plant (to ensure net power output is unchanged) in order to compensate for the energy used in the capture process (i.e. host plant compensation); and
- additional operations and maintenance costs associated with both the larger plant and the capture and compression requirements.

The relative share of cost increases of these effects varies across the different capture technologies – post combustion, oxyfuel or IGCC – reflecting differences in the processes. However, regardless of the process, it is the capture facilities and the additional energy requirements as part of the capture process that have the largest impact on costs (Figure 26).

**FIGURE 26 Cost impacts of adding CCS to a power station**

![Cost impacts of adding CCS to a power station](image)

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>30%</td>
</tr>
<tr>
<td>Fuel</td>
<td>20%</td>
</tr>
<tr>
<td>Fixed operating and maintenance</td>
<td>10%</td>
</tr>
<tr>
<td>Variable operating and maintenance</td>
<td>5%</td>
</tr>
<tr>
<td>Transport</td>
<td>5%</td>
</tr>
<tr>
<td>Storage</td>
<td>5%</td>
</tr>
</tbody>
</table>

**Note:** For a supercritical post-combustion plant based on Global CSS Institute and WorleyParsons (2011) data.
The cost of electricity production for any given technology is often described using levelised costs. The levelised cost of electricity (LCOE) represents the average price that an electricity generating plant would need to receive for each and every hour of operation over its entire economic life in order to recover all capital and operating costs, including receiving a competitive return on invested capital. Estimates for LCOE for the different capture technologies – post combustion, oxyfuel or IGCC – indicate an increase in costs over non-CCS power plants of around 40 per cent for gas fired power plants and more than 60 per cent for black coal plants (see Appendix D).

Although CCS increases the cost of production, assessing the cost effectiveness of abatement technologies is best done using a different cost metric. As climate change policy directly influences the level of CO\textsubscript{2} and other GHG emissions, the cost-effectiveness of different technologies should be based on the cost of each technology’s ability to avoid or reduce those emissions. The cost of CO\textsubscript{2} avoided identifies the cost of reducing emissions relative to the amount of fossil fuel emissions displaced, expressed in dollars per tonne of CO\textsubscript{2}.

Using the avoided cost of CO\textsubscript{2} allows different technologies to be ranked on the basis of cost-efficient technology choices to reduce emissions in any given location. The metric can also be compared with carbon prices certain governments are implementing, or to prices generated in models of the various policies that can be implemented to reduce CO\textsubscript{2} emissions, or even estimates of the costs of emitting CO\textsubscript{2} that impinge on the community.

In 2011, the Global CCS Institute presented a comparison of low-carbon technologies (Global CCS Institute 2011c) in the electric power sector based on a review of technology cost studies by a number of agencies including the IEA, the IPCC, the US Energy Information Agency (EIA), WorleyParsons, the US National Energy Technology Laboratory (NETL) and US National Renewable Energy Laboratory. As these studies each use differing methodologies and assumptions regarding key economic and technology criteria, care was taken to compare the data on the same economic basis and similar resource quality.

There are technologies that have zero or negative avoided costs, such as conventional geothermal and hydropower plants among others. Negative avoided costs can occur if the cost of the low-carbon technology is less than the fossil fuel technology. The finite availability of wind and hydro resources limits their role in meeting emission targets and requires higher cost options of CCS, solar and nuclear technologies (Figure 27). CCS remains a cost-competitive technology alongside other large-scale abatement options in the power generation sector.

**FIGURE 27 Costs of CO\textsubscript{2} avoided**

![Costs of CO\textsubscript{2} avoided](image)


*Note:* For all technologies except gas-fired CCS plants, the amount of CO\textsubscript{2} avoided is relative to the emissions of a supercritical pulverised coal plant. For gas-fired CCS, the reference plant is an unabated combined cycle plant.
Industrial sectors

Beyond the power sector, fossil fuel use in the industrial sector is also an important source of CO₂ emissions. However, there is considerable heterogeneity in the nature of emissions and the extent of existing capture processes. In certain instances, a relatively concentrated stream of CO₂ is produced as part of the industrial process resulting in relatively low capture costs associated with compression (and some concentration). Examples of this include natural gas processing and fertiliser production. Other industrial products, such as iron and steel production and oil refining have, like power generation, relatively low concentrations of CO₂ in flue gases that must first be concentrated and separated before compression, transport, and storage. In addition, investment is also required for capture facilities as well as additional power and steam generation facilities to enable recycling of the captured materials.

The technologies and costs for CO₂ capture in industrial processes have not been investigated to the same degree as studies conducted for power generation systems. Two recent reports have summarised existing literature or estimated costs (UNIDO 2010, Global CCS Institute and WorleyParsons 2011), for a number of industrial systems, including:

- gas processing (onshore, offshore, and liquefaction);
- fertiliser production (ammonia);
- coal-to-liquids;
- steel; and
- cement.

Industrial sector costs are usually reported with an avoided CO₂ cost metric, rather than in commodity units such as $/tonne steel, in order that the costs are comparable across sectors. In many studies, the additional energy required in the capture and compression components is assumed to rely on natural gas combined cycle (NGCC) power production, and the CO₂ generated from this power production is included in avoided CO₂ cost calculations. Often, only the cost of capture (which is always lower than the avoided cost due to additional energy consumption) is reported (Table 4).

### TABLE 4 CO₂ costs for industrial processes

<table>
<thead>
<tr>
<th>LNG</th>
<th>FERTILISER</th>
<th>NATURAL GAS PROCESSING</th>
<th>COAL-TO-LIQUIDS</th>
<th>CEMENT</th>
<th>STEEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>onshore</td>
<td>offshore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avoided cost</td>
<td>US$/tonne</td>
<td>9</td>
<td>10–20</td>
<td>16–19</td>
<td>18–21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>54–80</td>
<td>&gt;54</td>
</tr>
</tbody>
</table>


3.3

COMMERCIAL GAPS FOR LSIPS AND OTHER CCS PROJECTS

Although CCS technologies are competitive with alternative future large-scale technologies to reduce or avoid CO₂ emissions, CCS projects are not present in many markets due to the early stage of the technology, market prices that are too low to drive investment in CCS, and a lack of incentives for CO₂ abatement. CCS is also often not treated equivalently to other low-carbon technologies in terms of policy settings and government support. In order to achieve emissions reductions in the most efficient way, governments should ensure CCS is not disadvantaged.

There is currently a commercial gap facing many CCS projects in the power and higher capture cost industrial sectors due to the significant incremental capital and operating costs for CCS (Figure 28).
This commercial gap is a major factor limiting the development of CCS projects around the world. Leaving aside general cost reductions in CCS technologies through R&D and other development activities CCS projects have limited means to attempt to bridge the commercial gap in their business cases (Figure 29).

These means are further discussed below and can be broken into two key categories:

1. government support; and
2. additional revenue streams.
Government support

Many CCS projects have received significant monetary support from public funding programs in order to bridge the commercial gap (Figure 30).

FIGURE 30 Public funding to large-scale projects

Funding support for CCS projects is also expected to be awarded to additional projects under the NER300 process in Europe, the UK’s CCS Commercialisation Program and the CCS Flagships program in Australia.

However, it should be noted that support under such schemes does also introduce additional challenges for projects, such as:

- participating in a competitive process to access grant-funding support;
- focus of many programs on support for capital investment and less on the operational phase of the project;
- satisfying requirements under a funding agreement with government;
- pre-conditions for drawing down support; and
- claw-back risk.

To meet longer-term global emissions targets at least cost requires CCS demonstration projects to be undertaken now. This will require significant further support in the form of both grants and operating period support for CCS.

The need for stronger support for the operating period of CCS projects overlaps with the paramount necessity for clear carbon emission abatement policies, legislation and regulation, such as direct policy and/or regulatory action to prevent or limit emissions and establishing a price on carbon emissions. The level of support under current settings does not provide sufficient support for most CCS projects to proceed. The current CO\textsubscript{2} price is mostly below the level required to drive significant investment in CCS, and other low-carbon technologies. For example, the price of certified emission reduction unit (CERs) under the EU Emissions Trading Scheme (ETS) currently sits at around €7–8 per tonne of CO\textsubscript{2}, Australia’s carbon price is AU$23 per tonne of CO\textsubscript{2} and the price under the Alberta Government’s carbon offset program is CA$15 per tonne CO\textsubscript{2}.

There are initiatives being considered to provide stronger incentives for low-carbon technologies such as CCS. The EC is currently considering draft proposals to delay the sale of up to 1.2 billion carbon allowances as part of a rescheduling of allowance auctions to support the carbon price under the ETS.
In addition, the UK has recently sought to reduce risk and uncertainty for investment in low-carbon technologies through reforms to the electricity market. An important element of the reform package is the proposed use of technology specific price supports over the next 15–20 years for CCS, renewables and nuclear. See the box in section 4.2 for a discussion of the policy elements and CCS issues.

The outcome of such current and future policy initiatives will have a key bearing on the provision of a supportive environment to drive the development of CCS projects.

**Additional revenue streams**

Of note is the importance of multiple revenue sources and, in particular, the growing importance of the utilisation of CO₂ across a number of projects. This is borne out of the 2012 project survey which asked LSIP project proponents and operators to indicate the revenue sources supporting or expected to support their projects. Figure 31 is based on the 58 projects that responded.

**FIGURE 31 Revenue sources for LSIPs**

![Revenue sources for LSIPs](chart)

It can be seen that utilisation of CO₂ for EOR or other purposes was a feature of 20 projects (34 per cent) and was the most significant revenue stream after electricity sales. While this reflects the industries and regions where LSIPs are being developed, it does show the importance that utilisation is playing across a large number of current LSIPs.

To date, only two power capture projects have moved into the construction stage. Apart from government support for their capital investments both of these projects involve CO₂ sales for EOR (Table 5).
This observation is further borne out by examining the five projects that are targeting a FID over the coming 12 months. Of these five projects, four are diversifying their revenue through CO₂ utilisation for EOR or other purposes (Table 6).

**TABLE 6** Operating period bridges of projects approaching FID

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>OPERATING PERIOD BRIDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas Clean Energy Project</td>
<td>Utilisation revenues: CO₂ for EOR and urea for fertiliser production.</td>
</tr>
<tr>
<td>NRG Energy Parish Project</td>
<td>Utilisation revenues: CO₂ for EOR.</td>
</tr>
<tr>
<td>ROAD</td>
<td>EU-ETS</td>
</tr>
<tr>
<td>North West Sturgeon Refinery CO₂ Project</td>
<td>Credits under Alberta Government’s carbon offset program (CA$15/tonne CO₂ emissions).</td>
</tr>
<tr>
<td>Emirates Steel Industries</td>
<td>Utilisation revenues: CO₂ for EOR.</td>
</tr>
</tbody>
</table>

The Texas Clean Energy Project (TCEP) is illustrative of the important ways that utilisation revenues can be used to enable CCS development activities.

**TEXAS CLEAN ENERGY PROJECT**

TCEP is a 400 MW ‘polygen’ IGCC plant being developed by Summit Power Group, LLC, which is currently in negotiations with the Export-Import Bank of China to raise significant project finance for its US$2.9 billion project.

According to Summit, there are three factors that have allowed it to get very close to a bankable project include:

1. Utilising proven technologies that suppliers with strong balance sheets will guarantee. Siemens (power) and Linde and SK E&C (chemical) are the EPC contractors under fixed price, turnkey contracts and warrant availability and performance under 15 year contracts.

2. Accessing additional revenues from other than ratepayers alone – TCEP diversifies revenue risk via having three major revenue sources, all under separate long-term off-take agreements: power (30 per cent), CO₂ for EOR (20 per cent) and urea for fertiliser production (45 per cent of revenues) as well as 5 per cent of revenues coming from other by-product sales.

3. Targeting utilisation of CO₂ for EOR as an objective because it both helps to reduce the ultimate cost of CCS and it significantly reduces risks along the CCS chain.

Summit also intends to use TCEP as a reference plant that can provide a template for rolling out other polygen plants in other locations around the world – changing this as a lending proposition from a one-off plant to a potential new business line.
3.4

FINANCING AND RISK

Financing

Funding for CCS projects comes from a wide variety of private and public sector sources as shown in Table 7.

<table>
<thead>
<tr>
<th>TABLE 7 Potential CCS funding sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUBLIC</td>
</tr>
<tr>
<td>Grants.</td>
</tr>
<tr>
<td>Tax credits.</td>
</tr>
<tr>
<td>Loan guarantees.</td>
</tr>
<tr>
<td>Concessional equity.</td>
</tr>
<tr>
<td>Concessional debt.</td>
</tr>
<tr>
<td>PRIVATE</td>
</tr>
<tr>
<td>Sponsor equity.</td>
</tr>
<tr>
<td>Institutional equity (infrastructure funds, superannuation funds, pension funds etc.).</td>
</tr>
<tr>
<td>Sponsor debt (balance sheet financing).</td>
</tr>
<tr>
<td>Commercial debt.</td>
</tr>
<tr>
<td>MULTI-LATERAL AGENCIES AND EXPORT CREDIT AGENCIES</td>
</tr>
<tr>
<td>Concessional debt.</td>
</tr>
<tr>
<td>Credit guarantees.</td>
</tr>
</tbody>
</table>

As CCS moves towards commercialisation it is expected that increasing amounts of funding will be sourced as institutional equity and commercial bank debt. However, at the development stage a customised and sophisticated mixture of public, private, and multi-lateral funding sources will often be required.

Of the 16 CCS projects that have reached financial close, raising finance is more problematic for the high-cost, low CO₂ concentration projects.

Where private sector financing has been committed to-date for power sector CCS projects like Kemper County and Boundary Dam, it has typically been via equity and/or debt contributions from the key project sponsors. Such balance sheet financing will be limited by the appetite and ability of such sponsors (mainly major utility companies) to contribute a significant proportion of their capital budgets to an activity which may not currently deliver a financial return commensurate with the risks of project development.

Since the current public funding programs for CCS require private sector finance through cost sharing, the lack of ability to raise debt at the project level provides a significant barrier to the roll-out of CCS.

The ability of CCS projects (as opposed to project sponsors) to access debt markets has been affected by the lasting impacts of the GFC as well as the BASEL III capital and liquidity requirements.

The GFC severely affected the global financial system, constraining the availability of capital and significantly increasing the relative cost of borrowing for lower rated credits, particularly for those customers who are not considered to be ‘investment grade’. The ongoing economic uncertainty stemming from Europe in 2012 will continue to impact financial markets, reinforcing bank risk aversion and preference for higher rated borrowers. Figure 32 and Figure 33 show bank lending volumes in Europe and the US for non-investment grade borrowers.
FIGURE 32 Bank lending volumes in Europe for non-investment grade borrowers

FIGURE 33 Bank lending volumes in the US for non-investment grade borrowers

Source: ThompsonONE.
Note: Shaded period represents GFC. *2012 figure annualised based on data in first two quarters.
Both diagrams show the strong fall in volumes during the period of the GFC. They also show some recovery in lending volumes for 2011, but volumes still remain significantly below the levels achieved immediately before the GFC.

This increased bank risk aversion has a number of implications for the financing market for CCS demonstration projects.

1. CCS projects during the demonstration phase will struggle to raise non-recourse or limited-recourse project finance. Financiers will favour those projects that have been able to significantly de-risk their construction and operation activities.

2. Capital grants of 30–50 per cent of the capital costs of the CCS component of a project are not enough in isolation. Neither sponsor funds nor bank debt will fund the remaining cost unless a project can be made commercial – which will require revenues from CO₂ utilisation and/or some type of operating period support (e.g. long-term PPA, FiT, operating period subsidy etc.).

3. Even projects that can access the debt markets may find that debt availability from commercial banks is insufficient to meet the funding needs of their project.

A number of projects are attempting to plug the capital gap remaining after grant funding and debt availability by:

- seeking debt at concessional lending rates from multilateral development banks like the EIB and Asian Development Bank (ADB); and
- seeking support from export credit agencies – which can drive technology selection and project structuring decisions to ensure project eligibility.

However, funding remains a key barrier for the development of CCS projects.
Risk and risk transfer

Risk remains a challenge for CCS projects as the incorporation of capture technology into the power and industrial sectors (e.g., iron, steel, and concrete production) at scale introduces significant first-of-a-kind and other risks. The demonstration status of CCS, with less certainty over costs and performance, means that the risk contingency/spread applied is greater than for more established infrastructure asset classes. This in turn increases the cost estimates and makes it more difficult to achieve a financially feasible project.

In addition, the ability of project proponents to transfer or mitigate these risks can be limited, leading to a higher level of residual risk being faced by the project. This is due to the demonstration nature of CCS. Until the technology is proven at scale, equipment vendors may be less willing to provide fixed prices or performance warranties.

This can be seen from the 2012 project survey which asked LSIP project proponents and operators to indicate the contracting strategies being utilised for their projects. Figure 34 is based on the 59 responses received to this question.

The survey shows that a large number (24 per cent) of respondents are using construction management contracts. In these types of contracts the contractor does not normally take full responsibility for delivery of the completed project by the overall completion date nor take ultimate responsibility for the ultimate cost to the project owner/sponsor. The survey also shows that 51 per cent of respondents are using combination approaches where they are only able to transfer cost and time risk on some components of their project and not others.

However, 25 per cent of respondents indicate that their project is using a lump sum or design and construct contract, where cost of completion and time for completion risk is typically passed to the contractor (subject to limited exceptions and extensions of time in some circumstances). This shows progress is being made, with some original equipment manufacturers (OEMs) having the confidence in their technologies at scale to bear these risks.

As more CCS projects are successfully delivered, the risks faced will become better understood leading to CCS projects having a better ability to transfer, mitigate, and price risk.
3.5

OUTLOOK

Over the coming 12 months it is expected that, with recent progress made towards selecting projects under both NER300 and the UK funding competition, there will be a number of projects in a position where an FID can be made. Early indications are that these projects will comprise a range of pre-combustion, post-combustion and industrial projects.

In North America, a mixture of pre-combustion (Texas Clean Energy Project), post-combustion (NRG Energy Parish Project), and industrial (North West Sturgeon Refinery CO₂ Project) projects are also in a position where a FID can be made over the course of the next 12 months. All of these projects will rely strongly on EOR or other utilisation opportunities as a key component of the business case. This reflects the growing importance of utilisation of CO₂, syngas and/or urea to provide an operating period bridge.

In addition, utilisation of CO₂ for EOR will continue to be an important driver of CCS activity in regions like China, the Middle East and North Africa when conditions are suitable.

Apart from these developments CCS projects are likely to continue to focus on the ‘low-hanging fruit’ of natural gas extraction and natural gas, hydrogen and synfuels production where CO₂ is produced as part of the process and can be captured at low cost.

Ultimately demonstration projects need to be underpinned by climate policy, CCS-specific policy and an effective regulatory environment. The rate of project development to date suggests that the absence of policy support creates uncertainty and impedes project progress.
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 International policy legal and</td>
<td>57</td>
</tr>
<tr>
<td>regulatory developments</td>
<td></td>
</tr>
<tr>
<td>4.2 Regional, national, and sub-</td>
<td>63</td>
</tr>
<tr>
<td>national policy, legal, and</td>
<td></td>
</tr>
<tr>
<td>regulatory developments</td>
<td></td>
</tr>
<tr>
<td>4.3 Project views</td>
<td>76</td>
</tr>
<tr>
<td>4.4 Government funding support</td>
<td>84</td>
</tr>
<tr>
<td>4.5 Challenges and outlook</td>
<td>87</td>
</tr>
</tbody>
</table>
International and domestic climate change mitigation commitments signal the need to decarbonise energy-related emissions, and any delays will continue to undermine private sector investment in CCS activities and further stifle technology development.

Inclusion of CCS in the CDM and full ratification of the amendments to the OSPAR Convention were significant developments in the international legal and regulatory architecture for CCS, but challenges remain in the adoption of amendments to the London Protocol to allow for the export of CO₂ streams for the purpose of storage in sub-seabed geological formations.

Only modest CCS-specific policy developments have occurred in the past 12 months, however there has been a rebalancing of climate policy settings for carbon pricing more generally, and enhanced support for all low-carbon technologies within the UK specifically.

The level of funding for CCS demonstration projects, while still considerable, is increasingly vulnerable and it is clear that the level of funding support still available will service fewer projects than was perhaps initially expected.

The overall perception of CCS project participants is that the current mix of policy settings and prevailing regulatory environments are somewhat supportive of positive investment decisions in CCS demonstration projects, but policy settings over the medium to longer term are seen to be largely inadequate to ensure future project viability.

Policy, legal, and regulatory developments are key factors determining whether CCS will progress as an important GHG mitigation technique. There is a wide range of policy, legislation, and regulation that is relevant to CCS, from international climate change agreements, through national climate and energy policy, to project-specific legislation and regulation. Developments over the past year in this range of instruments and mechanisms are reviewed in this chapter. Some observations are also made on the challenges for policymakers and regulators, both from a global perspective and from the point of view of project proponents.

4.1

INTERNATIONAL POLICY LEGAL AND REGULATORY DEVELOPMENTS

United Nations mechanisms

In 2011, the 17th session of the Conference of the Parties (COP 17) to the UNFCCC agreed that a new international climate change regime would be established by 2015 for implementation in 2020. This new instrument or arrangement would require Parties to enhance their mitigation efforts in the post-2020 period, beyond the second commitment period of the Kyoto Protocol. The intention is that Parties will be held to account on the basis of common but differentiated responsibilities under the one instrument, unlike the Kyoto Protocol that divides Parties into developed and developing nations, with and without legally-binding carbon constraints, respectively.
Negotiations on the new regime will intensify over the next few years, and will be very important for the future of global climate change mitigation efforts. In the meantime, the Kyoto Protocol remains the principal mechanism for giving effect to these efforts. The Kyoto Protocol provides the compliance arrangements by which Annex B Parties (essentially Annex I, mainly developed, countries that have ratified the Kyoto Protocol) can deliver on their negotiated emission reduction targets. The Kyoto Protocol establishes three fully fungible carbon markets called flexibility mechanisms or Kyoto markets. These include two project-based markets called Joint Implementation (JI) and the CDM, as well as a cap and trade system called International Emissions Trading (IET).

JI and CDM allow for developed countries to claim offset credits for emission reductions generated from their investment in projects in other countries – JI for projects in Annex B countries and CDM for projects in non-Annex B countries, which are mostly developing countries. These credits, referred to as emission reduction units (ERU) and certified emission reduction (CER) units respectively, can be used by Annex B emitters to acquit against their carbon liabilities and/or sell on in a number of existing and emerging carbon markets. IET allows developed countries to trade in their assigned amount units (AAUs) which are generated as a consequence of their legally binding emission reduction targets and which are ‘supplemental’ to meeting their own needs.

The negotiating landscape for CCS under the UNFCCC remains complex. There are five main mechanisms affecting the global deployment of CCS in the UNFCCC agenda. These are:

- inclusion of project level CCS projects/abatement under the CDM;
- adoption of a Technology Mechanism;
- adoption of a Financial Mechanism;
- registration of Nationally Appropriate Mitigation Actions (NAMAs); and
- potential for New Market Based Mechanisms (NMBMs).

The UNFCCC is the principal international negotiating forum driving country-by-country action to prevent dangerous levels of climate change. It consists of the Convention itself, which is the parent treaty accountable to the COP, and the Kyoto Protocol, which is the subordinate legal instrument accountable to the Meeting of the Parties to the Kyoto Protocol (CMP).

Supporting the implementation of the Convention and the Kyoto Protocol are five subsidiary bodies, of which two are permanent (Subsidiary Bodies for Implementation, SBI; and Scientific and Technological Advice, SBSTA), and three are ad hoc working groups (the Long-term Cooperative Action under the Convention, AWG-LCA; Further Commitments for Annex I Parties under the Kyoto Protocol, AWG-KP; and the Durban Platform for Enhanced Action, ADP).

The AWG-LCA and ADP report and make recommendations to the COP; the AWG-KP reports and makes recommendations to the CMP; and the SBI and SBSTA report and make recommendations to either the COP or CMP depending on what they have been tasked to implement or advise on respectively (Figure 35).
CCS IN THE CDM

In 2010 at CMP 6, CCS was provisionally adopted into the CDM, providing that a limited number of issues were resolved. This initiated a year-long program throughout 2011 to enable the SBSTA to draft a suite of modalities and procedures (rules) which Parties negotiated in Durban. In 2011, CMP 7 conditionally adopted the rules that currently underpin the inclusion of CCS in the CDM. The conditions included a requirement that CCS project participants quarantine 5 per cent of their CERs to effectively serve as insurance to remedy any unforeseen or adverse environmental and/or social effects of projects. This reserve is however conditionally refundable at the end of the project.

The CMP tasked the SBSTA to further examine two additional CCS in CDM-related issues during 2012. The first of these was the need to establish an additional permanent global reserve of CERs as an additional fiscal safety net for host countries of CCS projects, should something unlikely or untoward occur. The second was the transboundary movement of CO2 across borders, for projects that involve the CO2 being captured in a developing country and transported and permanently stored in a different country.

The UNFCCC Secretariat has managed two related submission processes throughout 2012 on these issues. At the 36th Session of SBSTA in May 2012, the Secretariat was tasked with the drafting of a technical report on transboundary issues for consideration by SBSTA at its 37th meeting, to be held in the margins of COP 18 at Doha in November/December 2012. The matter of the establishment of a general reserve looks unlikely to be resolved in 2012.

Despite these outstanding issues, there appears to be nothing of a procedural nature stopping CCS project proponents from now applying to have their project registered under the CDM.

In July 2012, the CDM Executive Board (EB) established a 10-member CCS Expert Working Group (CCS WG), supported by a CCS Expert Roster. The Chair and co-Chair of the newly established CCS WG (Brazil and Australia) will help steward the process of CCS-related methodological developments. Members of the CCS WG were announced at the 68th meeting of the CDM EB in July 2012. The process to establish a roster of CCS experts followed establishment of the CCS WG, and members will essentially be called upon to assist with desk reviews of proposed new methodologies prior to the CCS WG forwarding its advice to the CDM Secretariat for consideration and approval by the CDM EB.

The acceptance of CCS in the CDM potentially marks an exciting new era for the global deployment of CCS as a major mitigation option in developed and developing countries alike. It will not only help facilitate the establishment and refinement of the institutional arrangements necessary to support CCS projects, but also enhances community confidence in its application due to its international acceptability.
The CDM has clearly been successful in helping deploy many sorts of mitigation projects in developing countries, but it is unlikely that, given the depressed value of the CERs, the CDM alone can make marginally uneconomic CCS projects economic (let alone early-mover CCS projects in developing countries). While most CDM commentators would suggest that it may take some time for CCS projects to be fully rewarded under the CDM, the mechanism (and other project-based schemes such as Joint Implementation) is generally recognised as a necessary and important source of additional funding.

CCS IN OTHER UNFCCC MECHANISMS

CCS is currently being explicitly discussed in the AWG-LCA and SBSTA negotiations, and it remains of intrinsic relevance to the other negotiating tracks.

The AWG-LCA track is examining cooperative action beyond 2012. Under this track, both the Technology Mechanism, including the Climate Technology Centre and Network (CTCN), and the Financial Mechanism’s Green Climate Fund (GCF) are being negotiated. These initiatives are critically important to the future of CCS, as developing countries will depend on the CTCN to facilitate needs assessments and project-level activities, and the GCF is a major source of finance for such projects.

The Technology Mechanism needs to be operational by the end of 2012, and the implementation issues surrounding this mechanism are being managed through the Technology Executive Committee and the SBI.

The Technology Mechanism will inevitably play a significant role in accelerating the demonstration and diffusion of low emission technologies such as CCS. The associated CTCN will help establish the enabling environments and capacity building needs required to overcome market (and human and institutional) barriers.

The Financial Mechanism already includes provision of an agreed ‘fast start’ finance for developing countries approaching US$30 billion up to 2012, and the establishment of a US$100 billion a year (by 2020) GCF administered initially by the World Bank to support adaptation and mitigation actions (projects, programs, policies, and other activities) in developing countries.

The AWG-LCA carries responsibility for the provision of funding resources for the GCF to support mitigation action and technology cooperation (especially for developing countries) by mobilising public and private-sector funding and investment. The GCF Board and the SBI is responsible for its implementation.

The GCF was launched at COP 17, and positively cites CCS as an example of a likely eligible technology. Six bids to host the GCF were received by the secretariat, including from Germany (Bonn), Mexico (Mexico City), Namibia (Windhoek), Poland (Warsaw), Korea (New Songdo City), and Switzerland (Geneva). At the time of writing, the GCF had just hosted its first board meeting, where these applications are to be considered, but the meeting had to be postponed three times due to procedural issues. It is expected the Board will forward to the COP a recommendation for a host at COP 18. The World Bank (GCF Interim Trustee) has been ready to receive contributions from Parties from as early as May 2012. While some Parties have formally expressed willingness to pay, at the present time no contributions have yet been received.

In regards to NAMAs, it was agreed at COP 16 that countries requiring international support in the form of technology, finance, or capacity building will be recorded in a registry where the action and the support for that action can be matched. It was also agreed that governments will continue to work towards establishing one or more new market-based mechanisms to enhance and promote the cost-effectiveness of mitigation actions. A key aspect of the NAMA agenda is the extent and possibility of linking them to NMBMs and existing crediting arrangements.

The AWG-LCA is also looking at the role and legitimacy of NMBMs and how they can facilitate real and enhanced mitigation action, as well as help transfer, develop, and deploy low-emission technologies such as CCS.

Negotiations affecting the Kyoto Protocol are managed under the AWG-KP track. CCS is explicitly cited in the Kyoto Protocol as being a legitimate mitigation technology. This negotiating track is relevant to CCS in that it:

- currently defines the legally-binding short to medium-term emission constraints (over what is called commitment periods);
- defines the scarcity of emissions within carbon markets (CDM, JI, and IET); and
- drives the market discovery of carbon prices.
International standards for CCS

In May 2011, the Standards Council of Canada (SCC) submitted a proposal to the International Standards Organization (ISO) to develop an internationally agreed standard/s for CCS. The SCC’s proposal is a consequence of a collaborative effort between the International Performance Assessment Centre for Geologic Storage of Carbon Dioxide (IPAC-CO2) and the Canadian Standards Association (CSA) to establish a bi-national CCS standard for Canada and the US and subsequently use the standard as a basis for accreditation under the ISO.

The proposal seeks to develop standards that cover: capture, transport, storage, risk management, and quantification and verification; and include materials, equipment, environmental planning and management, and other CCS-related activities.

By establishing an ISO standard for CCS, the ultimate objective is to have CCS-related activities conform to a global consensus on performance standards and to define the specifications and criteria that can be applied consistently to all CCS projects.

However, the objective to secure a global consensus on a uniform set of rules and criteria that can appropriately, dependably, and efficiently address all of the localised needs of CCS projects may prove to be challenging at this stage of global CCS developments.

ISO standards on CCS are likely to take several years to develop. The process has commenced, with the formation of a Technical Committee (ISO/TC265) which engages 13 voting countries (as represented by their respective national standards organisations) and 12 observing countries. The first meeting of TC265 was held in Paris in June 2012. The SCC and the Standardization Administration of China have been appointed Secretariat of the ISO work program.

A scoping document released by the TC in mid-2012 indicates recognition that not all CCS-related subject matter is ready for standardisation, and the TC further recognises that CCS is a dynamic and evolving subject, and care will be taken to ensure that standards remain up to date and do not impede innovation.

The application by sovereign nations of ISO standards is voluntary, and as such governments can choose to adopt them in their regulations or not. An ISO standard is ultimately decided on by an international consensus of designated experts who discuss, debate, and argue from within ‘national delegations’. They are subject to a periodic review at least every five years.

There are currently no known accredited national or international standards specific to CCS. There are however a large number of published peer-reviewed expert reports, best practices, and guidelines that contain transparent approaches and recommendations to address and/or redress CCS-related issues.

Policy makers have tended to avoid placing too much emphasis on institutionalising nascent and evolving CCS-related performance standards due to the limited amount of project level data currently available to inform the setting of appropriate performance thresholds. The setting of standards on the basis of incomplete information could potentially lead to overly conservative permit requirements being imposed on demonstration and pre-commercial CCS projects, and this could undermine the ability of proponents to proceed with innovative and often first-of-a-kind demonstration projects.

In September 2012, the Institute was notified of its Category A Liaison Organization status. This role will see the Institute inform and seek input from relevant stakeholders on issues as they arise throughout the discussions.

International marine legislation

Two key international marine treaties have a significant impact on offshore CO2 injection for storage: the Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR Convention), and the Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter at Sea (London Protocol). To eliminate the prohibition of some offshore CCS activities, amendments were made to the OSPAR Convention in 2007 and London Protocol in 2006 and 2009. These amendments are particularly significant given the number of LSIPs which plan to transport and store CO2 offshore for geologic storage in a range of jurisdictions (Table 8).

The 2007 amendment to the OSPAR Convention, which allows for CO2 injection and storage in North East Atlantic waters, has now entered into force, albeit four years after the original amendment was made. The requisite seven ratifications were reached on 23 June 2011 when Denmark ratified the amendment, joining Germany, Norway, Spain, the UK, Luxembourg, and the EU. In October 2011, the Netherlands also ratified the 2007 amendment. Thus far, all OSPAR contracting countries which have CCS demonstration projects have ratified the 2007 amendment, except for France where the ratification process is underway and expected to be completed by the end of 2012.

Two amendments were made to the London Protocol, to allow for offshore CO2 injection and cross-border movement of CO2. The former was addressed by the 2006 amendment to Annex I of the London Protocol, which added captured CO2 as one of the wastes or other matter that may be dumped in subsea geologic formations. This amendment, being an amendment of the Annex, did not require ratification, and automatically entered into force on 10 February 2007, 100 days from the amendment’s adoption.
The later 2009 amendment to the London Protocol seeks to lift the existing restriction on cross-border transport of CO\textsubscript{2} as waste for injection and geologic storage. This should be distinguished from moving CO\textsubscript{2} across international borders for EOR purposes, which is allowed under existing laws. To enter into force the 2009 London Protocol amendment requires the ratification of two-thirds of the contracting parties (28 of 42). Norway was the first contracting party to ratify the amendment, and the United Kingdom the second in November 2011. Thus only two ratifications have been received, nearly three years after agreeing to the amendment. However, most of the current LSIPs with offshore storage plans may not have direct issues with violating the provisions of the London Protocol, even absent the amendment.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>LSIP NAME</th>
<th>STORAGE OPTION</th>
<th>TRANSPORT DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>CarbonNet</td>
<td>Offshore deep saline formations</td>
<td>51–100 km onshore to offshore pipeline</td>
</tr>
<tr>
<td>Italy</td>
<td>Porto Tolle</td>
<td>Offshore deep saline formations</td>
<td>101–150 km onshore to offshore pipeline</td>
</tr>
<tr>
<td>Korea</td>
<td>KOR-CCS1</td>
<td>Offshore deep saline formations</td>
<td>251–300 km ship/tanker</td>
</tr>
<tr>
<td></td>
<td>KOR-CCS2</td>
<td>Offshore deep saline formations</td>
<td>251–300 km ship/tanker</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>ROAD</td>
<td>Offshore depleted oil and gas reservoirs</td>
<td>≤50 km onshore to offshore pipeline</td>
</tr>
<tr>
<td></td>
<td>Green Hydrogen</td>
<td>Offshore depleted oil and gas reservoirs</td>
<td>≤50 km onshore to offshore pipeline</td>
</tr>
<tr>
<td></td>
<td>Pegasus</td>
<td>Offshore depleted oil and gas reservoirs</td>
<td>151–200 km onshore to offshore pipeline</td>
</tr>
<tr>
<td>Norway</td>
<td>Mongstad CCM</td>
<td>Offshore deep saline formations</td>
<td>Onshore to offshore pipeline</td>
</tr>
<tr>
<td></td>
<td>Sleipner</td>
<td>Offshore deep saline formations</td>
<td>≤50 km direct injection</td>
</tr>
<tr>
<td></td>
<td>Snøhvit</td>
<td>Offshore deep saline formations</td>
<td>151–200 km onshore to offshore pipeline</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Teesside</td>
<td>Offshore deep saline formations</td>
<td>201–250 km onshore to offshore pipeline</td>
</tr>
<tr>
<td></td>
<td>Peterhead</td>
<td>Offshore depleted oil and gas reservoirs</td>
<td>101–150 km onshore to offshore pipeline</td>
</tr>
<tr>
<td></td>
<td>White Rose</td>
<td>Offshore deep saline formations</td>
<td>Onshore to offshore pipeline</td>
</tr>
<tr>
<td></td>
<td>C.GEN Killingholme</td>
<td>Offshore deep saline formations</td>
<td>151–200 km onshore to offshore pipeline</td>
</tr>
<tr>
<td>United States</td>
<td>PurGen One</td>
<td>Offshore deep saline formations</td>
<td>151–200 km onshore to offshore pipeline</td>
</tr>
</tbody>
</table>
4.2

REGIONAL, NATIONAL, AND SUB-NATIONAL POLICY, LEGAL, AND REGULATORY DEVELOPMENTS

Below the level of international negotiations and agreements, there has been moderate development in the policy environment at national and sub-national levels over the past year, but a surge of regulatory activity. A positive aspect is that many countries are hosting serious policy discussions on the role that national market-based mechanisms can play in establishing carbon prices, and the role carbon prices play in driving low-emission technology development objectives. There have been particularly notable developments in some jurisdictions, which will be watched closely by many others to evaluate the effectiveness of these emerging regimes.

An overview of recent policy developments by country is in Appendix E. A summary of the major developments is in Table 9. Significant developments include:

- Australia’s introduction of a carbon pricing arrangement from 1 July 2012 (transitioning to an ETS in 2015);
- commencement of California’s ETS at the start of 2012;
- Mexico’s passing of its General Law on Climate Change (GLCC) encouraging the development of an ETS; and
- South Africa’s latest Budget Statement indicating that a revised White Paper on a carbon tax will be published in 2012.

**TABLE 9 Summary of major policy developments**

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>POLICY ANNOUNCEMENT SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>Rio de Janeiro’s ETS to start in 2013 delayed (2012). Exploring national ETS. Continues to be a major CDM player.</td>
</tr>
<tr>
<td>EU</td>
<td>Released White Paper on enhancing mitigation ambition to 30 per cent below 1990 levels by 2020. On track to selling 200 million allowances by 2 Oct 2012 to support CCS projects. End of EU ETS phase II (31 December 2012), and start of phase III (1 January 2013).</td>
</tr>
</tbody>
</table>

continued on page 64
## Country Policy Announcement Summary

<table>
<thead>
<tr>
<th>Country</th>
<th>Policy Announcement Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>India</strong></td>
<td>- Intention to launch 9th Mission (clean coal technologies) under National Action Plan on Climate Change announced.</td>
</tr>
<tr>
<td></td>
<td>- Industrial energy efficiency targets with tradable instruments announced (mid-2012).</td>
</tr>
<tr>
<td></td>
<td>- National Clean Energy Fund (sourced from coal levy).</td>
</tr>
<tr>
<td><strong>Indonesia</strong></td>
<td>- Exploring a national ETS.</td>
</tr>
<tr>
<td><strong>Japan</strong></td>
<td>- Actively promoting its Bilateral Offset Crediting Mechanism.</td>
</tr>
<tr>
<td></td>
<td>- A new energy blueprint is expected to be released in late 2012.</td>
</tr>
<tr>
<td><strong>Korea</strong></td>
<td>- ETS law passed by National Assembly (May 2012) for 2015 commencement.</td>
</tr>
<tr>
<td></td>
<td>- Commitment of funds to the value of 2 per cent of GDP (2009–2013) to foster ‘green’ growth.</td>
</tr>
<tr>
<td><strong>Mexico</strong></td>
<td>- Passed The General Law on Climate Change (2012).</td>
</tr>
<tr>
<td></td>
<td>- Exploring a national ETS.</td>
</tr>
<tr>
<td></td>
<td>- National Energy Strategy 2012-26, presented to Congress in March 2012 includes CCS goals.</td>
</tr>
<tr>
<td><strong>Norway</strong></td>
<td>- Released a White Paper on Climate Change Actions (2012).</td>
</tr>
<tr>
<td></td>
<td>- Increased carbon tax rates.</td>
</tr>
<tr>
<td><strong>Romania</strong></td>
<td>- Secured derogation under EU ETS for free allocation of allowances to power plants in Phase III (2012).</td>
</tr>
<tr>
<td></td>
<td>- Exploring carbon tax for potential 2013 start.</td>
</tr>
<tr>
<td></td>
<td>- National Climate Change Response Policy, endorsed by Cabinet October 2011, identifies CCS as one of South Africa’s eight near-term Priority Flagship Programmes.</td>
</tr>
<tr>
<td><strong>Spain</strong></td>
<td>- Carbon Fund for a Sustainable Economy established (late 2011).</td>
</tr>
<tr>
<td></td>
<td>- Is the second largest buyer of CDM credits (CERs).</td>
</tr>
<tr>
<td><strong>Sweden</strong></td>
<td>- Increases in its energy and CO₂ tax (2011).</td>
</tr>
<tr>
<td></td>
<td>- Developing a carbon neutral by 2050 roadmap by end of 2012.</td>
</tr>
<tr>
<td><strong>Trinidad and Tobago</strong></td>
<td>- Release of National Climate Change Policy (mid-2011).</td>
</tr>
<tr>
<td></td>
<td>- Released CCS Roadmap <em>Supporting deployment of CCS in the UK</em> (2012).</td>
</tr>
<tr>
<td></td>
<td>- Clean energy standard strongly supported by President (March 2012).</td>
</tr>
</tbody>
</table>

*continued from page 63*
Generally speaking, and as indicated in Figure 36, there is a broad relationship between the carbon intensity of a country (depicted as emissions per capita on the right-hand axis) and the comprehensiveness of its CCS-relevant policy portfolio (depicted as an index on the left-hand axis). Given this, it is not surprising that much of the policy and regulatory developments continue to be in developed countries, and in those developing countries with relatively high levels or intensities of carbon emissions.

**FIGURE 36 Relationship between policy and emissions**

- **Coverage of supporting policies**
- **Emissions per capita (RHS)**
- **Index (LHS)**
  - 1.0 = Comprehensive suite of policies
  - 0.5 = Emerging policy environment
Comprehensive CCS policies

Across most countries, CCS policy development has focused on:
- long-term carbon pricing under climate change policy;
- the need to accelerate development of the technology through large-scale demonstration programs and increased R&D expenditure; and
- developing the necessary regulatory infrastructure.

Given the radical technological change required to decarbonise the energy system during this century, combined with short-term concerns over the rate at which climate policies are being implemented, it is widely acknowledged that relying on a carbon price alone will not achieve least-cost paths for both the development and deployment of the technologies required. At the same time, the rate of development of CCS projects has not occurred at a rate commensurate with expectations only a few years ago.

It is vital to recognise that a suite of CCS-friendly policies can be complementary (mutually reinforcing) or non-complementary (can undermine one another and/or be redundant) depending on how they are designed and implemented. The IEA (2011b) observes that in managing the policy interactions “policy packages should be regularly reviewed to maintain coherence over time, particularly if policies interact strongly. To promote investment certainty, reviews should generally be limited to scheduled intervals and follow understood criteria. In the event of a major unforeseen shock, a judgement is needed on whether the benefits of restoring policy balance outweigh the damage to investment certainty caused by intervening.”

The UK Government is implementing the first comprehensive attempt globally to set a policy to drive CCS deployment beyond the first demonstration facilities. Support for CCS is enabled through actions to reform electricity market arrangements and the implementation of the CCS Roadmap. Details of the UK approach are given in the following Box. This policy package is being closely watched to see what effect it has on CCS demonstration and deployment in that country, and the extent to which aspects of the regime are applicable elsewhere.
The UK Government acknowledges that the EU ETS is the cornerstone of UK action to reduce GHG emissions from the power and industrial sectors in Europe. However, they have stated that:

**Whilst the EU ETS is successfully delivering emissions reductions across the UK and Europe, so far the carbon price has not been sufficient to incentivise the required levels of new low carbon investment** (DECC 2011).

To reduce risk and uncertainty for investment in low-carbon technologies (necessary to support an estimated £110 billion investment in new generating capacity and transmission investment by 2020), the UK Government introduced three mechanisms to support low-carbon technologies:

- a Carbon Price Support scheme (also known as the carbon floor price);
- a Feed-in Tariff supported though technology-specific ‘contract for differences’ for low-carbon energy; and
- an Emissions Performance Standard.

It has also introduced a ‘CCS Commercialisation Program’ to provide capital subsidies and address technical and regulatory barriers specific to CCS.

The combination of instruments seeks to manage investment expectations regarding market demand and price outcomes over a sufficiently long term.

Overall, the policy framework seeks to provide:

- long-term instruments to provide stable and predictable incentives for companies to invest in low-carbon generation, including CCS;
- to limit CO₂ emissions from new fossil fuel power stations; and
- reduce existing policy risk.

**CARBON PRICE SUPPORT**

The Carbon Price Support scheme was legislated in 2011 and is levied on all fossil fuels used to generate electricity. The levy (part of the broader Climate Change Levy arrangements) will be set annually, depending on the forecast EU ETS carbon price, to achieve an overall carbon price trajectory in the UK that rises to £30/tonne by 2020 and then to £70/tonne by 2030.

**CONTRACT FOR DIFFERENCES**

The Contract for Differences (CfD) introduced in the draft Energy Bill in May 2012 is proposed as a long-term transition mechanism with different arrangements for CCS, renewables, and nuclear. The CfD is an agreement for a project to effectively receive a fixed price, also known as a ‘strike price’, for the energy delivered.

If the strike price is higher than the electricity wholesale market price, the generator is paid the difference, and conversely, if the electricity market price is higher than the strike price, the generator pays back the difference. Strike prices will be established at levels sufficient to support the different types of technologies being supported.

The price transition arrangements are in four phases:

**Stage 1: 2014–17**

A project (and technology) specific strike price will be agreed through negotiation between projects and government. For CCS, this phase will also be part of the CCS Commercialisation Program (discussed on page 68).

**Stage 2: 2017–early 2020s**

The use of tenders or auctions to procure generation, but still segregated on a technology basis and primarily focused on renewable generation.

**Stage 3: Early–mid 2020s**

CfDs established in a technology-neutral process (by tendering or auction).
Stage 4: Late 2020s

Phase out CfDs and rely on carbon pricing only for continuing low-carbon technology deployment.

At the time of writing this report, there remain a number of issues to be resolved with implementing the CfDs, including the counter-party and contract term. The draft Energy Bill implements the CfDs by statute, obliging all energy retailers and/or marketers to pay for the CfDs and spread the costs across their customer base. This approach may require further regulatory changes to provide the necessary contract security for low-carbon generators.

For CCS projects supported through the CCS Commercialisation Program, the length of the contract is recommended to be a 10-year term. This is in contrast to renewables with a 15-year term, and nuclear with an in-principle recommendation of no less than 15 years.

The strike price for CCS projects may also have a price review clause included in the terms, so that it can be reviewed at the end of construction and following a period of further testing of the CCS plant.

EMISSIONS PERFORMANCE STANDARDS

Announced in 2010, the draft Energy Bill limits the amount of CO₂ emitted by new fossil fuel power stations to 450 kg/MWh. With the carbon floor price and CfDs driving investment away from unabated coal plants, this regulation is not expected to have any direct effects. Instead, it acts indirectly as a regulatory backstop to clearly signal that the most carbon-intensive (unabated coal) power stations will not be permitted to be built.

CCS ROADMAP AND COMMERCIALISATION PROGRAM

A policy goal of the UK Government is commercial deployment of CCS during the 2020s. A CCS Roadmap (Figure 37) has developed a 10-year work program that, beyond the electricity market reform and the CCS commercialisation program, includes:

- CCS innovation;
- continuing regulatory framework development;
- storage review and research;
- transport infrastructure;
- CCS cost examination;
- workforce skills and supply chain development; and
- international policy engagement.

The framework seeks to deliver “investment decisions to build CCS equipped fossil-fuel power stations, in the early 2020s, without a capital subsidy, at an agreed CfD strike price that is competitive with the strike prices for other low carbon generation technologies” (DECC 2012).

The CCS Commercialisation Program provides £1 billion in direct grant support that, dependent on what industry brings forward, may cover:

- demonstrating either full-chain or key-elements of CCS projects in the power or industrial sectors;
- developing infrastructure, which might be available to subsequent projects; and
- investigate alternative options, including enhanced hydrocarbon recovery.

It is expected that recipients of funding will be announced in October 2012, prior to announcements for successful applicants under the NER300 program. The intention is that funding from both programs will be able to support UK-based CCS projects.
FIGURE 37 UK CCS Roadmap
Europe

In the UK, as elsewhere in Europe, efforts continue to develop CCS regulatory frameworks. The main driver for this has been the EU CCS Directive. The Directive provides a regulatory framework for CO₂ storage and mandates EU member states to transpose its requirements into domestic legislation. On 25 June 2011, the deadline for transposing of the regulatory framework closed, however, the implementation of the Directive is still in progress for some member states.

EU member states are bound to communicate to the European Commission the legislative and regulatory measures they have adopted to meet the Directive’s requirements. While many EU states began the process, all but Spain failed to complete their transposition within the deadline. Consequently, the Commission initiated infringement cases against 26 out of the 27 EU member states that failed to fully comply with the Directive, or for failing to communicate their compliance to the Commission. For jurisdictions that have communicated to the Commission that they have complied with the Directive, the Commission has been verifying whether there has been an accurate transposition of the regulatory framework.

Table 10 provides a snapshot of status of transposition of the CO₂ Storage Directive in EU member states. Nine of the 26 infringement cases have been closed already, including Denmark, France, Italy, Lithuania, Malta, the Netherlands, Portugal, Romania, and Slovakia. Jurisdictions with pending applications under the NER300 funding program have completed or nearly completed the transposition. This is partly due to the requirement set out under the NER300 rules that for contenders to secure funding, transposition of the Directive must have been correctly completed. Further, it is worthwhile noting that EU countries with ongoing CCS demonstration programs have completed or at least begun the process of developing their CCS legislation and regulation, underscoring the importance of CCS regulations in CCS demonstration and deployment.

EU member states faced different challenges in the transposition process, which have to some extent impacted upon the timely and comprehensive adoption of national legislation. Germany may be highlighted as one of such jurisdiction that has encountered difficulties in adopting a CCS regulatory framework. The Bundestag (Lower House of the German Parliament) passed the CCS Law on 7 July 2011 however, the draft law was rejected by the Bundesrat (Assembly of German States – Upper House) on 23 September 2011. This led to a formal conciliation procedure applied for by the German Government on 26 October 2011. The result was a compromise that was approved by the German parliamentary mediation committee and the passage of a CCS law in Germany on 29 June 2012, which would allow CCS in Germany on a test or experimental basis. The CCS law differs from the draft initially passed by the Bundestag, for it restricts the amount of CO₂ to be captured and stored to 1.3 million tonnes and provides individual states the option to opt out. The new German CCS law will be examined by the Commission to determine whether it meets the requirements of the Directive.

Non-EU member countries, such as Norway, Liechtenstein, and Iceland are members of the European Free Trade Association (EFTA) and participate in the single European market with members of the European Union under the European Economic Area (EEA) agreement. Their participation in the internal market, however, carries an obligation to adopt all EU legislation relating to the market, including the EU CCS Directive. Norway has been drafting new regulations for the storage and transportation of CO₂ in subsea reservoirs on the Norwegian Continental Shelf. CCS activities in Norway, such as Sleipner and Snøhvit, are currently regulated under existing petroleum laws. Two new regulations are being drafted: one by the Ministry of Petroleum and Energy for transport and storage of CO₂ in relation to managing the CO₂ and geologic reservoirs as natural resources (resource management), and another by the Ministry of Environment for environmentally safe storage of CO₂. The draft regulations will undergo public consultations once drafting is complete.
<table>
<thead>
<tr>
<th>EUROPEAN UNION MEMBER STATES</th>
<th>STATUS OF TRANPOSITION</th>
<th>NER300 FUND APPLICATION</th>
<th>CURRENT LSIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Belgium</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>1 (Maritsa TPP)</td>
</tr>
<tr>
<td>Cyprus</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Denmark</td>
<td>Infringement case closed</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Estonia</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Finland</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>France</td>
<td>Infringement case closed</td>
<td>Pending</td>
<td>1 (Ulcos BF)</td>
</tr>
<tr>
<td>Germany</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Greece</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Hungary</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Ireland</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Italy</td>
<td>Infringement case closed</td>
<td>Pending</td>
<td>1 (Porto Tolle)</td>
</tr>
<tr>
<td>Latvia</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Lithuania</td>
<td>Infringement case closed</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Malta</td>
<td>Infringement case closed</td>
<td>None</td>
<td>1 (Sargas Malta)</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>Infringement case closed</td>
<td>Pending</td>
<td>4 (Eemshaven, ROAD, Green Hydrogen, Pegasus)</td>
</tr>
<tr>
<td>Poland</td>
<td>Ongoing infringement case</td>
<td>Pending</td>
<td>1 (Belchatow)</td>
</tr>
<tr>
<td>Portugal</td>
<td>Infringement case closed</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Romania</td>
<td>Infringement case closed</td>
<td>Pending</td>
<td>1 (Getica)</td>
</tr>
<tr>
<td>Slovakia</td>
<td>Infringement case closed</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Slovenia</td>
<td>Ongoing infringement case</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Spain</td>
<td>Fully transposed</td>
<td>None</td>
<td>1 (Compostilla)</td>
</tr>
<tr>
<td>Sweden</td>
<td>Ongoing infringement case</td>
<td>Pending</td>
<td>0</td>
</tr>
<tr>
<td>UK</td>
<td>Ongoing infringement case</td>
<td>Pending</td>
<td>6 (Peterhead, Don Valley, C. Gen Killingholme, Teeside, White Rose, Caledonia)</td>
</tr>
</tbody>
</table>
North America

UNITED STATES

There is no comprehensive federal climate policy in the US. In the absence of a comprehensive federal scheme, GHG control is proceeding through federal regulation under the existing Clean Air Act and individual state initiatives. New bills and regulations are being proposed and released with the aim of incentivising CCS innovation and development.

CCS continues to be recognised as a source of ‘clean energy’ in a Bill before the US Senate. On 1 March 2012, the US Senate Committee on Energy and Natural Resources received a Bill sponsored by Senator Jeff Bingaman, entitled The Clean Energy Standard (CES) Act of 2012. The draft Bill, if passed, will require large utilities to produce at least 24 per cent of their electricity from ‘clean’ sources by 2015, increasing by 3 per cent annually through 2035. Clean energy is defined in the draft Bill to include “electricity generated at a facility that captures and stores its CO₂ emissions”. The fate of the ‘Bingaman Bill’, and the fate of other climate legislation, remains highly uncertain.

The US EPA has actively drafted and released rules allowing for CCS operations. On 27 March 2012 the EPA released its proposed emissions performance standards for new fossil-fuelled power plants, limiting GHG emissions to 1000 lbs CO₂ per megawatt hour. For new power plants with CCS, the proposed limit may either be satisfied by meeting the annual standard yearly or a 30-year average of CO₂ emissions.

In the past year, the EPA continued to develop technical guidance materials for the Class VI Injection Well Rule and has released seven guidance documents on well testing and monitoring, primacy application and implementation manual, site characterisation, area of review evaluation and corrective action, well construction, financial responsibility, and public participation considerations for geologic sequestration wells. Six more guidance documents for the Rule are expected to be issued by the EPA as it continues to evaluate risks to drinking water sources, human health, and the environment.

On 12 July 2012, the US EPA finalised Step 3 of the GHG Tailoring Rule for the Prevention of Significant Deterioration (PSD) and Title V Operating permit programs (Table 11). Step 3 retains the existing permitting thresholds as state permitting authorities have not had sufficient time and opportunity to develop the necessary infrastructure and increase their GHG permitting expertise and capacity. Step 3 also revises the federal program for establishing plant-wide applicability limitations (PALs) for GHG emissions by allowing GHG PALs to be established on a CO₂e basis, not just on a mass basis (or tonnes per year), and allowing GHG-only sources to apply for CO₂e-based PALs as a minor source candidate. This third instalment of the Tailoring Rule will take effect on 1 July 2013. CCS is considered as one of the control technologies that may be used to reduce emissions from facilities covered by the Rule, provided that CCS is determined to be the Best Available Control Technology (BACT).

Individual states continue to consider and adopt policies to eliminate barriers to CCS. For example, proposed legislation in California (SB 1139) is drafted to address pore space ownership and direct state agencies to develop a quantification methodology for projects seeking to demonstrate geologic storage, including simultaneous sequestration via enhanced oil recovery. The methodology would be used for GHG reporting, implementation of California’s market-based compliance mechanisms, and compliance with GHG performance standards under California law. Another example is Illinois, where in February 2012 draft CCS legislation was re-introduced to its General Assembly for consideration. The CCS Bill (SB 3758) seeks to address significant areas of CCS regulations including pore-space ownership, storage project development (definitions and requirements), and unitisation of lease blocks.

CANADA

In the latter half of 2011, the Canadian Government published for public comment its proposed regulations to reduce CO₂ emissions from coal-fired electricity generators. Under these proposed regulations, new coal-fired generators, as well as mature units nearing retirement, will be required to abide by stringent performance standards based on the emissions performance of high-efficiency NGCC plants. If units covered under these regulations incorporate CCS, a temporary exemption is given from the standard until 2025. Following the consultation period, which closed in October 2011, the Canadian Government announced on 5 September 2012 the final regulations, which will enter into force on 1 July 2015.

CCS regulations are also being developed in the Canadian provinces of Alberta, British Columbia, Nova Scotia, and Saskatchewan.

Alberta has made significant progress in its CCS Regulatory Framework Assessment (RFA) that began in early 2011 by identifying and addressing gaps in its regulations. The recommendations from the RFA have suggested improvements in:

- geologic site characterisation and site closure;
- post-closure stewardship fund;
- monitoring, measurement, and verification requirements; and
- environmental issues.
TABLE 11 Schedule for PSD and Title V Operating Permit Applications—‘GHG Tailoring Rule’

<table>
<thead>
<tr>
<th>Tailoring rule</th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permit type</td>
<td>PSD</td>
<td>PSD</td>
<td>Title V</td>
</tr>
<tr>
<td>Entry into force</td>
<td>2 January 2011 (to 30 June 2011)</td>
<td>1 July 2011 (to 30 June 2013)</td>
<td>1 July 2013</td>
</tr>
<tr>
<td>Facilities covered</td>
<td>1. new sources subject to PSD anyway for other regulated pollutants; 2. modified sources subject to PSD anyway for other regulated pollutants.</td>
<td>1. new sources subject to PSD anyway for other regulated pollutants; 2. new sources.</td>
<td>1. modified sources subject to PSD anyway for other regulated pollutants; 2. modified source; 3. modified minor source for PSD.</td>
</tr>
<tr>
<td>GHG emission levels</td>
<td>1. have potential to emit ≥ 75,000 t/yr CO₂e; 2. increase and net emissions increase ≥ 75,000 t/yr CO₂e; and &gt; 0 t/yr mass basis.</td>
<td>1. have potential to emit ≥ 100,000 t/yr CO₂e; and ≥ 100/250 t/yr mass basis.</td>
<td>1. have the potential to emit/emit ≥ 100,000 t/yr CO₂e; and ≥ 100 t/yr GHGs on mass basis.</td>
</tr>
</tbody>
</table>

Alberta expects to conclude the RFA at the end of 2012 with submission of a final report to Alberta’s Energy Minister.

In February 2012, British Columbia released a Natural Gas Strategy, wherein CCS will be promoted through the development of a regulatory framework and amendment of existing legislation, in consultation with its Oil and Gas Commission. The CCS regulatory framework being developed will be built on existing oil and gas legislation and regulation, the Petroleum and Natural Gas Act and the 2008 Oil and Gas Activities Act. Under the latter law, exploration and use of storage reservoirs fall under the definition of oil and gas activities, which are regulated by the province’s Oil and Gas Commission.

The CCS Research Consortium of Nova Scotia is in the final year of its research into the technical and economic feasibility of capturing CO₂ from coal-fired power plants in Nova Scotia and storing it both onshore and offshore. A legal and regulatory report will be released as part of the resulting products of this research.

In Saskatchewan, its climate change legislation, the Management and Reduction of GHGes Act, which received Royal Assent in 2010, is expected to be proclaimed by November 2012. This Act establishes emissions reduction targets for the province with a 2 per cent annual improvement in emissions intensity and payment into a technology fund for failing to meet the target.
Australia

A core pillar of the Australian Government’s recent Clean Energy Legislation (CEL) is the establishment of a carbon pricing mechanism, which commenced on 1 July 2012. The mechanism acts like a tax through imposing an emission liability at a fixed carbon price on entities emitting 25,000 tCO₂e a year or more. The current price is set at AU$23/tCO₂, with a pathway rising at 2.5 per cent each year in real terms. After three years, the fixed price period transitions to a market determined period, driven by a cap and trade ETS.

On 28 August 2012, Australia and the EC announced their intention to link Australia’s ETS with the EU ETS. Initially, this would be through a partial link from July 2015, followed by a full two-way link no later than July 2018. Australian businesses will be able to buy and use EU Emissions Allowances for compliance under the Australian scheme from July 2015. To facilitate these arrangements, the Australian Government will not proceed with the implementation of its price floor and will limit the use of Kyoto Protocol eligible international units under the Australian scheme. In addition, Australia will set its price ceiling with reference to the expected 2015–16 price of European allowances.

While carbon pricing is vital for the deployment of clean energy technologies, the prevailing suite of complementary measures that specifically support renewables clearly indicates some recognition by Australian policy makers that the carbon pricing mechanism is, by itself, not yet at a sufficient price point to make large-scale clean energy investments commercially attractive. This clearly applies equally to CCS technologies as it does to renewables.

While the CEL package aims to support Australia’s transition to a clean energy economy, it also led to the Government announcing in late 2011 that it would not proceed with its original intention to require all new coal-fired power stations to be built CCS ready (CCSR). This is due to a policy rationale that the efficiency of a carbon price can be relied upon to determine investment decisions for both clean energy and other mitigation options, as well as some stakeholder pushback.

Australia’s Department of Resources, Energy and Tourism hosted a public consultation process in late 2010 inviting views on a discussion paper it released on CCSR policy, and while some stakeholders expressed a good understanding of and support for CCSR approaches, concern was also expressed over the practicality of introducing such mandatory standards. This was especially in regards to the difficulty of, and risks associated with, defining criteria for a CCSR power station when CCS was still at an early stage of development and demonstration.

Australia’s regulatory framework for offshore and onshore CCS activities remains one of the most developed globally. The Australian Government, with jurisdiction over Commonwealth waters, already set in place primary and secondary legislation to govern CCS activities offshore. State governments similarly exercise jurisdiction over offshore areas however, this is limited to Australia’s coastal waters or seas three nautical miles from the shore baseline. For instance, the offshore CCS regulations of Victoria – the Offshore Petroleum and GHG Storage Act 2010 and the Offshore Petroleum and GHG Storage Regulations 2011 – entered into force on 1 January 2012.

As state and federal Governments have complementary jurisdiction over offshore CCS activities, a system of joint state/federal authority has been set in place to manage offshore CCS activities. In the past year, Australia has streamlined the authority regulating offshore CCS activities by creating a new national body – The National Offshore Petroleum Titles Administrator. Commencing on 1 January 2012, the National Offshore Petroleum Titles Administrator has jurisdiction over the administration of offshore GHG injection and storage projects.

For onshore CCS activities in Australia, the state Governments of Victoria, Queensland, and South Australia have established their respective regulations, while in New South Wales and Western Australia new onshore CCS regulations are under development.

Legislative consistency has been the goal of Queensland CCS legislators who have begun amending other legislation that may potentially limit the application of its onshore CCS legislation. For example, an amendment was made in the Geothermal Energy Act 2010 to change the definition of ‘authorised activity’ that is carried out under the GHG Storage Act 2009 (GHG Act). In consultation with CCS project proponents, links have also been identified between the GHG Act and other state laws such as the Water Act 2000 and the Petroleum and Gas (Production Safety) Act 2004. Legislative mapping is being considered to identify further connections to other regulations.

Apart from looking at the impacts of CCS regulations on other laws, Australian regulators, through a cross-jurisdictional body, the CCS Working Group, have also been investigating ways of harmonising CCS regulations across Australia. The CCS Working Group, operating under the Council of Australian Governments (COAG) Standing Committee on Energy and Resources, is currently looking at several issues including:

- establishing national consistency on long-term liability;
- cross-jurisdictional CO₂ storage;
- use of abandoned wells and reservoirs for storage; and
- identification of potential CO₂ pipeline corridors.
Asia

Japan’s 2010 Basic Energy Plan is currently under review. In June 2012, following the agreement between Japan CCS and the Japanese Ministry of Economy, Trade and Industry to implement the first national integrated CCS demonstration project in Tomakomai City, Hokkaido, Japan CCS has commenced work on engineering design, procurement, and services for boring monitoring wells as well as other activities. In late 2011, the Institute published a report by the Chiyoda Corporation (2011), Preliminary Feasibility Study on CO₂ Carrier for Ship-Based CCS, which provides a detailed discussion of the regulatory ramifications of ship-based CCS operations under international marine regulation, as well as domestic Japanese legislation.

Korea has taken great strides in promoting climate change mitigation through market-based instruments and remains committed to CCS with the announcement of US$150 million funding for CCS for the next decade. During the past 12 months, a review of the domestic regulatory regime for CCS has been completed by the Korean Carbon Capture and Storage Association and a report on the regulatory review has been finalised.

In Asia more broadly, the Asia-Pacific Economic Cooperation (APEC) has been carrying out a study on ‘Permitting Issues Related to Carbon Capture and Storage for Coal-based Power Plant Projects in Developing APEC Economies’. The regulatory assessment study examines permitting regimes in Malaysia, China, Korea, Chinese Taipei, and Mexico, and was released in September 2012. Malaysia has developed a CCS strategy that outlines the medium-term establishment of a CCS regulatory regime and the longer-term broad uptake of the technology. In China, preparatory work on analysing CCS regulations is also underway to identify gaps in current legislation as well as barriers to CCS operations.

South Africa

Progress has also been made in South Africa and further definitive steps have been taken in terms of formulating CCS regulations. An interdepartmental task team (IDTT) for CCS, including the Departments of Energy, Environmental Affairs, Mineral Resources, Trade and Industries, Science and Technology, National Treasury, and Transport was formed specifically to develop a regulatory framework for CCS in the pilot and demonstration stages and eventually commercial deployment. Legal and regulatory studies regarding a planned CO₂ test injection and CCS Ready are also being completed by the South African Centre for CCS (SACCCS) in collaboration with the Department of Energy and the IDTT.
4.3 PROJECT VIEWS

Projects across all locations largely back up the view that only moderate progress has been made in policy settings over the past year (Figure 38). Recent policy changes are viewed more positively in some locations than in others, especially in Australia (where carbon pricing commenced on 1 July 2012), United Arab Emirates (UAE) (likely driven by increasing interest in EOR), Europe (with implementation of the CCS Directive and significant national action in the UK, the Netherlands, and Romania), and Canada (with draft regulations for an emissions performance standard on all new coal-fired plant).

FIGURE 38 Project views on whether policy has changed over the past year
Projects in these jurisdictions seem to be signalling greater confidence in government intent to establish and/or implement more CCS-friendly policy settings. A positive observation is that very few projects consider the current policy environment to be materially worse than last year. The perceived value of these policy settings by project proponents varies considerably (Figure 39).

**FIGURE 39** Value of the prevailing suite of government policy settings in supporting a positive business case

![Bar chart showing the value of prevailing policy settings](chart.png)

Projects in Asia and North America place much less value on prevailing policy settings than do projects in Europe, perhaps indicating a need for further support in these regions if demonstration projects are to proceed. The importance of policy for projects is also clearly indicated by responses to a range of questions asked around a range of policy issues (Figure 40).
International climate change commitments are driving national climate change policy settings.

Adequate incentives in place to minimise any risk of project being commercially stranded in the future.

CCS can be commercially viable by 2020 in this location.

Early movers in CCS technology have a high propensity to take on the commercial risk and prefer minimal government intervention.

The importance of CCS to mitigate emissions can only increase over time.

CCS can only be commercially viable in this location by 2020 with market oriented carbon regimes.

Government should be primarily responsible for investment in common user infrastructure, such as pipelines.

Current government policy signals are sufficient for project proponents to secure competitive project finance.

Funding challenge of CAPEX is much less than OPEX.

Major and current risk to the success of this project is policy uncertainty.

Getting the storage site selection right is far more important than resolving long term liability arrangements.

Prospect of future carbon constraints negates any thought of investing in conventional fossil fuel technologies.

Government support should be prioritised towards storage solutions rather than capital costs.
Perhaps not surprisingly, project proponents are increasingly optimistic about the role that CCS must play in climate mitigation over time, and as such consider that fossil fuel technologies can continue to deliver highly competitive, secure, and reliable energy to support essential economic activity. Mostly they consider that CCS can be commercially viable by 2020, but also view market-oriented carbon regimes as being important to achieve this outcome.

Many project proponents also draw a link between their national government’s emission reduction commitments or pledges under the UNFCCC and the nature and adequacy of domestic climate change policy settings as a major driver of investment in CCS projects. Policy uncertainty remains a major risk, but interestingly proponents are split on the adequacy of existing policy settings in securing project finance, and in minimising the risk of projects being commercially stranded in the future. It does seem that early mover proponents (i.e. pre-commercial demonstration) are generally not in a position to bear all of the commercial project risk and prefer instead some form of equitable risk sharing arrangement with governments.

This year’s survey also raised some novel ways for how the CCS community might think about addressing some of the better known challenges of CCS projects. For example, about two-thirds of those surveyed did not disagree that getting the storage site selection right can be far more important than resolving upfront long-term liability arrangements (40 per cent agreed and one-third neither agreed nor disagreed). This is not to say that resolving liability arrangements is not critical, but rather that if the site is well selected then the associated liability risks may also diminish and/or be more readily acceptable to permitting authorities. Perhaps related to this matter is a strong preference for government support to be prioritised towards storage solutions over more upstream CCS components.

Interestingly, respondents rated the implementation of policies to access common user infrastructure (CUI) as being relatively low among a range of CCS-relevant policy options however, the majority (not all) view such infrastructure to be primarily the responsibility of governments. While investment in or the construction of pipelines tends not to be the domain of capture plant and/or storage developers, the efficient linking of source to sink will be critical to the successful commercial deployment of CCS more generally. It may also influence the location of new additional projects, and given the future volumes of CO₂ that it is envisioned need to be handled, it will certainly be critical for governments to consider upfront what the future capacity requirements may be and the extent to which public-private partnerships must financially provide for such investments.

Project proponents have a variety of views as to what are the most effective policy instruments that can adequately cater for the commercial and operational requirements of their projects (Figure 41). Project proponents consider that most of the heavy lifting for future CCS development and ultimately commercial deployment needs to be given effect through carbon pricing arrangements (clearly identified as the most important), followed by power purchase agreements, feed-in tariffs, up-front capital subsidies (such as grants or low-interest loans), access to viable storage solutions, and regulated returns (especially in the US where some projects will be operating in regulated electricity markets). Streamlined regulatory approvals were considered an operational priority for projects in the post-FID (execute and operate) stage, as well as the natural gas processing sector, but less of an imminent consideration for projects in the pre-FID that may still be undertaking pre-feasibility analysis.

**FIGURE 41** Project proponent preferences for enabling policy instruments

<table>
<thead>
<tr>
<th><strong>MEAN RESPONSES</strong></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Highest importance</strong></td>
<td><strong>Second most important</strong></td>
<td><strong>Third most important</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon pricing arrangements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regulated returns on investment</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Offtake arrangements</td>
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<td></td>
<td></td>
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<tr>
<td>Feed-in tariffs</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Access to direct subsidies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to a viable storage solution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streamlined regulatory approvals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to indirect subsidies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to common user infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions performance standards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clean energy targets</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
There is relatively less support among the project sample for the implementation of policies such as energy performance standards (EPS) or accessing CUI such as CO₂ pipelines. In regards to an EPS, this may reflect the nascent stage of CCS technology developments and, as such, CCS is still viewed as being very much in a pre-commercial demonstration phase (albeit at an increasing engineering scale). As for CUI, this could reflect the EOR nature of the current fleet of CCS projects (already with pipeline access), as well as a lack of critical CO₂ volume needing to be transported due to either a weak compulsion for emitters to have to manage their emissions and/or the fledgling state of the CCS industry.

A policy preference for implementing clean energy targets also seems to hold low purchase among the project sample (except in Canada), which is a little surprising given the popularity of such a policy choice among many jurisdictions for supporting renewable technology development, deployment, and diffusion.

A majority of project proponents are also of the opinion that their current regulatory environment would readily facilitate an investment decision (Figure 42). This figure represents a broad spectrum of projects geographically, and includes many jurisdictions which have established, or are in the process of implementing, legal and regulatory frameworks for the technology. A smaller number of project respondents, however, have indicated that the regulatory environment in their jurisdiction remains inadequate to enable them to make an investment decision. While it is notable that the number of projects within this category is relatively small, their geographical distribution may be of concern for governments which have sought to enact regulatory frameworks, or provide funding and incentives to drive national development of the technology. From these results it is clear that project respondents from Australasia and Europe appear evenly split on the question, with projects in both regions offering divergent opinions on their regulatory environment. Projects in the US and Asia offer a very different perspective, however, with projects in both regions suggesting that their regulatory environment is overwhelmingly supportive of an investment decision.

The negative responses observed in some of the regions above may be tempered by the fact that, in many jurisdictions, there have been few perceived changes to the regulatory environment in the past 12 months (Figure 43). A large majority (73 per cent) of projects have reported their regulatory requirements as unchanged, or that their activities remained unfettered by regulatory developments. The pace of development and seeming lack of progress suggested by European projects in response to this question may also help to explain why project proponents in the region believe the regulatory environment is unsupportive of an investment decision. In some circumstances – only 6 per cent of the responses – regulatory requirements are considered to have regressed to the extent that they now hinder the making of an investment decision. These particular responses, however, are attributable (unsurprisingly) to the small number of projects which have been cancelled in the past 12 months.
For the large majority of projects, these results are perhaps symptomatic of a more restrained pace of legal and regulatory development in many jurisdictions over the past 12 months. The promulgation of fewer new laws, and a focus upon the implementation of regulations and processing amendments to existing frameworks, has perhaps resulted in some issues, previously viewed as uncertainties, to be now considered by some project proponents as unresolved. More encouraging are the occasions where project proponents have highlighted progress and changes to their regulatory environment, which have assisted in the making of an investment decision.

A number of project proponents in Europe, Australasia, and MENA all highlighted recent changes that demonstrate progress by governments and which inspire more commercial confidence. Two of the regions, Europe and Australasia, where project proponents have suggested their regulatory environment did not support an investment decision at present, have also been named as jurisdictions where there is progress from regulators.

The results from these particular questions also reveal a clear dichotomy in the responses received from Australasian projects. Despite proponents in the region indicating that their regulatory environment did not support a firm decision about funding, the responses also suggest that there has been substantial progress by regulators in progressing regulations, which assists in the making of an investment decision. These responses are perhaps indicative of the success of project-specific legislation, which has enabled the development of individual projects through the crafting of dedicated regulatory models to address the precise requirements of both the project and regulator.

The 2012 survey also sought a project-level appraisal of a number of legal and regulatory elements that were either ‘addressed’, ‘partly addressed’, or ‘not addressed’ by regulation and guidance in their particular jurisdiction (or ‘not applicable’).
FIGURE 44 Project-level appraisals of the domestic regulatory environment
Figure 44 details the number of project-level responses by individual issue. It would appear that several of the legal and regulatory elements, highlighted for consideration in the survey, have been addressed to a significant extent by laws and regulations enacted in some jurisdictions. The view of a number of project proponents is that the selection and evaluation of storage sites, the definition of project boundaries, and issues regarding property and access rights appear to have been addressed to an extent in many countries worldwide. These responses also suggest, conversely, that the current legal and regulatory regimes are incomplete in various jurisdictions and that there are issues requiring further clarification from regulators. The adoption of rules to accommodate CCS under market-based mechanisms, an operator’s duties with regard to remediation and financial security, the post-operational transfer of long-term liability, and standards for the cross-border movement of CO₂ have all been indicated as ‘unaddressed’ by project proponents in some jurisdictions.

The survey responses also indicate that a number of these issues have only been ‘partly addressed’ by the legal and regulatory regimes in some jurisdictions. A constructive interpretation would therefore suggest that many regulators have already begun the process of regulatory development, or that these jurisdictions already provide, to some extent, a supportive environment for CCS activities. Such a positive outlook, however, does not take account of the details omitted from the regulations, particularly the effect of partial regulation upon projects at different stages of the project lifecycle.

A different perspective, perhaps one borne out by many project proponents’ portrayal of the regulatory environment, is that the regulatory process in several jurisdictions has progressed but at a slower rate (as regulators take steps to implement overarching regulatory requirements or make broader policy considerations around the technology).

Appendix F provides a detailed breakdown, by region, of the legal and regulatory issues which several LSIPs have identified as insufficiently addressed by regulators in their respective jurisdictions.

In the survey responses the partial development, or failure to address, market rules to accommodate CCS within prevailing market mechanisms was highlighted as particularly significant by LSIPs.

Notable from the responses is that for projects across Europe, Asia, Australasia, and North America the number of negative responses far outweighs the examples of successful or complete development of legislation to address this issue. For LSIPs in Asia, this disparity is possibly symptomatic of the immaturity of CCS legal, regulatory, and policy frameworks within the region. In North America however, the negative results perhaps indicate the uncertainty many LSIPs continue to face with regard to policies around carbon pricing. North American proponents have also classified the issue as ‘not applicable’ in some instances, indicative perhaps of the role EOR plays in supporting project development in Canada and the US. These particular results may be of concern to regulators and policymakers in Europe, who have sought to clarify the role CCS will play under the EU Emissions Trading Scheme and climate change policy architecture.

Similar assumptions may also be behind proponent responses to issues of standards for the cross-border movement of CO₂, operator’s remediation and financial security requirements, and the post-operational transfer of liability. Respondents in Asia highlighted these issues as insufficiently addressed in their domestic systems, perhaps underlining once more the nascent stage of development of the legal and regulatory frameworks in these jurisdictions. However the responses to these issues from proponents in the US and Canada suggest a different situation, with far fewer proponents viewing the legislation as entirely incomplete or indeed applicable. These results are perhaps again symptomatic of the nature of operations undertaken by LSIPs in North America where there is a prevalence of EOR activities regulated under well-characterised legal and regulatory regimes. A more detailed exploration of the legal and regulatory regimes governing EOR is provided in Chapter 9.

Most notable within these responses are those from European and Australsian project proponents, which highlight deficiencies in some aspects of their domestic frameworks. Despite considerable legislative activity at the national and supranational levels in these regions, it would appear that several specific issues remain. In the EU, these responses are perhaps symptomatic of the pace of the transposition process within several Member States, with a number of delays observed in the past 12 months. The issues of remediation and liability have also proven to be of particular concern for potential operators in Europe and Australia, with some concerned that framework legislation and secondary guidance does not go far enough in determining the extent of their operational and long-term responsibilities.

The responses received to these questions from projects in Asia and North America are particularly striking when contrasted with their earlier responses to the questions addressing the ability to make a FID. Despite the majority of projects in these regions suggesting that their legal and regulatory environment supports a final investment decision, it would appear that this view is not substantiated when considering many of the elements which conventionally make up a regulatory regime for CCS. One explanation is that some of these projects, particularly in North America, have already passed this point in the project lifecycle, or are to be regulated under pre-existing regulatory regimes for EOR operations. The reasons behind these results are less clear in Asia, where many of the projects surveyed remain in the early phases of the project lifecycle.

Project respondents have also highlighted several areas of successful regulation. The law and regulations governing the definition of project boundaries, the drafting and implementation of a monitoring plan, and the selection and evaluation of a storage site have all been identified as sufficiently addressed (to an extent) by projects in Australasia, Europe, and North America.
Conceivably, positive responses are to be expected (to a degree), especially in those regions where there has been widespread development of regulatory frameworks for the technology. Europe’s Member States and Australia have enacted substantial regulatory frameworks for CCS in recent years, supported in many instances by extensive secondary legislation and guidance. The breadth and sophistication of the regulatory models developed have in some measure inspired confidence in LSIPs in these regions. There are however, qualifications to these examples, notably the number of projects which have indicated that some of these issues remain only ‘partially addressed’. In the EU, as suggested previously, this is the likely result of an ongoing process of transposing the requirements of the EU Directive into national laws. In Australia, an example of project-specific legislation has provided the clarity and assurances required by operators.

The issue of incorporating CCS activities into pre-existing planning and permitting regimes has also revealed some not entirely unexpected results, with project respondents in North America, Europe, and Australasia all signalling that the issue has been addressed or partially addressed by domestic legislation. In Australia and many European Member States, CCS activities have in some circumstances been brought within the scope of existing regulations, ensuring that the technology is subject to existing obligations around industrial operation, health and safety, land use planning, and environmental protection.

4.4

GOVERNMENT FUNDING SUPPORT

Governments around the world have provided a range of different types of funding support to CCS demonstration projects. The discussion in this section refers to all direct financial support, including tax credits, not just allocations such as grants. However, it does not quantify the level of revenue support provided under pricing mechanisms such as the EU ETS or the support through electricity pricing adjustments proposed in the UK’s reforms to the electricity market.

The key change to funding arrangements supporting demonstration projects in the past 12 months has been a reduction of nearly US$4 billion due to a more than halving in value of the EU ETS price and the withdrawal of funding from some programs that were developed as part of the stimulus program associated with the GFC during 2008 and 2009.

In total, it is estimated that approximately US$20.7 billion is available to support LSIPs. Approximately 65 per cent of the available funding has been allocated to specific projects (Figure 45).

**FIGURE 45 Public funding support commitments to CCS demonstrations by country**
CCS funding programs and GFC stimulus

In 2008 and 2009, many governments announced major public spending programs that focused on stimulating the economy in response to the GFC. During this time, there was significant support for increasing government spending to offset declines in private spending. Included in these large stimulus programs was government spending for clean energy, partly in anticipation of coordinated global policy action to reduce GHGs at COP 15 in 2009. The total funding for clean energy programs amounted to US$195 billion (Czajkowska and Munro 2012). Of this, US$9.3 billion was provided to CCS, approximately 5 per cent of the total global green stimulus package (Table 12).

TABLE 12 Stimulus funding for CCS

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>PROGRAM TITLE</th>
<th>FUNDING</th>
<th>FUNDING (IN US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>CCS Flagships Program</td>
<td>AU$4.0 bn</td>
<td>US$4.1 bn</td>
</tr>
<tr>
<td>Canada</td>
<td>Clean Energy Fund</td>
<td>CA$0.6 bn</td>
<td>US$ 0.6 bn</td>
</tr>
<tr>
<td>EU</td>
<td>European Energy Programme for Recovery (EEPR)</td>
<td>€1 bn</td>
<td>US$1.2 bn</td>
</tr>
<tr>
<td>US</td>
<td>ARRA – Clean Coal Power Initiative</td>
<td>US$3.4 bn</td>
<td>US$3.4 bn</td>
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<tr>
<td></td>
<td>ARRA – FutureGen</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>ARRA – Industrial Carbon Capture and Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>US$9.3 billion</strong></td>
<td></td>
</tr>
</tbody>
</table>

1. Based on July 2012 exchange rates. As the US dollar has appreciated relative to most currencies since the GFC, the US dollar values reported here are lower than would have been the case at the time the programs were announced.

Funds from stimulus programs form a major part of the total funding for CCS developments, representing 40 per cent of the total global funding (Figure 46).

FIGURE 46 CCS funding programs by stimulus funding

US$ billion
- Orange: Stimulus
- Blue: Non-stimulus
Stimulus spending programs were designed to be ‘timely, targeted, and temporary’ and most had legislated deadlines for commitment of the funds to specific projects. For example, funds in the American Recovery and Reinvestment Act (ARRA) were required to be allocated to projects by 30 September 2010, while EEPR funds were required to be committed by 31 December 2010.

Where funds in these programs formerly committed to projects were subsequently returned to governments due to project cancellations or suspensions, that money is not currently available to other CCS projects. Over the past 15 months, US$1.4 billion has been returned associated with project suspensions in the US (AEP Mountaineer), Canada (Project Pioneer), and Europe (Vattenfall Jänschwalde).

Australia’s CCS Flagships program has been repurposed away from stimulus funding and is now considered an integral part of Australia’s clean energy initiative in response to climate change risks. Nonetheless, since the program was announced in 2009, funding has been reduced by more than US$600 million in response to other budget priorities of the Australian Government.

The bulk of the project-level funding allocated to date has been awarded to 19 projects receiving US$200 million or more each. In total, these LSIPs have been allocated US$8.6 billion, accounting for 64 per cent of total CCS project funding awarded. FutureGen 2.0 is the largest single project recipient receiving US$1.048 billion. See Section 3.3 for the full breakdown.

NER300 funding program declines

The NER300 program in Europe was designed to support CCS and innovative renewable energy projects through the sale of 300 million allowances in the EU ETS. At the time of the program’s design, the market price in the EU ETS was in the range of €16–20/tonne and projected to rise to €25/tonne by December 2013. However, with the recession in Europe depressing energy demand, and the use of renewable energy targets and energy efficiency policies resulting in the ETS acting as a residual carbon market, prices began to decline during 2011.

When sales of the NER300 EUAs commenced in December 2011, prices had fallen to around €9/tonne. By August 2012, around 180 million allowances sold at an average price of a little over €8/tonne.

In July 2012, the European Commission announced that around 60 per cent of the funds raised from the NER300 program would be provided to CCS projects. It is estimated that total funding from the program for CCS projects will be approximately €1.2 billion (US$1.5 billion), after accounting for the costs incurred by the European Investment Bank in selling the NER300 allowances through a range of financial channels. This contrasts with the €4.5–6 billion initially thought to be available for CCS projects when the funding arrangements were announced in 2008. The change is due to both a substantial fall in ETS prices as well as reduced overall level of funding due to the subsequent decision to include innovative renewable energy projects.
4.5

CHALLENGES AND OUTLOOK

Carbon prices are currently recognised as essential but not sufficient drivers of CCS projects. The importance placed by project proponents on carbon prices emphasises the need for governments to continue both national and international actions to put a price on carbon emissions. To this end, there have been some positive developments in the past year, such as the introduction of a carbon price in Australia. However, much more needs to be done.

The challenges of addressing climate change are often presented in the public domain as being insurmountable and politically fraught. While the challenges remain great, there is clearly a substantial level of international collaboration, goodwill, and legal basis to form a legitimate expectation that sustained mitigation action will not only form tomorrow’s business-as-usual expectations, but will increasingly be deliverable and affordable. Nevertheless, it is clear from the negotiations throughout 2012 that reaching agreement on the post-Kyoto framework will experience substantial challenges.

At the level of international negotiations, key issues include the length of the second Kyoto commitment period and the extent to which surplus ‘rights to pollute’ (allowances) from the first commitment period can be carried over to the second. This latter point is very important, as it will influence the supply of allowances and hence the global price of carbon. While the second Kyoto commitment period starts on 1 January 2013, there is still debate whether it ends in 2017 or 2020.

Within the UNFCCC framework, the AWG-LCA and AWG-KP are destined to end their work plans in 2012. Any outstanding issues will thus need to be tasked to the remaining bodies – the ADP, SBI, and/or SBSTA. The SBI is already managing the implementation of the institutional arrangements supporting NAMAs, for which the issues of technology transfer and climate financing remain critically important.

The post-2020 action (mitigation and adaptation) to combat climate change is being negotiated in the ADP. The first meeting of the ADP was held in May 2012, and it is clear that the lack of distinction between developed and developing nations in the need for action will create some tension for some time. This makes the concept of ‘equity’, in conjunction with the NAMA process, fundamental to the success of any new climate change regime.

International action is also commencing to develop standards for CCS. As noted above, the setting of standards on the basis of incomplete information could potentially lead to overly conservative permitting requirements being imposed on demonstration and pre-commercial CCS projects, which could undermine the ability of proponents to proceed with innovative and often first-of-a-kind demonstration projects.

To overcome these problems, it is suggested that a ‘one size fits all’ approach should be avoided where possible. When appropriate, a fit-for-purpose approach is sufficient to provide for accurate, conservative, relevant, credible, reliable, complete, and verifiable data monitoring plans and measurement methodologies. A large number of published peer-reviewed expert reports exist that provide for approaches and/or recommendations to address and/or redress CCS-related issues. The adequacy of applying these existing and extensive suites of best practice guidelines and protocols should be tested first before imposing additional sets of rules on CCS projects. It would seem that sufficient technical and scientifically valid analysis, methodology, and procedures currently exist to appropriately address CCS demonstration-related issues.

There has been good progress over the past year in relation to one international marine agreement affecting CCS (the OSPAR Convention) but not the other (the London Protocol). While many LSIPs may undertake offshore CCS transport and storage, at this stage their planned CCS activities require CO₂ to cross international boundaries only from domestic to international waters, and not into another contracting party’s jurisdiction. Considering that this does not amount to ‘cross-border’ movement of CO₂ from one jurisdiction to another, the IEA (2011c) argues that it is unlikely that the situation would be covered by the London Protocol prohibition. While there is little information to suggest that these projects are planning to send captured CO₂ to another jurisdiction for storage, any cross-border plans may be precluded by the current prohibition under the London Protocol. Eliminating the prohibition against cross-border transport and storage of CO₂ will be especially important for jurisdictions that find that CCS is a viable GHG mitigation option but which do not have the suitable geology for storage or have limited storage capacity.

Delays posed by slow progress internationally will inevitably require national and sub-national policies to address any associated uncertainty around investing in low-carbon technologies such as CCS, and to address more general carbon-related obligations.

Modest policy developments have been reported over the past year, with the most notable perhaps being the ongoing implementation of the UK’s climate change policies, Australia’s establishment of a carbon price, Korea’s adoption of an emission trading scheme in 2015, and South Africa’s budgeting for a phased introduction of a carbon tax in 2013. Increasingly, carbon pricing arrangements (carbon tax and emissions trading schemes with international linkages between national schemes) are emerging, as are performance standards and innovative financing and funding measures.
Governments have a wide array of policy and regulatory instruments available to use to address the level of emissions and facilitate climate mitigation action. These include:

- a range of policy levers that in effect establish a price on carbon emissions, such as establishing a tradable market in emissions (the EC’s ETS), imposing a direct tax on emissions (Norway), setting a minimum ‘floor’ price to drive technology deployment (the UK’s carbon floor price scheme), or a combination of these approaches (such as Australia’s initial carbon tax moving to a trading scheme);
- market-based and/or technology-specific drivers to favour deployment of low-carbon or ‘clean’ technologies, such as feed-in tariffs, portfolio quotas for electricity supply companies, and a range of other market mechanisms aimed at harnessing the power of the market to support the development and ultimate deployment of low-carbon technologies;
- direct policy and/or regulatory action to prevent or limit emissions, such as emissions performance standards (Canada and UK), direct bans on certain technologies such as no new coal-fired power stations (Denmark, New Zealand), specific requirements on deployment of some technologies such as new fossil fuel generation (above a certain capacity) to integrate CCS (Scotland) or to undertake a CCS Ready assessment (EU CCS Directive), and requirements that new plants be CCS Ready (France, UK); and
- both direct and indirect support for the development and deployment of emerging technologies, such as direct capital assistance (Australia’s CCS Flagships program, EC NER300 grants), and aid for focused research and development.

Within this context, the perception of CCS project participants is that only modest policy change has taken place recently, and that while the current mix of policy settings are viewed as being supportive of positive investment decisions in CCS projects, they are seen as inadequate. Investors in CCS projects (including financial institutions, emitters, manufacturers, and service providers) are clearly focusing on the opportunities and risks presented by an evolving balance of policy settings aimed at supporting CCS projects while also intended to drive commercially attractive mitigation outcomes.

The IEA (2012c) observes that the technologies with the greatest potential for saving energy and reducing CO₂ emissions are making the slowest progress. In particular, they state specifically that CCS is not receiving the necessary rates of investment into full-scale demonstration projects and that nearly half of new coal-fired power plants are still being built with inefficient technology. In addition to broad climate policy, adequate government funding of demonstration projects is also required to spur investment. In this regard, available funding, while considerable, is shrinking and is increasingly vulnerable. A major challenge for government is to ensure that CCS is treated equitably with other emerging clean-energy technologies.
5 CCS IN DEVELOPING COUNTRIES

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5.2 Status of CCS in developing countries 93
5.3 Demonstration projects provide drivers for CCS in developing countries 96
KEY MESSAGES

- 70 per cent of CCS deployment will need to occur in non-OECD countries to achieve global emission reduction targets by 2050.
- Undertaking enabling, pre-investment, and demonstration activities today puts developing countries in a position to benefit tomorrow from CCS emission reductions.
- At least 19 developing countries are currently engaged in CCS-related activities, mostly at the early stage of scoping out the opportunities and potential for CCS.
- Implementing CCS pilot or demonstration projects acts as a catalyst for CCS development around all aspects of the technology, both technical and non-technical.

5.1 IMPORTANCE OF CCS IN DEVELOPING COUNTRIES

In order for CCS to play a role in reducing global CO₂ emissions on a significant scale, it will need to be deployed in both developed and developing countries (‘Annex 1’ and ‘Non-Annex 1’ countries respectively, under the UNFCCC), particularly since it is expected that in the coming decades all the net fossil fuel growth (and associated CO₂ emissions) will come from developing countries. The IEA estimates that 70 per cent of CCS deployment will need to happen in non-OECD countries to achieve global emission reduction targets by 2050 (IEA 2012b).

A substantial challenge for many developing countries is to increase access to energy in a sustainable, climate-friendly way. Many developing countries are also interested in continuing to utilise their indigenous fossil fuel resources to ensure energy security and to continue to benefit from them economically.

While developing countries may face many obstacles to CCS deployment, under the UNFCCC Annex 1 parties have agreed to assist developing countries to undertake mitigation action. As previously reported in the Global Status of CCS: 2011, since 2009 a number of governments and organisations have collectively contributed or allocated hundreds of millions of dollars to current and future activities to support CCS capacity and project development in developing countries. Organisations and countries that have contributed significant funds in this space include the EU, the Global CCS Institute, the Norwegian Government, the UK Government and the US Government. These contributors have provided direct support by financing specific activities, as well as contributing to CCS capacity development funding mechanisms managed by organisations such as the ADB, APEC, the CSLF, the World Bank, and the Institute itself.

The most significant funding contribution in 2012 has come from the UK Government. At the CEM held in London on 25–26 April 2012, the UK Government announced £60 million to support CCS in developing countries, in response to a call for funding from the Working Group on CCS Funding Mechanisms for Developing Countries, a subgroup of the CEM Carbon Capture Utilisation and Storage (CCUS) Action Group.

The significant emission reductions that can be obtained by CCS underpin the international funding support outlined above, but emission reductions need to be realised at the project level within individual countries. However, a number of recurrent...
concerns are shared by a number of developing countries. Key concerns tend to include the high cost of CCS, access to energy, and permanence of storage. This underlies the importance of capacity development and knowledge sharing, even at the early stages:

- Analyse the costs of CO₂ mitigation efforts compared to the cost of climate change impacts on health, population migration, catastrophic events, etc. The IEA estimates that abandoning CCS as a mitigation option in electricity generation increases investment cost in other low-carbon technologies by 40–57 per cent in order to meet emissions reduction targets (IEA 2012b).
- Keep abreast of developments in capture and compression technology. Reducing the energy penalty will be vital for large-scale deployment of CCS, addressing not only a significant cost component but also the ‘energy access’ issue. However, it is only through ongoing research and development and ‘testing’ CCS at large-scale demonstration projects that the energy penalty issue can be addressed.
- Learn from the experience of existing pilot and large-scale demonstration projects, in particular about the monitoring, measurement, and verification techniques that can be utilised to track the permanence of CO₂ storage.

**Why should developing countries prepare for CCS now?**

These aforementioned concerns and the challenges posed by CCS are prompting a ‘wait and see’ approach in some developing countries. Such an approach was a key issue identified by the CEM Working Group on CCS Funding Mechanisms for Developing Countries. The Working Group identified the importance of acting now. If countries identify that CCS is a relevant technology for their low-emission strategies, then it is important for countries to start undertaking the enabling, pre-investment, and demonstration activities now in order to be in a position to benefit from emission reductions from CCS in the coming decades. Many of these enabling and pre-investment activities will need to address country-specific requirements.

Enabling and pre-investment activities that need to be undertaken before implementing a CCS project include, but are not limited to:

- developing geologic storage assessment;
- developing legal and regulatory frameworks;
- understanding the technology and project development framework through pre-feasibility and feasibility studies;
- understanding funding and commercial issues; and
- good practices for public engagement.

Some of these activities can take a number of years to develop. For instance, storage characterisation from the basin level down to the site-specific level can take 3–6 years or longer, depending on how much information is already available. Developing appropriate legislative and regulatory frameworks for implementing CCS can also take considerable time, depending on the individual circumstances of each country or region.

The storage and regulatory aspects not only take time to develop, but are not transferable from country to country. The fact that these aspects are not transferable is an argument against taking a ‘wait and see’ approach. Taking a more active approach is particularly relevant for developing countries which have an ongoing interest or reliance on fossil fuel from the perspective of: “securing revenues from fossil fuel production; consuming fossil fuels to promote economic growth; promoting energy security; promoting regional cohesion; and facilitating foreign-policy objectives, such as earnings from CCS technology exports” (Meadowcroft and Langhelle 2009).

Some countries have undertaken dedicated CCS scoping studies to investigate their CCS potential. These studies generally consider key aspects such as the country’s emissions profile (whether there is a high degree of emissions from fossil fuel based power generation and/or industrial processes which is suited to CCS), its storage potential, and the feasibility of transporting CO₂ to likely storage sites.
5.2

STATUS OF CCS IN DEVELOPING COUNTRIES

Of the 75 LSIPs identified around the world in this report, 17 are in developing countries. This is an increase of five since 2011. There are at least 19 developing countries engaged in CCS activities. Activities in these countries range from capacity development, pre-investment, and planning activities, and in two cases it involves operation of a CCS project. Most of these 19 countries are at an early stage of scoping out the opportunities and potential for CCS. There is a growing awareness of CCS as a potential mitigation technology within developing countries, especially by those which have a heavy reliance of fossil fuel based energy and industries. This growing awareness and importance has been facilitated by the inclusion of CCS in the UNFCCC’s CDM.

The CCS development lifecycle represented in Figure 47 is a tool developed by the Global CCS Institute to help conceptualise different stages of CCS development. This tool helps identify what sort of capacity development and pre-investment activities are relevant for a country based on where they are in the lifecycle. The lifecycle is split into five major stages, and the rotating circles imply that moving through the different stages is an iterative process and not necessarily linear. In fact, it can be seen that some countries are operating in different stages, sometimes concurrently, driven by their own needs, interests, approaches, and projects.

Figure 47 identifies what sort of activities a country has undertaken or is undertaking. The purpose of the figure is to provide an overview of the key types of activities being undertaken at a country level. It should be noted that different sectors within individual countries will be at varying stages of the lifecycle.

While most developing countries are still at the early ‘scoping’ stage, there are some developing countries which are further along the development lifecycle, notably Algeria, Brazil, Mexico, South Africa, the UAE, and China.

The In Salah project in Algeria, which is a gas processing project, started injecting CO\textsubscript{2} in 2004. More than 3 million tonnes of CO\textsubscript{2} have been stored in a deep saline aquifer (more than 2 km underground) so far. The natural gas extracted at the site contains a small percentage of CO\textsubscript{2}; this CO\textsubscript{2} needed to be separated out of the gas stream to ensure purity standards for sale. The two original partners in the project, BP and Sonatrach, decided to invest US$100 million to store the CO\textsubscript{2} geologically, rather than just vent it, thereby making a valuable contribution to the demonstration of CCS and its monitoring, measurement, and verification (MMV).

In Brazil, Petrobras has reported that the Miranga CO\textsubscript{2} Experimental Site sequesters close to 200,000 t of CO\textsubscript{2} per annum, work which is being undertaken on a commercial scale. Petrobras plans to sequester CO\textsubscript{2} at the Lula oil field as part of an EOR project. This project is part of a plan by Petrobras to invest in 2–4 large-scale CCS demonstration projects as part of its sustainability and climate change plan.

Mexico has made significant progress in 2011–12 in putting CCS on its policy agenda. The development of a National CCUS Strategy and Regulatory Framework was identified as a goal in Mexico’s National Energy Strategy 2012–26 which was presented to the Mexican Congress in March 2012. Mexico also released a country-level storage atlas in May 2012 and is now focusing on developing a regional atlas. In addition, the country is undertaking scoping studies for a CCS demonstration project. Mexico has a high potential for EOR, and there is recognition of a synergy between achieving low-emission goals (especially from the power generation sector) and increasing yields from aging oil and gas fields.

South Africa is committed to addressing climate change while continuing to improve access to household electricity, address energy security, and alleviate poverty. They recognise that the negative impacts of climate change will ultimately cost more and have a bigger negative impact, especially on the poor, than the cost of addressing climate change. With the majority of South Africa’s GHG emissions coming from the energy industry, CCS has been identified as a key technology that can help achieve CO\textsubscript{2} emission reduction goals. As such, South Africa’s National Climate Change Response Policy, which was endorsed by its Cabinet on 12 October 2011, identifies CCS as one of South Africa’s eight Near-term Priority Flagship Programmes. South Africa is currently focusing on a number of planning and enabling activities to facilitate the implementation of a CO\textsubscript{2} test injection project. These activities include evaluating its regulatory framework, creating a public engagement strategy, and undertaking a technical feasibility study.

As discussed in more detail in Chapter 2, the UAE has three LSIPs in the planning and development stage. The plan is to use the CO\textsubscript{2} captured from a network of projects for EOR.

There is a growing recognition in China of the importance of CCS as part of a portfolio of solutions for reducing the country’s GHG emissions from its large and rapidly expanding power generation and other coal-based industries. The past 18 months have seen a number of important developments regarding CCUS in China, particularly on policy and projects, and active involvement and support from the Central Government.
<table>
<thead>
<tr>
<th>Scope</th>
<th>Put CCS on policy agenda</th>
<th>Create enabling environment for CCS</th>
<th>Project delivery</th>
<th>Multiple large-scale CCS projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify basic CCS technical potential</td>
<td>Identify key stakeholders</td>
<td>Stimulate debate</td>
<td>Investigate CCS as a policy option</td>
<td>Establish funding and financial incentives</td>
</tr>
<tr>
<td>Create enabling environment for CCS</td>
<td>Establish CCS expertise</td>
<td>Build CCS expertise</td>
<td>Build public engagement expertise</td>
<td>Identity</td>
</tr>
<tr>
<td>Project delivery</td>
<td>Project delivery</td>
<td>Project delivery</td>
<td>Project delivery</td>
<td>Project delivery</td>
</tr>
<tr>
<td>Multiple large-scale CCS projects</td>
<td>Multiple large-scale CCS projects</td>
<td>Multiple large-scale CCS projects</td>
<td>Multiple large-scale CCS projects</td>
<td>Multiple large-scale CCS projects</td>
</tr>
</tbody>
</table>

**KEY:**
- Activity in this place

**FIGURE 47 CCS development lifecycle**

- Algeria
- Botswana
- Brazil
- China
- Egypt
- India
- Indonesia
- Jordan
- Kenya
- Kosovo
- Mexico
- Maghreb
- Malaysia
- Philippines
- South Africa
- Trinidad and Tobago
- Thailand
- UAE
- Vietnam
China is now clearly transitioning from purely focusing on CCS R&D to taking steps towards creating an enabling environment for the demonstration and deployment of CCS.

In March 2011, the National Development and Reform Commission (NDRC) issued China’s Notification on Orderly Development of Coal-Chemistry, which requires all new coal-chemical demonstration projects to be capable of substantially reducing CO₂ emissions. This means that newly-built coal-chemical demonstration projects will need to consider installing technologies such as large-scale CCUS facilities in order to control their CO₂ emissions.

In March 2011 the Chinese Government issued its much-anticipated 12th Five-Year Plan (2011–15) (FYP), a blueprint outlining the key economic and development targets for the country. Unlike previous plans, there is considerable focus on energy and climate change and plans for a slower and more sustainable growth trajectory. The key targets to reduce China’s GHG emissions under this plan include:

- reducing carbon intensity (CO₂ emissions per unit of GDP) by 17 per cent;
- reducing energy intensity (energy consumption per unit of GDP) by 16 per cent; and
- increasing the share of non-fossil energy to 11.4 per cent.

Following the release of the national 12th FYP, in November 2011 the NDRC issued the 12th Five-Year Work Plan on Controlling GHG Emissions. This work plan outlines China’s goal of developing new CCUS technologies and indigenous intellectual property rights. It includes broad goals to develop the technology across a range of sectors including thermal power, coal-chemical, cement, and steel. It also states China’s plans to develop fully integrated CCS demonstration projects with the captured CO₂ to be used for EOR or for geologic storage. More recently, in March 2012, NDRC issued the 12th FYP on Coal Industry Development, which states that China will support research and demonstration of CCUS.

For the first time, the recent period has also seen strong public endorsements of CCS from a number of senior Chinese leaders, including from the NDRC Vice Chairman, Xie Zhenhua, at a CCS Conference in July 2011. In March 2012, senior NDRC leaders reinforced China’s commitment to developing CCS with the signing of the MoU with the Global CCS Institute to strengthen the parties’ cooperation on CCS.

Coinciding with these positive policy developments is a recent increase in the number of LSIPs in China. In the 2012 project survey, five new LSIPs were recorded in China, bringing the total number of China’s LSIPs to 11.

Appendix G summarises some of the specific activities that have been undertaken in the 19 countries identified.

Policy, legal, and regulatory developments

There has been a preliminary analysis of legal and regulatory issues and/or review in the majority of developing countries that have an interest in CCS, including Brazil, China, Botswana, India, Indonesia, Jordan, Kosovo, Malaysia, Philippines, South Africa, Thailand, Trinidad and Tobago, and Vietnam. Most of these preliminary analyses can be found in studies funded through APEC, the ADB, the CSLF, the Global CCS Institute, and the World Bank; some studies are still being finalised.

The depth of analysis differs between studies. For instance, in Botswana the World Bank on behalf of the Government is undertaking a CCS feasibility study to evaluate CCS opportunities in the country, as well as make recommendations as to an appropriate legal and regulatory environment. At a CCS workshop conducted in 2010, Botswana identified areas upon which regulations need to be defined, including possible leakage of CO₂ and its impact on groundwater quality, CO₂ streams for storage, suitability of storage sites, and permits for filling pore spaces.

In addition, the UAE commenced a study to develop a CCS Value Proposition taking into account the necessary CCS regulatory framework and international standards set by the UNFCCC.

In Latin America, CCS is seen as a crucial component in the region’s efforts to combat climate change, particularly for emerging oil-based economies such as Mexico, Brazil, and Venezuela. However, undertaking commercial-scale CCS projects in the region is difficult without a legal framework in Latin America. The Latin American Thematic Network on Carbon Dioxide Capture and Storage was formed to help facilitate the development of CCS. The Network seeks to promote collaboration and integrate CCS activities by scientists, research centres, and other agencies.

Refer to Appendix E for a summary of the key policy context in a number of countries including Brazil, China, India, Indonesia, Malaysia, Mexico, Saudi Arabia, South Africa, and Trinidad and Tobago.
Storage developments

Brazil, Mexico, and South Africa are developing countries that have already undertaken a country-level storage assessment. Brazil is in the process of finalising its storage atlas for publication later in 2012. Mexico released their country-level storage atlas in May 2012 as part of the North American Carbon Atlas Partnership program. Mexico is now focused on investigating basins in the north of the country. South Africa released its national storage atlas in 2010, and is undertaking three more detailed storage assessments at basin level, the outcomes of which will feed into decisions around a test injection project. China has also undertaken some fairly developed regional-scale storage assessments as well as some detailed site characterisation, especially in relation to EOR.

Very preliminary storage assessments have been undertaken (or are currently being undertaken) as part of broader CCS scoping studies in a number of other developing countries, including Botswana, Indonesia, Jordan, Kosovo, the Maghreb region, Malaysia, Philippines, Thailand, and Vietnam.

5.3

Demonstration projects provide drivers for CCS in developing countries

The developing countries that are most advanced along the CCS lifecycle are countries that are developing or have already implemented a CCS pilot or demonstration project. Pilot and demonstration projects are a key part of ‘learning by doing’. These projects provide a catalyst or focus for associated activities such as capacity development, enabling, and pre-investment.

Demonstration projects and their learning by doing underscore the importance, at least in the short term, of funding for enabling and pre-investment activities in developing countries. In the medium term, more significant funding is needed for the ‘extra’ CCS costs associated with construction and operation of at least 5–10 demonstration projects in these countries.

As discussed above, a key catalyst underpinning interest in CCS in a number of developing countries is the link with enhanced oil recovery and/or gas processing. Given that EOR can help make CCS projects commercially viable, developing countries with EOR potential are well placed to take further CCS steps in the future (e.g. Indonesia, Malaysia, the Middle East, and countries in North Africa).

GLOBAL CCS INSTITUTE’S APPROACH TO CAPACITY DEVELOPMENT

The Global CCS Institute defines capacity development as a country’s ability to build awareness, understanding, knowledge, and ultimately the skills required to progress CCS. It may be appropriate to build knowledge and understanding across a variety of stakeholder groups, including policy makers, regulators, industry, and not-for-profit organisations. All these groups are vital in making CCS a viable low-carbon energy solution. CCS capacity can be built around a number of different topics, for example;

- government understanding of legal and policy issues and how this applies to legislation and regulation development and application;
- technical knowledge and skills in engineers, geologists, and project managers;
- understanding financial and commercial issues, risks, and incentives by policy makers, lenders, and companies; and
- the ability of companies and governments to effectively and genuinely engage with the public and local stakeholders around a specific CCS project.
The Global CCS Institute facilitates capacity development by:

1. helping countries develop and implement tailored capacity-development programs; and
2. supporting important capacity development activities delivered through other key organisations.

It has identified an approach to helping countries develop and implement tailored capacity development programs, outlined in Figure 48 below. This approach is adapted and modified as needed, depending on the country’s situation.

**FIGURE 48 Global CCS Institute approach to capacity development**

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>DESCRIPTION</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select countries of focus</td>
<td>Identifying countries of focus, currently: - China - India - Indonesia - Malaysia - Mexico - South Africa</td>
<td>- Engagement with countries of focus. - CCS scoping study. - Capacity assessment.</td>
</tr>
<tr>
<td>Conduct capacity assessment</td>
<td>- Understanding of country situation and context. - Understanding capacity strengths and opportunities.</td>
<td>- CCS scoping study. - Capacity assessment.</td>
</tr>
<tr>
<td>Design capacity development program</td>
<td>- Developing a clear, integrated capacity development work plan with defined approach, activities, processes and stakeholder engagement.</td>
<td>- Tailored capacity development program. - Capacity development initiatives/activities implemented. - Capacity development progress reports.</td>
</tr>
<tr>
<td>EXECUTE AND PROGRAM MANAGE</td>
<td>- Implement the program as agreed with country stakeholders. - Tracking progress against plan objectives. - Evaluating performance. - Refining the plan where necessary.</td>
<td>- Capacity development information and knowledge products.</td>
</tr>
<tr>
<td>Refine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iterate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Global CCS Institute has also provided funding to (and works with) other key CCS capacity development organisations, such as the ADB, the Cooperative Research Centre for GHG Technologies (CO2CRC), the CSLF, the IEA, and the World Bank. Many of the capacity development activities identified in Appendix G have been supported through these organisations and the Global CCS Institute.
6

CAPTURE

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6.3 Key challenges to large-scale demonstration of capture 110
6.4 Moving towards commercial-scale demonstration 114
Capturing CO₂ at a commercial scale is currently being undertaken in gas processing and industrial processes that produce high-purity CO₂. Capture is starting to be applied to power generation at the demonstration scale.

Creating a viable business case for first-of-a-kind capture projects at commercial scale in power generation remains the key challenge for power generation. The high capital costs and ongoing operational costs (partly due to additional energy requirements associated with capture) are the key obstacles.

Advances have been made in oxyfuel combustion through the commissioning of two small-scale oxyfuel combustion demonstration projects.

Pilot-scale facilities are demonstrating capture of CO₂ from coal-fired power generation, but more operational experience is required.

Further work needs to be supported to reduce the cost of capture, including promoting more efficient combustion processes, improved integration and flexibility of CCS into the power plant, and ongoing R&D into new capture technologies.

Capture demonstrations in iron and steel and cement manufacturing need to be further encouraged.

6.1 INTRODUCTION

Capturing CO₂ that would otherwise be emitted to the atmosphere, cleaning it, and compressing it to the point where it can be transported represents the greatest additional costs for applying CCS to power generation. In some other processes, for example gas processing, the CO₂ is already captured as part of the process, so the greatest cost is that of compressing, transporting, and storing the CO₂ instead of venting it to the atmosphere. This chapter provides an update on the progress made in capture technology, its challenges, and an outlook across the different sectors where CCS can be applied.

The most advanced technology options for CO₂ capture from fossil fuel usage are:

- pre-combustion capture from gas streams;
- post-combustion capture from combustion flue gas; and
- oxyfuel combustion – the direct combustion of fuel with oxygen.

These three approaches are shown for coal-based power systems in Figure 49. These technologies can also be applied to gas-fired power systems and are also applicable to certain non-power generation applications.
Pre-combustion capture in IGCC power plants requires a partial reaction of the fuel with oxygen or air under high pressure. This produces a synthetic gas consisting of CO₂, CO, and H₂. Further hydrogen can be produced through a water-gas shift reaction. The CO₂ from the resulting gas can be removed using an acid gas removal (AGR) process which uses solvents. The separation of CO₂ produces a hydrogen-rich gas that is burned in a gas turbine to produce electricity.

Pre-combustion capture of CO₂ using AGR processes is already practised commercially at full-scale in oil and gas processing, and chemicals plants where CO₂ is separated as part of the standard industrial process. This process is slightly different to pre-combustion for power generation.

The second main process for separating CO₂ from flue gases is post-combustion capture. This involves the removal of the CO₂ from the flue gas after the fuel has been completely combusted. It can be applied to newly designed fossil fuel power plants, or retrofitted to existing plants. Processes using liquid solvents (absorption) are currently the most advanced options for post-combustion capture, but there is research and development underway to investigate other technologies such as membranes and solid adsorbents. Post-combustion capture can also be applied to other industries producing flue gases containing CO₂ such as cement production, oil refining, and petrochemicals.
A third technology is oxyfuel combustion, where the fuel is burned with high-purity oxygen instead of air. This eliminates the nitrogen in the flue gases and produces a flue gas with a high concentration of CO$_2$. The oxygen is sourced through an air separation unit (ASU). The resulting flue gas contains mostly CO$_2$ and is then cleaned, dried, and compressed.

Oxyfuel combustion can be applied to both new plants and can also be retrofitted to existing plants. In a coal-fired oxyfuel power plant, some flue gas (mainly consisting of CO$_2$) is recycled to use in the oxygen-fired boiler, effectively replacing nitrogen from air to keep the temperature at a level acceptable for boiler tube materials. Oxyfuel technologies can also be used in other industries including cement, steel manufacturing, and oil refining.

Within each of these three advanced capture technologies are multiple pathways such as solvents or membranes. The selection of the technology and its pathway needs to consider the fuel being used, the climate conditions, the availability of resources (such as water) at the chosen locations, and the operational requirements of the plant.

Figure 50 illustrates the spread of technologies for power generation from the existing portfolio of LSIPs. The majority of projects apply post-combustion capture, which reflects retrofitting of existing power stations with capture technology. New plants are favouring pre-combustion technology. There is a mix of retrofit and new plants for the six oxyfuel projects.

**FIGURE 50 Number of power generation LSIPs by capture technology and stage**

![Graph showing the distribution of LSIPs by capture technology and stage](image)

Pre-combustion is the technology used for all the projects that are currently operational. This covers natural gas processing and syngas or fertiliser production.

In industries such as steel mills and cement plants, capture processes are still in early stages of development in comparison with power generation and gas processing projects. However, it is possible that an existing capture technology can be tailored to suit the particular production process. For example, biofuel production may require only simple capture technologies, as almost pure CO$_2$ is produced from fermentation and it often only requires dehydration and compression before being transported.
CAPTURE TECHNOLOGY PROGRESS

Progress has been made in capture technology during 2012. This progress relates to ongoing construction of large-scale capture projects covering pre-combustion across a range of industries and post-combustion capture applied to coal-fired power generation and the demonstrating of oxyfuel technology at smaller scale.

This section describes the progress made in power generation, followed by the progress made in the non-power generation sector.

Pre-combustion capture progress in power generation

Pre-combustion carbon capture systems for power generation have been demonstrated at pilot and demonstration scale and there are projects under construction that will demonstrate the technology at a commercial scale. The focus of RD&D is on the reduction in capital cost and in particular a reduction in parasitic energy requirements of existing and new pre-combustion capture systems.

In the US there are pre-combustion carbon capture projects in power and/or industrial applications that are progressing into construction or are showing promise in achieving a positive FID. These projects partially offset the cost of capture through additional revenue from captured CO₂ such as enhanced oil recovery.

The most developed commercial scale IGCC with CCS plant is being built by the Mississippi Power Company – a subsidiary of Southern Company – in Kemper County in the US. Construction is well underway, with operations scheduled to commence in 2014. Globally, this will be the first to combine commercial-scale IGCC and CCS. Its construction and operation aims to demonstrate that commercial scale IGCC and CCS is both technically and commercially viable. The project will generate 524 MW of electricity and approximately 65 per cent of its emissions will be captured using a Selexol acid gas removal unit. The annual CO₂ to be captured will be approximately 3.5 Mt. Engineering has been a joint effort between Southern Company Services and a third party, with the latter undertaking procurement and construction management. Through this joint approach to engineering the project is already achieving additional project delivery cost savings.

Another project in the US is the Texas Clean Energy Project (TCEP) being developed by the Summit Power Group. This will be a 400 MW (gross) IGCC poly-generation plant with CCS. Some of the produced syngas will be used for power generation and the balance will be used for the production of granulated urea for commercial sale. Using poly-generation will create additional revenue for the project. The project will capture 90 per cent of the CO₂ from the production of urea using Rectisol. EPC contracts and operation and maintenance agreements were finalised in early 2012 with three EPC contractors. The project is expected to make an FID in late 2012.

In a similar project, SCS Energy is developing the Hydrogen Energy California Project. This is a 400 MW (gross) IGCC poly-generation plant. A portion of the syngas produced is proposed to fuel a gas turbine power block and the balance will also be used for the commercial production of granulated urea.

Other projects of note in the US involve modifications to existing industrial gas processing and chemicals facilities, and include the Air Products Steam Methane Reformer EOR Project in East Texas that is planning to capture 1 Mt per annum of CO₂ from existing syngas plants. Also, the Leucadia Energy CCS Project in Lake Charles, Louisiana, is planning to capture 4.5 Mt per annum of CO₂ in an existing methanol plant (from syngas). All the aforementioned projects have received significant government funding from US DOE/NETL.

One of the projects at an advanced stage of development outside of the US is the Chinese 250 MW GreenGen IGCC/CCS project. Following completion of Stage I, the project will be enlarged to 650 MWe though the addition of a 400 MW unit. The exact duration of the subsequent R&D operational program for the plant (rather than subsequent commercial power generation) has not yet been finalised however this project shows the successful operation of IGCC outside North America.
The Global CCS Institute uses a Technology Readiness Level (TRL) to indicate the development level of the capture technologies described. This system was developed by NASA in the 1980s to better understand the developmental pathways of immature technologies. The TRL uses a scale of 1–9 to measure development from a basic concept (1) through to being available at commercial scale (9), with each step representing an increase in the level of maturity of a technology. The nine TRLs are described in the box below. TRLs 1–5 are often denoted as research, while TRLs 5–9 are focused on development and demonstration activities. Significant investment of time and money is required to progress from lower to higher TRLs, although it is difficult to gauge the amount of time required to progress through to higher TRL values. NASA have analysed the development of a range of different NASA technologies through increasing levels of TRL maturity (Peisen 1999) and found that for their technologies it can take over 16 years for a technology to mature to TRL-9. However, MHI, a major technology provider, has given some contextual data for TRL maturity for IGCC power generation. MHI indicate that it took about 25 years to move from level 3 to level 8 and then a further five years to reach level 9 (Sakamoto 2010).

**TABLE 13 Technology Readiness Levels (TRLs) description**

<table>
<thead>
<tr>
<th>READINESS LEVEL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL-9</td>
<td>Full-scale commercial deployment (400–500 MW)</td>
</tr>
<tr>
<td>TRL-8</td>
<td>Sub-scale commercial demonstration plant (&gt;25 per cent commercial scale)</td>
</tr>
<tr>
<td>TRL-7</td>
<td>Pilot plant (&gt;5 per cent commercial scale)</td>
</tr>
<tr>
<td>TRL-6</td>
<td>Process development unit (0.1–5 per cent of full scale)</td>
</tr>
<tr>
<td>TRL-5</td>
<td>Component validation in relevant environment</td>
</tr>
<tr>
<td>TRL-4</td>
<td>Laboratory component testing</td>
</tr>
<tr>
<td>TRL-3</td>
<td>Analytical, ‘proof of concept’</td>
</tr>
<tr>
<td>TRL-2</td>
<td>Application formulated</td>
</tr>
<tr>
<td>TRL-1</td>
<td>Basic principles observed</td>
</tr>
</tbody>
</table>

An achievement of TRL-9 indicates that the first successful operation at a scale normally associated with commercial deployment has been achieved. This refers to the physical scale of deployment only. Thus, a technology may reach TRL-9 and be technically mature but still not meet project economic requirements in existing markets. The TRL system does not address the commercial or economic feasibility of deploying the technology.

The TRL classification is not intended to express overall project development risk. This is project-specific, and progress on first-of-a-kind projects may be influenced by the extent to which sophisticated project proponents have gained confidence in technology components and their ability to integrate these into a viable process. This may mean the project proponent may select a particular technology component with a lower (less mature) TRL if the project-specific business case is better than that for an alternative technology component with a higher (more mature) TRL.
Post-combustion capture progress in power generation

Post-combustion capture (PCC) for LSIPs has experienced some setbacks during the past year. The application of post-combustion has mostly focused on power generation and projects have had difficulty in creating a commercially viable project using PCC. Nevertheless, progress has been made in the LSIP using PCC that is under construction, Boundary Dam in Canada, and it is expected to be operational in 2014. There are many projects in the planning stages – all for power generation.

The major challenges in PCC revolve around the relatively large parasitic load CCS imposes on a power plant, the majority of which is due to capture (especially the energy needed to regenerate the solvent). Development of new chemistry (solvent-based and non-solvent based), new process designs, and novel power plant integration schemes (e.g. waste heat and heat recovery) – all aimed at reducing the parasitic load of CCS – are the focus of virtually all RD&D in PCC. Reducing the parasitic load by 50 per cent without increasing cost of capture would reduce the cost of carbon abatement by approximately 27 per cent.

In general, capital cost reductions, solvent degradation, solvent volatility, and other such parameters are secondary to the prime issue – reduction in parasitic load on the host power plant imposed by the PCC process itself. These secondary issues, while important, do not constitute the major challenge in PCC and consequently receive less R&D attention.
Southern Company has commissioned a 25 MW-equivalent post-combustion capture facility using MHI’s MK-CD\textsuperscript{TM} technology at Plant Barry, Alabama, US (Figure 51). The captured CO\textsubscript{2} from the project will be supplied to the Southeast Regional Carbon Sequestration Partnership (SECARB) for permanent underground storage in a deep saline geologic formation (Southern Company 2012). This is the largest active integrated CO\textsubscript{2} capture and storage project on a coal-fired power plant in the world. The project philosophy is for the project to:

- be fully representative of full-scale design (processing steps, equipment, and physical aspects);
- establish and demonstrate a contracting and execution strategy; and
- have operations and maintenance in realistic conditions.

The project would also seek to continue community outreach and education to ensure seamless deployment.

The following demonstration testing items have or will be undertaken for the carbon capture unit:

- confirmation of plant performance (base heat and mass balance on major constituents and key trace elements) for design and alternative coal;
- monitoring of emission and waste streams;
- parametric testing for development of simulation tools for plant control;
- performance optimisation;
- dynamic response testing for capture plant load following; and
- long-term testing to validate equipment reliability and life.

Southern Company has retained the in-house capability to engineer and deliver pilot and commercial-scale demonstration projects. Southern Company carefully examined the approach to capture plant project delivery as it would apply to a commercial scale facility and developed a modular approach for off-site plant module fabrication followed by on-site module coupling/connection. This reduced the capital cost and most importantly significantly reduced construction time.

The approach to development and delivery of the Plant Barry pilot-scale demonstration facility highlights the understanding and investment required of proponents to develop, de-risk, and scale-up technology to a commercial and suitably operational scale.

**FIGURE 51** MHI’s MK-CD\textsuperscript{TM} technology at Plant Barry in Alabama, US

Photo courtesy of Southern Company.
The CO₂ Technology Centre at Mongstad (TCM) in Norway – a joint venture between the Norwegian Government (represented by Gassnova), Statoil, Shell, and Sasol – was officially opened on 7 May 2012 (Figure 52). This is the world’s largest facility for testing, developing, and improving carbon capture technologies.

The US$1 billion TCM is a unique and flexible facility for developing the technology needed to significantly reduce CO₂ emissions from large point sources worldwide. Over 5.5 million staff-hours were invested in establishing this centre, which is able to test two large-scale CO₂ post-combustion capture technologies with two real-life CO₂ point sources. TCM will have access to the flue gases from a heat and power plant fired by natural gas and the flue gas from a refinery cracker, with an annual capacity of up to 100,000 tonnes of CO₂. These two types of flue gases have different CO₂ contents (about 3.5 per cent and 13 per cent, respectively), providing TCM with a unique opportunity to be able to investigate capture technologies relevant for both power plants and industrial applications.

The initial CO₂ technologies to be tested at Mongstad are a chilled ammonia process from Alstom and an amine process from Aker Clean Carbon. Both technologies are post-combustion capture and utilise a solvent for absorbing the CO₂ from the flue gas, and both will be capable of capturing 85 per cent of the CO₂ contained in the flue gas slipstream from the refinery cracker and the combined heat and power plant. TCM will be responsible for developing the remaining test programs after the first initial phase of approximately 12–19 months. Aker, Hitachi, Mitsubishi, and Siemens have expressed their interest in further use of the amine plant after the current test program.

TCM also have an open invitation until the end of 2012 to utilise the available area, utilities, and other infrastructure of TCM towards construction and testing of further carbon capture technology facilities.

FIGURE 52 Opening of the Technology Centre, Mongstad, Norway, May 2012
ABSORPTION CAPTURE PROCESSES

Absorption processes rely on a solvent dissolving the CO\textsubscript{2} into a liquid. The absorbed CO\textsubscript{2} is then released by changing the temperature and/or pressure. The solvent is then recovered for re-use. Much of the current research in absorption-based PCC is focused on developing new solvents that reduce the energy required to release the CO\textsubscript{2} from the solvent. Some early-stage research is also being conducted in more novel chemistries such as ionic liquids and phase separation solvents (TRL-5).

The use of naturally occurring enzymes (such as carbonic anhydrase) as a catalyst to effectively increase the reaction kinetics of certain low-energy solvents (e.g. amines and carbonate solvents such as potassium carbonate) and enable them to operate more efficiently has created considerable interest (TRL-5). Cost reductions in carbon capture of AU$20 per tonne of CO\textsubscript{2} captured have been claimed for deployment of this type of technology (CO2CRC 2012).

In addition to lower regeneration energy requirements, RD&D activity for solvent-based capture systems is focused on faster reaction rates, contactor improvements (e.g. foams and fluid curtains), higher liquid capacities, chemical stability and corrosion, and desorption process improvements. Systems integration is also the subject of RD&D activity, including heat and waste heat recovery.

ADSORPTION

Adsorption processes rely on CO\textsubscript{2} being collected on the surface of a solid. Then, similar to absorption, the solid is exposed to alternating temperatures and/or pressures to release the CO\textsubscript{2}. Adsorption processes for PCC are not as developed as absorption processes and are still in the research and development stage (TRL-4). Early stage work, conducted mostly at academic institutions, is focused on the development of new materials such as carbon-based sorbents (e.g. activated carbon), metal organic frameworks (MOFs), zeolites, immobilised amine sorbents, and regenerative solid sorbents (e.g. limestone or chemical looping concepts).

OTHER PROCESSES

Novel process configurations, along with novel membrane materials, could reduce the parasitic load on a power plant. This has been tested at a scale of 1 tonne of CO\textsubscript{2} per day scale (TRL-4) and is currently being scaled to 20 tonnes of CO\textsubscript{2} per day (TRL-6) at a coal-fired power plant. Other developments around membranes for PCC are still at the laboratory stage (TRL-4), focusing chiefly on improving membrane material properties.

Although receiving much less R&D attention, it is worth mentioning current R&D activity focused on growing microalgae in ponds as a route to the fixation of CO\textsubscript{2} directly from flue gas streams and in so doing avoiding the substantial parasitic energy penalty of CO\textsubscript{2} capture. The biomass produced could then be subsequently used as a combustion fuel for energy production or other value-added products such as nutritional supplements. This work is at an early stage of development and it is probably able to contribute only a relatively small amount to overall CO\textsubscript{2} emissions reductions (Novel CO\textsubscript{2} Capture Taskforce 2012). Consideration is being given to the possible use of genetically modified microalgae.

Oxyfuel combustion progress for power generation

2012 is a crucial year for oxyfuel combustion technologies as key demonstration projects providing vital information for technology scale-up come into operation. These projects are focused on demonstrating integrated oxyfuel power plant operation at pilot to sub-commercial scale (TRL 6–7). While oxyfuel projects are not yet at full scale, there are some projects being developed that will target a higher TRL. Oxyfuel technology must also be fully applied to a power plant module as it is not possible to have a ‘slipstream’ in the same way as pre- or post-combustion capture can be applied to a slipstream from a power plant. Oxyfuel is an ‘all or nothing’ approach.

In December 2011, CIUDEN first successfully tested its 30 MWth oxy-CFB (circulating fluidised bed) boiler at its test facility in Spain which also includes a 20 MWth oxy-PC (pulverised coal) boiler. Successful operations at CIUDEN demonstrate the achievement of TRL-6 for oxyfuel combustion with CO\textsubscript{2} capture as applied to electric power production with circulating fluidised beds. Plans for the Compostilla 300 MWe unit will be based upon successful pilot plant operation. This project is expected to be operational by 2015 when it will move the TRL to level 8 for oxyfuel combustion in power generation.

In March 2012 CS Energy announced successful oxy-firing trials as part of the project commissioning stage for its Callide project in Australia. This project retrofitted a retired 100 MWth (30 MWe) coal-fired power plant for oxyfuel combustion. The facility includes an air separation unit, an oxy-PC boiler, and a steam turbo-generator. 10 per cent of the flue gas produced is processed further to demonstrate the capture features of the technology. Successful operation of this plant will demonstrate TRL-7 for oxyfuel combustion with CO\textsubscript{2} capture as applied to electric power production.
The Kimberlina, California, project of Clean Energy Systems is now on hold. This 50 MW pilot plant was intended to demonstrate the direct combustion of natural gas and oxygen producing a gas that is mostly steam and CO₂. After exiting the expansion turbine, the steam is condensed to water, leaving pure CO₂ for compression and storage. Funding sources include the US DOE and the California Energy Commission.

In Germany, Vattenfall had planned for a 250 MW fully integrated oxyfuel combustion project (TRL-8) at Jänschwalde. This project was cancelled during 2012 for reasons mainly associated with the lack of political support for the project's proposed geologic storage. This project was expected to be operational by 2015 allowing the oxyfuel technology to proceed to TRL-8.

China Datang Corporation and Alstom announced their intention to commence feasibility studies for a 350 MW oxyfuel combustion plant for Daqing. The project plans to capture up to 1 Mtpa. A final investment decision is planned for 2015.

Progression of capture in the non-power generation sector

The majority of ongoing progress in large-scale projects has occurred in the non-power generating sector. The main reason for this is that these processes (e.g. gas processing and fertiliser production) already require the CO₂ to be removed as part of the commercial operations. Hence the cost associated with capturing the CO₂ and compressing it so that it is ready for geologic storage is much less compared to the costs associated with power generation.

The projects under construction in gas processing and chemicals are continuing to progress.

BIOMASS BIOPROCESSING

Progress has been made in projects where a high-purity stream of CO₂ is produced. This includes fermentation, fertiliser manufacturing, and CTL projects. Much of the recent development in carbon capture from biomass bioprocessing, which has the potential for a net negative carbon emissions profile, has occurred in the US. In November 2011 an integrated system for collecting CO₂ from an ethanol production plant and geologically sequestering it began injecting 1000 tonnes per day of CO₂. The CO₂ is a by-product from processing corn into fuel-grade ethanol at the ADM ethanol plant in Decatur, Illinois (Figure 53).

Additionally, the design, construction, and operation has commenced of a new collection, compression, and dehydration facility at the ADM plant which will be capable of delivering up to 2000 tonnes of CO₂ per day. This Illinois-ICCS project is expected to be operational in 2013. Integration of the new facility with the existing 1000 tonnes per day CO₂ compression and dehydration facility will be undertaken to achieve a total daily injection capacity of up to 3000 tonnes of CO₂ (NETL 2012). The completion of this project will demonstrate capture from an industrial process at 1 Mtpa.

**Figure 53** CO₂ being captured, dehydrated, and compressed at ADM ethanol plant

Photo courtesy of Archer Daniels Midland Co.
STEEL AND CEMENT PRODUCTION

Steel and cement production give rise to a large amount of CO₂. It is expected that CCS will play a key role in reducing global emissions from these sectors.

Some progress is being made at the pilot scale in the steel sector. Most of this is organised through the Ultra-Low Carbon Dioxide Steelmaking (ULCOS) project in France. This project is aiming to develop technology that will produce less CO₂ emissions per tonne of steel. The project has made funding available to construct and operate a pilot project at Ijmuiden in the Netherlands. Post-combustion capture is being studied in the ULCOS project for demonstrating CCS from steel production. A commercial-scale ULCOS project with capture is planned for 2016. A FID for this project is expected by March 2013. They have determined that the most promising process route for Europe is a re-engineered blast furnace operating with pure oxygen and where the top gas is separated of its CO₂ while the remaining reducing gas is re-introduced into the blast furnace to be used as a reducing agent, rather than burned in gas burners. The process has been validated at pilot scale and scale-up is under way with a large pilot and a full-scale CCS demonstration plant planned in Florange, France. The Florange demonstration has been proposed as an NER300 project and is now ranked eighth on an interim shortlist, pending a final award decision in late 2012. A significant challenge is that the process modifications to incorporate CCS into the iron and steel production processes are complex (Figure 54).

FIGURE 54 Top gas recycling blast furnace

Source: ULCOS.
Other steelmaking processes are also under development, such as HIsarna, ULCORED, and ULCOWIN. The main focus of these technologies is for more efficient steelmaking processes. Capture from these processes is also being investigated.

To date, there are no large-scale projects proposed for the cement industry. Some desktop studies have applied CCS to the cement industry and have developed concepts for applying capture to cement plants and have come up with estimates of their financial impact. There is a small-scale pilot project planned at the Brevik cement plant in Norway. This project aims to be operational by 2018 and capture up to 10,000 tpa.

6.3 KEY CHALLENGES TO LARGE-SCALE DEMONSTRATION OF CAPTURE

Commercial-scale demonstration of capture requires demonstration of capture technologies at increasing TRLs, up to a level of 9, and then integrating that capture technology into a power station. Beyond this, the challenges associated with capture technologies are predominantly commercial. Reducing the costs of capture will require ongoing innovation through the development of new capture technologies and developing systems for integrating capture plants into a power plant.

NEED TO FUND COMMERCIAL-SCALE DEMONSTRATIONS (TRL-9) TO ENCOURAGE RD&D

The 2012 project survey of LSIPs has highlighted that only two projects moved to the Execute stage since the 2011 project survey. This slow progress of projects reaching FID and commencing construction can have a negative impact on continued investment in RD&D for second and third-generation capture technologies.

Optimisation and enhanced integration, combined with technology improvements, will undoubtedly be necessary to reduce cost and improve performance on a system and component basis. Progress at the commercial CCS demonstration scale has a key role in indicating the priority areas to be addressed and in providing the confidence and drivers for continued investment in RD&D for second and third generation technologies.

For all technologies, there is an underlying need to construct and operate commercial-scale facilities with carbon capture to demonstrate the host power generation or host industrial technology integrated with the capture. This will allow industry to become familiar with the technology and gain confidence that commercial-scale capture is achievable.

NEED TO FUND ONGOING RESEARCH AND PILOT SCALE DEMONSTRATIONS (TRL-6+)

Improvements in the cost of capture are required and this will require ongoing research and development focused on improving component performance and developing new capture processes (e.g. improved membranes, TRL-4+).

Progress of CO₂ capture in the power sector is currently aimed at achieving process development at the unit scale. Advancing to pilot and sub-commercial scale demonstrations (and larger) will be slow and will require an order of magnitude greater level of funding.

Furthermore, the early commercial-scale demonstration projects will inevitably identify unexpected construction and operating problems (through ‘learning by doing’). However, such learning by doing may not lead to the significant changes in cost and performance required to make CO₂ capture more economically viable (NETL 2010). RD&D at smaller scale (TRL-4 and 5), which is complementary to demonstration programs, is essential to promote step changes in performance/operability and manage the complexity and risk with new components; only in this way can they contribute to improved performance in the next generation of commercial-scale CCS projects.

Ongoing support to develop new technologies and to develop these technologies to pilot and demonstration scale is required to achieve the desired large cuts in capture costs.
Southern Company operates the National Carbon Capture Center (NCCC) which is located near Wilsonville, Alabama, in the US (Figure 55). The NCCC, majority funded by the US DOE, is located adjacent to the Plant Gaston pulverised coal power plant which has a KBR Transport Reactor designed to operate as either a 2 t/h coal gasifier or combustor in either air-blown or oxygen-blown operating modes (NETL 2008b).

The facility is a highly flexible test centre for pre- and post-combustion capture technologies where developers evaluate pre-commercial innovative system components in an integrated process at commercially relevant process conditions involving real process streams sourced from large-scale power plants and related processes. ‘Test-bays’ with all services (such as steam, water, purge gases, and power) to support technologies for testing have also been developed so as to reduce the costs for technology developers to test their technologies at process development unit scale. The facility is large enough to produce commercially representative data while remaining sufficiently small for economic operation.

The US DOE maintains a database of approximately 300 promising technologies (at required TRL) as candidates for testing at NCCC. NCCC is also a neutral test site for carbon capture (it does not hold onto IP for carbon capture if it arises during technology development testing). Such hosting facilities are essential to minimise costs for technology development and scale-up.

**FIGURE 55 Test facility for amine solvents at NCCC**

Photo courtesy of Southern Company.
INTEGRATION WITH POWER GENERATION

Project integration is a key challenge for CCS. A large proportion of proposed industrial-scale projects include power-related projects that extend the scope of project integration. These project proponents may or may not have experience or expertise in all of that scope, particularly the storage components.

In a workshop in November 2011 held by the Global CCS Institute and the CSLF, it was highlighted that the focus of the first large-scale CCS demonstration plants in the power sector should be on ‘making CCS work at scale’ and that real innovation and integration was something for next-of-a-kind projects. In such projects, integration and experience could drive down the costs of CCS, but for now it is important to strike the right balance between plant operation and integration. In particular, CCS industry experts identified that more work is needed in the following areas:

- integration/regeneration of plant heat (and cooling) in the CO₂ capture process;
- integration of environmental control systems (SOx, NOx, and CO₂ removal) to maximise efficiency;
- improvement of options for operational flexibility, while ensuring CCS system reliability;
- impacts of CO₂ compositions and impurities for CCS operations (in particular for transportation systems); and
- understanding the scale-up risks of CO₂ capture processes.

It was also emphasised that one of the keys to successful project integration is to facilitate effective collaboration and communication between the various entities involved in the project. Identifying the project team and ‘getting them all in the same tent’ is key for successful project integration. In the case of oxyfuel technology, for example, the industrial gas companies and the power companies have different design philosophies that need to come together in a project.

It is expected that flexible operation of coal-fired power plants with CO₂ capture will be required in many electricity systems; however, current knowledge in public literature is limited.

It is very likely that different CO₂ capture technologies will have different impacts on plant performance, and there is a trade-off between flexibility, costs, and efficiency (IEAGHG 2012b). CCS may impose additional constraints on the flexible operation of power plants, but in general there are ways of overcoming these limitations. There are some instances when a plant with CO₂ capture may be able to ramp up its net power output more quickly and produce more peak generation than a plant without capture (IEAGHG 2012b).

Post-combustion capture with aqueous solvents can be undertaken, with relatively few changes, to an industry-standard pulverised coal fired power plant with air combustion. The majority of integration modifications required for post-combustion capture involve integration with the turbine part of the power station. Current demonstration projects have been designed to demonstrate capture, and only a secondary focus has been on efficiency. During start-up, the CO₂ absorber could be operated using lean solvent from a storage tank, and the CO₂-rich solvent from the absorber would be stored and fed to the regenerator later. This would enable a natural gas combined cycle or pulverised coal fired power plant with CO₂ capture to start up and change load as quickly as a plant without capture (IEAGHG 2012b). The practicality of CO₂ solvent storage has been discussed with some leading technology suppliers, with these companies all confirming the technical feasibility of storing solvent (IEAGHG 2012b). The solvent storage tanks are conventional sized tanks as used at oil refineries, but they are nevertheless large (IEAGHG 2012b). Plants could be built with a wide range of storage volumes, solvent regenerator sizes, and peak power generation capacities; selecting the optimum would be a difficult commercial decision (IEAGHG 2012b).

Southern Company and MHI are now undertaking operating flexibility (plant-ramping) trials at Plant Barry in Alabama, US. These studies will provide design and dynamic modelling information necessary to design the next generation of larger scale carbon capture plants; these will be capable of flexible commercial-scale operation and meet dynamic performance requirements for power generation (Southern Company 2012).

An important operating option for oxyfuel power plants could be storage of oxygen in liquid or gaseous form. This interim storage option could be important in improving plant ramp rates by adding to oxygen production rates (higher than those possible with only an air separation unit), (Chalmers 2010). Liquid oxygen storage would typically be included for a safe change-over from oxygen to air firing, and in the case of an air separation unit trip, no additional liquid oxygen storage would be needed to satisfy the ramp rate. From an economic perspective this is expected to be a relatively attractive option for short-term peak power generation (IEAGHG 2012b).

The flexibility of IGCC plants without capture is relatively poor. Hence, the addition of capture is not expected to reduce the flexibility. It seems likely that the most practical options for providing operating flexibility at these plants will involve interim storage of hydrogen (or syngas in cases where CO₂ capture is not used). It is expected that increased integration could improve efficiency, but would reduce flexibility (Chalmers 2010).

Compressed CO₂ could be stored at capture plants to reduce the variability of flows of CO₂ to transport and storage (if this is found to be necessary). Buffer storage of CO₂ would enable a smaller capacity CO₂ pipeline to be built, but this would constrain the ability of the power plant to operate at continuous full load, which may not be commercially attractive (IEAGHG 2012b).
While the current focus is on demonstrating capture, more practical project experience is required to integrate capture and power generation. This experience will lead to the development of more efficient systems by investigating ways where capture and power generation can operate more flexibly and more efficiently (in line with the operational requirements of the power plant).

**CHALLENGES WITH POST-COMBUSTION CO₂ CAPTURE REGULATORY APPROVAL**

To reduce CO₂ emissions from existing and new power plants, amine-based post-combustion capture technology is considered a crucial part of the CCS chain. The use of amine-based solvents is the most advanced of the post-combustion options, and it is therefore well positioned for use in demonstration projects and future commercial plants.

However, the amine-based liquid absorbents used in these processes degrade slowly. As a result of side reactions between the amine and components present in the flue gas components, a wide range of reaction by-products are formed. At present, the knowledge about the type and level of components being emitted by the post-combustion process is limited. In recent years, concerns have been raised about the nature of the emissions, either on their own or following chemical reaction in the atmosphere (Mitch 2002).

Additionally, technology providers are developing improved amines for post-combustion capture application. These technology providers are seeking to protect their intellectual property by keeping their improved amine formulations confidential. This conflicts with the regulatory approvals process for carbon capture systems in many jurisdictions, which require the nature of emissions from post-combustion capture systems (as well as the composition of post-combustion capture solvents) to be released into the public domain.

As post-combustion capture moves towards large-scale demonstration, this topic has received considerable attention (especially in Europe and Norway). Although academic studies are increasing, there is a considerable lack of validated information in the public domain, especially that involving IP-protected improved amines. This knowledge gap constitutes a potential deployment risk to amine-based post-combustion capture CCS.

In order to assist regulators in the regulatory approval of amine-based post-combustion capture projects (including those using IP-protected amine solvents), the Global CCS Institute and Australia’s Commonwealth Scientific Industrial Research Organisation (CSIRO) are undertaking a site-based peer-reviewed amine solvent post-combustion carbon capture case study – using results from the Loy Yang Power Station in Victoria – to assist in the development of a regulatory framework or standard and in development of best practices using a well described amine-based post-combustion capture process.

**NEED FOR CAPTURE FROM GAS-FIRED POWER GENERATION**

The emphasis in capture from power plants has been on coal, but there is an increasing recognition that CCS will have to be applied to natural gas fired plants as well.

The renewed focus on unconventional gas, such as coal seam gas and shale gas, will mean that there will be a greater use of gas, and for longer. This has two implications for CO₂ emissions. Firstly, more gas processing plants will be constructed producing high CO₂ flue gases, and secondly more gas turbines will be built for power generation. Capture from gas turbines has not received much attention due to the low concentration of CO₂ in the flue gases when using natural gas. Nevertheless, if the desired levels of atmospheric CO₂ are to be achieved by 2050, CCS will have to be applied to gas-fired power plants as well as those using coal.

In a recent report on carbon capture from gas-fired power generation, it was established that adding post-combustion capture reduces the thermal efficiency of a natural gas combined cycle plant by 7–8 per cent, increases the capital cost by about 80–120 per cent, and increases the cost of electricity by about 30–40 per cent (IEAGHG 2012a).

Recycling part of the cooled flue gas to the gas turbine compressor inlet would increase the CO₂ concentration in the feed to the CO₂ capture unit, which could increase the thermal efficiency by about 0.3 per cent and reduce the cost of electricity by up to 8 per cent. IEAGHG has acknowledged that this study could be extended to assess a combination of high-efficiency proprietary solvents and flue gas recycling (IEAGHG 2012a).
6.4 MOVING TOWARDS COMMERCIAL-SCALE DEMONSTRATION

There are some developments underway that will make capture more efficient. These include the demonstration plants mentioned above where different capture technologies are being investigated. Other ways to improve capture include improving energy efficiency of the host power station and/or adopting novel capture processes.

Efficiency improvements for conventional coal-fired power plants

A major contribution to the reduction of CO₂ from fossil-based plants will be achieved through increases in the efficiency of the basic technologies of pulverised coal combustion and combustion (gas) turbines. The impact of efficiency improvements on CO₂ emissions is substantial. A 2 per cent efficiency gain yields a 5 per cent CO₂ reduction (Global CCS Institute 2012a).

Considerable work is underway to develop and qualify advanced materials for use in new conventional pulverised coal combustion power plants that will enable the use of ultra-supercritical steam conditions with higher temperatures (up to 700–750°C) and pressures (up to 350 bar). Furthermore, one of the greatest improvements to the overall IGCC technology is the development of high-firing-temperature larger gas turbines of higher efficiency. These improvements will lead to higher plant efficiencies and lower CO₂ emissions per MWh (Global CCS Institute 2012a). These type of efficiency improvements generate ‘no regrets’ from a carbon capture perspective in that they do not make the task of carbon capture more difficult.

However, other efficiency improvement options for conventional pulverised coal combustion power plants, such as those which recover low-grade heat previously lost to the atmosphere, may actually make the task of (post-combustion) carbon capture more difficult – as the (post-combustion) carbon capture systems may rely on these sources of low-grade heat for solvent regeneration. Other sources of heat would therefore be required from the host plant, the use of which would then result in overall lower efficiencies.

Conventional pulverised coal combustion power plants, which utilise the Rankine thermodynamic cycle for producing power, have an effective upper limit of thermal efficiency. For example, measures for efficiency enhancement currently being considered would result in a net efficiency of just over 50 per cent Lower Heating Value basis (or 48 per cent Higher Heating Value basis) without carbon capture (Meier 2012). However, for such a facility, there would be virtually no low-grade heat available for use in regeneration of (post-combustion) carbon capture solvents. The net thermal efficiency of such a facility could be reduced to as low as 35 per cent after retrofitting with conventional (post-combustion) carbon capture technology.

Power generation technologies

The substantial thermal efficiency reductions resulting from incorporation of carbon capture technology to conventional pulverised coal combustion power plants have led to increased attention being given to investigations examining alternative fossil fuel-based host power generation technologies. These technologies need to provide high thermal efficiencies when coupled with carbon capture.

Two notable examples of alternative host power generation technologies which provide improved fundamentals for carbon capture are described.

CHEMICAL LOOPING COMBUSTION

Chemical Looping Combustion (CLC) technology is a form of oxyfuel combustion without the use of an air separation plant. It can be used for combustion of coal for power generation. It relies on the use of paired fluidised beds (an oxidiser and a reducer) and the use of a solid oxygen carrier. The reducer exit gas contains almost all of the CO₂ generated by the system and CLC therefore can be said to exhibit ‘inherent carbon capture’, as water vapour can easily be removed from the reducer exit gas via condensation, leading to a stream of almost pure CO₂. The production of a sequestration-ready CO₂ stream therefore does not require any additional separation units and there is no energy penalty or reduction in power plant efficiency (NETL 2008a).

Theoretically, the efficiency penalty for CO₂ capture only comes from the compressors that give the CO₂ stream the right pressure for subsequent transport and geologic storage.
Analysis of CLC system performance has indicated that the thermal efficiency of a CLC system can be expected to be over 41 per cent with carbon capture (Global CCS Institute 2012b). The units are expected to be able to start up and then adjust their power production rate in a similar manner to a conventional pulverised coal combustion power plant.

A key current requirement for CLC is to scale-up the technology. Currently, the largest CLC system being demonstrated is the 1 MWth unit at University of Darmstadt in Germany. Once successful, this will see the technology achieve TRL-5. The test work in 2012 on this CLC system is seen as being critical to the development of CLC.

**DIRECT INJECTION CARBON ENGINE**

A Direct Injection Carbon Engine (DICE) power generation unit is based around a large low-speed diesel engine that is fuelled with micronised refined carbon fuel, which is made from coal and water instead of diesel oil.

Analysis of DICE system performance has indicated that the thermal efficiency of a DICE system can be expected to be up to 50 per cent with carbon capture (Wibberley 2012). One reason for this is the inherently high efficiency of the diesel thermodynamic engine cycle. Another key reason is that a DICE, unlike other power cycles, has large quantities of highly usable low-grade heat present in cooling streams. This heat can be used to regenerate post-combustion capture solvents without reducing net power output. For improved post-combustion capture solvent, the quantity of usable low-grade waste heat is a close match with solvent regeneration requirements. This is a significant advantage compared to applying post-combustion capture to conventional pulverised coal-fired plants and to natural gas combined cycle power plants, which both are likely to experience significant reductions in net power output as a result of the regeneration energy requirements of post-combustion solvent capture.

This process is currently the subject of RD&D work being undertaken by CSIRO in Australia building on the earlier work done by the US DOE in 1980-90s. The work is currently at TRL-4.
7

TRANSPORT

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7.1 A BRIEF INTRODUCTION TO CO₂ TRANSPORTATION

Safely and reliably transporting CO₂ from where it is captured to a storage site is an important stage in the CCS process. Transportation of CO₂ is already a reality, occurring daily in many parts of the world.

Pipelines are – and are likely to continue to be – the most common method of transporting the very large quantities of CO₂ involved in CCS. There are already millions of kilometres of pipelines around the world that transport various gases, including CO₂.

Transport of smaller volumes of CO₂ is currently undertaken by truck and rail for industrial and food grade CO₂. The cost of transportation by truck or train is relatively high per tonne of CO₂. For the large volume of CO₂ that would be captured via CCS, it is much cheaper to transport by pipeline, so it is unlikely that truck and rail transport will have a significant role in CCS except for small pilot projects.

Ship transportation can be an alternative option for many regions of the world. Shipment of CO₂ already takes place on a small scale in Europe, where ships transport food-quality CO₂ (around 1000 tonnes) from large point sources to coastal distribution terminals. Larger-scale shipment of CO₂, with capacities in the range of 10,000 to 40,000 m³, is likely to have much in common with the shipment of liquefied petroleum gas (LPG), an area in which there is already a great deal of expertise and which has developed into a worldwide industry over a period of 70 years.

As discussed in the cost section of this report, when looking at all the components of an integrated CCS project, the transportation aspect of the project contributes only a small proportion of the total cost compared to capture, compression, and storage. Even though the cost share of CO₂ transportation may be in the order of 2–5 per cent of the total CCS facility, they are still significant in the demonstration phase with US$2–7 per tonne of CO₂ for transportation distances under 200 km. Studies undertaken by ElementEnergy (2010a) and ZEP (2011) also suggest that, over time, when CCS hubs or clusters have emerged (as opposed to point-to-point projects), a significant reduction in total transportation distance and costs may be achieved.

The existing experience with CO₂ transportation may have led to a general perception among the CCS community that CO₂ transport is not considered a major barrier to the deployment of CCS. While in general this may be true, this component of the CCS chain requires careful consideration in design and operation. Before discussing these, this chapter will first outline the status and new developments of CO₂ transportation infrastructure, including the emerging CCS hubs, clusters, and networks.
7.2

**CO₂ TRANSPORTATION — STATUS AND NEW DEVELOPMENTS**

CO₂ pipelines and ships form an essential element in the deployment of CCS technologies. The total transportation distance covered (or to be covered) by the 75 LSIPS currently under development and in operation is around 9000 km. More than 70 per cent of these projects are looking to use onshore pipelines, in particular in the US and Canada (Figure 56). This planned infrastructure development is approximately 1.5 times the size of the existing network of dedicated CO₂ EOR pipelines presently available in the US.

Offshore pipelines are mainly considered by projects in Europe, in particular in the Netherlands, Norway, and the UK. In these countries projects are looking to transport their CO₂ via pipeline or ship to various offshore storage locations in the North Sea. The only offshore pipeline for CO₂ currently in use is part of the Snøhvit project (Norway), which has been operational since 2008 and covers some 153 km linking Hammerfest to the Snøhvit field under the Barents Sea. Further CO₂ transportation by pipeline in Europe occurs in the Netherlands, with approximately 85 km of pipeline supplying 300 kt per annum of gaseous CO₂ to greenhouses, as well as other pipelines in Hungary, Croatia, and Turkey for EOR (Buit et al. 2011).

**FIGURE 56** Pipeline transportation distances provided by LSIPs

As mentioned above, there is significant experience with CO₂ pipeline development and operation in North America. There are 36 CO₂ pipelines currently operating in the US alone, transporting 48–58 Mtpa of CO₂ in 2010 (DiPietro and Balash 2012). These onshore pipelines around 6500 km in length and deliver mainly naturally sourced CO₂ for EOR purposes, as opposed to captured anthropogenic CO₂. Six of these pipelines cross provincial/state boundaries and one crosses an international border into Canada (Interstate Oil and Gas Compact Commission 2010).
EXTENSIONS OF EXISTING CO₂ EOR NETWORKS

In the US much of the existing pipeline infrastructure was built in the 1980s and 90s, however, there has been significant new investment over the past five years. This includes the 514 km Green pipeline completed in 2010 and the 373 km Greencore pipeline expected to be complete by the end of 2012. Proposals for new pipelines also exist to link the St John's CO₂ dome on the border of New Mexico and Arizona to West Texas and to extend the Greencore pipeline further South to access additional CO₂ supplies and North into Montana to provide CO₂ for further CO₂ EOR projects. A map of the existing EOR pipeline network can be found in Chapter 9 on CO₂ EOR, and a complete list of the major US CO₂ pipelines is provided in Appendix H.

Table 14 shows a number of LSIPs that could be considered as extensions or components of existing CO₂ EOR pipeline networks in the US; they are driven mainly by opportunities to increase oil production based on access to new sources of CO₂. This is in contrast to most of the proposals in Europe, the Middle East, and Australia for new CCS networks that are based mainly on direct storage or at least a combination of both permanent storage and CO₂ utilisation. Furthermore, the business model and considerations for tapping into existing CO₂ infrastructure are significantly different from the requirements for establishing a new CO₂ network.

Despite these differences between existing EOR networks in North America and new CCS network developments in other parts of the world, the primarily opportunistic growth of CO₂ EOR pipeline infrastructure may provide some lessons for new common user CCS infrastructure development. Bradley (2011) found that the construction of large pipelines in the early 1980s, running hundreds of kilometres to connect natural CO₂ sources in Colorado and New Mexico to the Permian basin, supported a rapid expansion in many individual CO₂ EOR projects. In similar fashion, the construction of ‘trunk lines’, with a large capacity, connecting one or two LSIPs with a proven storage formation could enable other (smaller) capture projects to come online more easily. This would occur because costs of CO₂ transportation for smaller projects with separate individual pipelines to storage sites are high. There are substantial economies of scale in larger pipelines.

**TABLE 14 LSIPs as part of existing EOR networks in the US**

<table>
<thead>
<tr>
<th>LSIP</th>
<th>PIPELINE</th>
<th>LENGTH (KM)</th>
<th>OPERATOR</th>
<th>LOCATION (STATE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indiana Gasification</td>
<td>Planned pipeline to connect to Delta Line</td>
<td>-</td>
<td>Denbury</td>
<td>IN to LA or MS X</td>
</tr>
<tr>
<td>Lake Charles Gasification</td>
<td>Green Line</td>
<td>441</td>
<td>Denbury</td>
<td>LA, TX</td>
</tr>
<tr>
<td>Air Products</td>
<td>Green Line</td>
<td>411</td>
<td>Denbury</td>
<td>LA, TX</td>
</tr>
<tr>
<td>Enid Fertilizer</td>
<td>Enid–Purdy</td>
<td>188</td>
<td>Merit</td>
<td>OK</td>
</tr>
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<td>Val Verde</td>
<td>134</td>
<td>Sandridge</td>
<td>TX</td>
</tr>
<tr>
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<td>Central Basin</td>
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<td>Kinder Morgan</td>
<td>TX</td>
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<td>Bravo</td>
<td>351</td>
<td>Oxy Permian</td>
<td>NM, TX</td>
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<td>Free State</td>
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<td>Denbury</td>
<td>MS</td>
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<td>Greencore</td>
<td>373</td>
<td>Denbury</td>
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<tr>
<td>Shute Creek</td>
<td>Shute Creek</td>
<td>–</td>
<td>Exxon, ChevronTexaco, Andarko</td>
<td>WY</td>
</tr>
<tr>
<td>Kemper County</td>
<td>Sonat</td>
<td>80</td>
<td>Denbury</td>
<td>MS</td>
</tr>
<tr>
<td>Riley Ridge Gas Plant</td>
<td>Greencore planned extension</td>
<td>–</td>
<td>Denbury</td>
<td>WY</td>
</tr>
<tr>
<td>Medicine Bow</td>
<td>Greencore planned extension</td>
<td>–</td>
<td>Denbury</td>
<td>WY</td>
</tr>
</tbody>
</table>
CO₂ hubs, clusters, and transportation networks

The initial demand for additional CO₂ transportation capacity will likely unfold in an incremental and geographically dispersed manner as new dedicated capture plants, storage and EOR facilities are brought online. Large-scale deployment of CCS is likely to result in the linking of proximate CO₂ sources, through a hub, to clusters of sinks, either by ship or so-called ‘back bone’ pipelines. For example, the 240 km Alberta Carbon Trunkline in Canada is designed to accommodate about 14 Mtpa of CO₂ (in a dense phase) for EOR purposes. The initial CO₂ will be captured from the existing Agrium fertiliser plant and a new oil sands upgrader operated by Northwest. Other sources for this pipeline could develop from the Alberta Heartland, which is host to petrochemical and refining industries.

While hubs, clusters, and networks are terms used somewhat interchangeably, in examining their use in describing projects some subtle differences become apparent:

- A CO₂ cluster may refer to a grouping of individual CO₂ sources, or to storage sites such as multiple fields within a region. The Permian Basin in the US has several clusters of oilfields undergoing CO₂ EOR fed by a network of pipelines.
- A CO₂ hub collects CO₂ from various emitters and redistributes it to single or multiple storage locations. For example, the South West CO₂ Geosequestration Hub project in Western Australia seeks to collect CO₂ from various sources in the Kwinana and Collie industrial areas for storage in the Lesueur formation in the Southern Perth Basin (Figure 57).
- A CO₂ network is an expandable collection and transportation infrastructure providing access for multiple emitters. For instance, the CO₂Europipe project has developed a roadmap towards a Europe-wide infrastructure network for the transport and storage of CO₂ (Neele et al. 2011).

The incentives for CCS projects to be developed as part of a hub, cluster, or network include economies of scale (lower per unit costs for constructing and operating CO₂ pipelines); these costs are lower than can be achieved with stand-alone projects where each CO₂ point source has its own independent and smaller scale transportation or storage requirement. A coordinated network approach can also lower the barriers of entry for all participating CCS projects, including for emitters, that don’t have to develop their own separate transportation and storage solutions.

Source: Government of Western Australia (2011).
Benefits and opportunities of integrated network projects are not linked only to economies of scale or technical performance of the transportation network. Network projects can also minimise and streamline efforts in relation to planning and regulatory approvals, negotiations with landowners, and public consultations. For example, a progress report from the South West Hub in Western Australia cites the long lead times associated with obtaining a range of licenses, permits, and approvals for land access rights associated with constructing and operating CO₂ pipelines and highlights the importance of a coordinated approach (Government of Western Australia 2011). Figure 57 displays a schematic overview of the planned pipeline route.

PROPOSALS FOR NEW CO₂ CLUSTERS AND HUBS

For new CO₂ network initiatives, an important distinction should be made between ‘overarching’ initiatives (a network that might emerge over time from integrating multiple CCS projects) and ‘anchor’ LSIPs (which might be the first phase of some of these broader and longer-term network initiatives). For example, the South Yorkshire and Humber CCS Cluster in the UK is designed around capture of CO₂ from the fossil fuel fired power plants and other industrial sources in the region with geologic storage in reservoirs of the southern North Sea. The long-term aim of the cluster is to capture around 40–60 Mtpa of the CO₂, representing approximately 10 per cent of the UK’s annual CO₂ emissions. There is also a parallel focus in the region for advancing three anchor LSIPs within this network that when combined will capture up to 10 Mtpa CO₂ by 2020 from the proposed White Rose oxyfuel project, 2Co’s Don Valley IGCC Project, and C.Gen’s North Killingholme project. Table 15 provides an overview of such anchor LSIPs and their relation to the proposed integrated networks in various parts of the world. Storage options for the Humber Cluster, while preliminary, are being evaluated by National Grid Carbon and include saline reservoirs and oil and gas reservoirs. In parallel, 2Co are working with Talisman Energy on CO₂ EOR and CO₂ storage in the North Sea.

**TABLE 15 CO₂ network initiatives related to CCS**

<table>
<thead>
<tr>
<th>CO₂ NETWORK PROPOSALS FOR CCS</th>
<th>DESCRIPTION AND ANCHOR LSIPS (HIGHLIGHTED IN BOLD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotterdam CO₂ Hub (The Netherlands)</td>
<td>The Rotterdam CO₂ Hub aims to capture and store 5 Mtpa of CO₂ from anchor projects like ROAD, as well as the Green Hydrogen and Pegasus projects by 2015, expanding to 20 Mtpa in 2020–25 and providing the basis for low-carbon industrial and economic growth in Rotterdam.</td>
</tr>
<tr>
<td>Humber Cluster (United Kingdom)</td>
<td>The Humber and Yorkshire region has the long-term potential to capture and store upwards of 40 Mtpa CO₂ from numerous sources. Anchor projects include the White Rose Oxy-fuel project, the Don Valley Power Project, and C.Gen’s North Killingholme project.</td>
</tr>
<tr>
<td>Teesside Cluster (United Kingdom)</td>
<td>The cluster in the Teesside region would capture and store up to 15 Mtpa CO₂ from the Teesside Low Carbon project (formerly Eston Grange), an aluminium smelter, and emissions from other surrounding industries.</td>
</tr>
<tr>
<td>Scottish CCS Cluster (United Kingdom)</td>
<td>The Caledonia Clean Energy Project could accelerate the development of a Scottish CCS Cluster. The CO₂ captured in the Firth of Forth area will be transported by pipeline to the St Fergus terminal in close proximity to SSE’s Peterhead project, where CO₂DeepStore will store it in depleted reservoirs under the North Sea.</td>
</tr>
<tr>
<td>Southwest Hub (Australia)</td>
<td>The South West CO₂ Geosequestration Hub project in Western Australia seeks to collect up to 5–6 Mtpa of CO₂ by 2018–22 from industrial processes, including the Perdaman Collie Urea project, as well as from alumina production and power facilities for storage in the Lesueur formation in the Southern Perth Basin.</td>
</tr>
<tr>
<td>CarbonNet Project (Australia)</td>
<td>The CarbonNet CCS network aims to integrate multiple CCS projects across the entire CCS value chain within the next 10 years. The network is initially sized to capture and store around 1 Mtpa of CO₂ from power stations in the Latrobe Valley by 2018, with the potential to rapidly scale up to support over 20 Mtpa thereafter.</td>
</tr>
<tr>
<td>Masdar CCS Project (United Arab Emirates)</td>
<td>The Abu Dhabi CCS network (Masdar) aims at capturing existing CO₂ emissions from power and industrial sites as well as developing a network of CO₂ pipelines to transport the CO₂ to Abu Dhabi’s oil reservoirs for EOR. Anchor projects include: Emirates Steel Industries (ESI) CCS Project, Emirates Aluminium CCS Project, and Hydrogen Power Abu Dhabi (HPAD).</td>
</tr>
<tr>
<td>Alberta Carbon Trunk Line (Canada)</td>
<td>The Alberta Carbon Trunk Line will be a 240 km pipeline constructed by Enhance Energy to initially collect captured CO₂ from the Agrium Fertilizer plant and Northwest Heavy Oil Upgrader for distribution for EOR or storage in geologic reservoirs.</td>
</tr>
</tbody>
</table>
As shown in Table 15, the key anchor project in the port of Rotterdam is the ROAD project. Located within the Maasvlakte section of Rotterdam’s port and industrial area, ROAD could be one of the first LSIPs to reach execution in Europe and therefore act as a stepping-stone for the realisation of the Rotterdam CO2 cluster envisaged by the Rotterdam Climate Initiative (RCI). The port of Rotterdam hosts the largest coal terminal in Europe, extensive storage facilities for liquified natural gas (LNG), and five major refineries. To maintain this dominant position in the longer run and to attract new investments it is believed that a CCS infrastructure is needed.

RCI, which is to be fully developed by 2035, represents the concept of a regional ‘aggregation hub’ for CO2 transported to Rotterdam, including by pipeline from the port of Antwerp and by ship from the Ruhr Area in Germany down the Rhine River (Figure 58). Other clusters in Europe are under consideration, albeit at very preliminary stages, but include areas around the East Irish Sea, the Thames in the UK, the French port of Le Havre, and the Baltic Sea region. In support of the latter CCS cluster, the Norwegian Institute for Strategic Analysis (INSA 2012) published a Pre-study on transportation and storage solutions for CO2 in the Baltic Sea region, covering a range of CCS issues of direct relevance to the different countries in the region.

Given the economies of scale that can be achieved, the benefits of integrated CO2 transportation networks are apparent, but a network approach can also entail additional challenges, in particular from commercial, financial, and legal perspectives, including:

- design of a multi-user charging framework that reflects the separate infrastructure development, operation, and decommissioning costs and is linked to the allocation of capacity in the system;
- development of innovative commercial structures for CO2 networks and hubs to accommodate numerous partners/owners and their different priorities for access to the network;
- obtain financing for assets that will initially be ‘oversized’ in anticipation of future volumes of CO2 being added to the transportation infrastructure; and
- metering or monitoring different sources of CO2 which feed into a common network. Each source could fluctuate, so sources need to be individually tracked and emitters need to receive specific benefits for each tonne of CO2 supplied.

**FIGURE 58** Plausible flows of CO2 within and between North Sea basin countries in 2030

Source: ElementEnergy (2010b).
7.3

DESIGN CONSIDERATIONS FOR CO₂ PIPELINES

Pipeline engineering is a mature profession. However, for the specific field of CO₂ transportation, there are a number of issues that need to be taken into account. With more projects completing their FEED studies, further insights are being created among the key design considerations of CO₂ infrastructure – see for example the FEED study of the CO₂ transport pipeline for the Jänschwalde project in Germany (Vattenfall 2012), the American Electric Power Mountaineer Project FEED (AEP 2012), and the FEED close-out studies created by the ScottishPower CCS Consortium that focuses on CO₂ pipelines (ScottishPower CCS Consortium 2011). In addition, a series of interviews with CCS project engineers and CO₂ pipeline operators has been undertaken by the Global CCS Institute to discuss the main design considerations for CO₂ transportation infrastructure. For pipeline transportation system design the following data is generally required:

1. pipeline route, profile, and depth of cover;
2. maximum and minimum inlet, operating, and delivery temperatures/pressures;
3. ground/environment temperature;
4. pipe material/grade, diameter, wall thickness, and roughness;
5. piping pressure loss through compression, pumping, and measurement stations;
6. CO₂ mixture properties (level of impurities) and density/pressure changes;
7. pipeline flow and flow build-up;
8. cost data of materials and labour; and
9. applicable codes, standards, and regulations.

Items 6–9 are considered to be of special importance when designing CO₂ pipelines (compared to standard practices around the transportation of hydrocarbons) and are discussed in more detail below.

CO₂ composition and phase changes

For most of the LSIPs in the US that are seeking entry into existing CO₂ EOR pipeline systems, design specifications are controlled in terms of conditions, temperature, and pressure as well as composition (see Table 16). However, there are significant differences between the US experience with CO₂ EOR pipelines (mainly dealing with naturally occurring CO₂), and the expertise needed to design transport systems for anthropogenic CO₂. The composition of CO₂ that is captured from power plants, for instance, will influence the hydraulics calculations that are needed to design these pipelines.

TABLE 16 CO₂ composition specifications for CO₂ EOR pipelines in the US and expected CO₂ compositions from CO₂ capture

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>KINDER MORGAN CO₂ PIPELINE SPÉCS</th>
<th>DENBURY CO₂ PIPELINE SPÉCS</th>
<th>CANYON REEF CARRIERS CO₂ SPECS</th>
<th>POST-COMBUSTION</th>
<th>PRE-COMBUSTION</th>
<th>OXYFUEL COMBUSTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>≥95%</td>
<td>≥95%</td>
<td>≥95%</td>
<td>&gt;99%</td>
<td>&gt;95.6%</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>Water</td>
<td>0.064%</td>
<td>0.047%</td>
<td>0.064%</td>
<td>0.14%</td>
<td>0.14%</td>
<td>0.14%</td>
</tr>
<tr>
<td>H₂S</td>
<td>0.00127–0.0254%</td>
<td>0.0015%</td>
<td>&lt;0.19%</td>
<td>trace</td>
<td>&lt;3.4%</td>
<td>trace</td>
</tr>
<tr>
<td>N₂</td>
<td>≤4%</td>
<td>≤4%</td>
<td>≤4%</td>
<td>&lt;0.17%</td>
<td>&lt;0.6%</td>
<td>&lt;7%</td>
</tr>
<tr>
<td>CH₄</td>
<td>≤5%</td>
<td>≤5%</td>
<td>≤5%</td>
<td>&lt;0.01%</td>
<td>&lt;0.035%</td>
<td>–</td>
</tr>
<tr>
<td>O₂</td>
<td>≤0.00136%</td>
<td>–</td>
<td>≤0.00136%</td>
<td>&lt;0.01%</td>
<td>trace</td>
<td>&lt;3%</td>
</tr>
</tbody>
</table>

continued on page 124
Impurities or by-products such as nitrogen, argon, methane, and hydrogen lower the density of a CO₂ stream, resulting in a higher pressure drop. The critical pressure will also increase, meaning that higher pressures are needed to prevent the occurrence of what is known as a two-phase flow (i.e. gas and liquid CO₂). Hydrogen especially has a significant influence on this. Moreover, combinations of impurities (e.g. from different sources) could together raise the critical pressure more than that from one component in isolation. The characteristics of CO₂ with impurities are therefore vitally important to know in order to properly engineer a CO₂ transport system. Detailed thermodynamics of CO₂ with impurities has been modelled, but the available models need to be further validated.

### Pipeline flow and flow build-up

Similar to modelling of the effects on impurities on the phase behaviour of the CO₂ stream, pressure changes in CO₂ from intermittent sources need to be very carefully managed to avoid two-phase flows of CO₂. Intermittency has not been a significant issue for existing CO₂ EOR pipelines where flow is relatively uniform, but it requires careful examination for projects using CO₂ from power plants and other industrial sources that may operate with variable and irregular capture rates. Minimum pressures of CO₂ gas and start-up or shut-down procedures of the capture plant need to be carefully understood to avoid potentially damaging transportation equipment. Moreover, flow assurance models need to take into account the pressure and temperature needed at the wellhead, since for safety and operational reasons the CO₂ to be injected must have about the same pressure and temperature as the reservoir.

### CO₂ transportation costs

As mentioned in the introduction of this chapter, CO₂ transportation costs may be in the order of 2–5 per cent of the investments needed for a complete CCS facility. However, they are still significant in the demonstration phase (with US$2–7 per tonne of CO₂ for transportation distances under 200 km) and are therefore considered to be an important element of every CO₂ pipeline system design. There are a number of well-defined approaches for estimating the cost of pipelines; in essence, they all identify three major cost components. These are:

- construction (e.g. materials, labour, equipment, design, land acquisition, insurance, project management);
- annual operational and maintenance costs (e.g. labour, maintenance, fuel costs); and
- end of project life abandonment costs.

The costs for CO₂ transportation may differ on a project-by-project basis, due to a number of factors like the expected volumes of CO₂ available and the corresponding optimal pipe diameters; the cost of labour in the local market; the expected economic lifetime of the infrastructure; as well as the type of terrain along the pipeline route. Pipeline construction through difficult terrain (e.g. on the seabed) can be costly not only in terms of additional materials (e.g. isolation layers), but also in relation to the offshore equipment that needs to be hired to lay a pipe under the sea. The most important cost factors in constructing a pipeline are related to the materials used. For example, material costs (such as carbon steel) can account for as much as 15–35 per cent of the pipeline cost (ZEP 2011).
Pipeline design codes and standards

Design codes and standards are being developed to ensure safe and reliable operation of CO₂ transportation infrastructure. The experience with CO₂ transportation in the US and Canada has resulted in a good amount of standards for CO₂ pipelines design, construction, and operation (Table 17). European and Australian regulations are very extensive for pipelines in general, but CO₂ transportation is not covered specifically. The Recommended Industry Practice for design and operation of CO₂ pipelines that has been published addresses the gaps in existing standards (DNV 2010). As a basis, this Recommended Industry Practice could be useful to draft a specific (international) CO₂ transportation standard.

**TABLE 17 Standards and codes for the development of CO₂ pipelines**

<table>
<thead>
<tr>
<th>REGION</th>
<th>APPLICABLE STANDARDS FOR CO₂ PIPELINES</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>The US Federal Code of Regulations, Title 49, Volume 3, Part 195 – Transportation of Hazardous Liquids by Pipeline – and the associated ASME standards B31.4 and B31.8 are the main American codes which address the transportation of liquids and gases by pipeline respectively.</td>
</tr>
<tr>
<td>Alberta (Canada)</td>
<td>The Canadian Standard Association (CSA) 2662-07 for oil and gas pipeline systems is relevant for CO₂ pipelines. In addition, Alberta’s Energy Resources Conservation Board (ERCB) stated that the processes described in its Directive 56 “set out the key applications requirements for prospective developers of CCS projects with respect to transportation of CO₂ via pipeline”.</td>
</tr>
</tbody>
</table>
| Europe          | In Europe, pipeline safety regulations do not consider CO₂ as a specified named substance in the prescriptive manner of the US federal regulations. Standards relevant to the transport of fluids in pipelines include:  
  - ISO 13623 – Petroleum and Natural Gas Industries – Pipeline Transportation Systems, 2nd ed. 2009;  
  - PD 8010: 2004 Parts 1 – Steel pipelines on land and 2 – Subsea pipelines;  
  - BS EN 14161: 2003 – Petroleum and Natural Gas Industries. Pipeline Transportation Systems;  
  - DNV OS-F101 – Submarine Pipeline Systems (2007); and  
  - NEN 3650/3651 for transport pipeline in the Netherlands. |
| Australia       | Australian Standard (AS2885): Pipelines and Gas and Liquid Petroleum (covering the design, construction, testing, operation, and maintenance of petroleum pipelines) has a strong applicability to CO₂ pipelines.                                                                                                                          |
| China           | Standard GB/T 9711-2005 is applicable to CO₂ pipelines.                                                                                                                                                                                                                                                                                                             |
| Industry best practice guideline | DNV’s Design and Operation of CO₂ Pipelines (DNV-RP-J202) is a private standard and draws upon several other standards including ISO 13623 (Petroleum and Natural Gas Industries – Pipeline Transportation Systems) and the American Society of Mechanical Engineers (ASME) ASME-B31.4 – Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids (2006). |

The establishment of international standards could potentially harmonise and guide both regulators and operators alike and minimise burdens associated with securing permitting approvals, construction, and operation of new CO₂ pipelines. In May 2011, the Standards Council of Canada (SCC) submitted a proposal to the ISO to develop an internationally agreed and voluntary standard for CCS. The ISO has subsequently agreed to pursue a proposed program (TC-265) of work that includes the full life-cycle of a CCS system, and intends to establish a separate working group to develop a standard covering CO₂ transport (see also Chapter 4 on policy, legal, and regulatory developments for CCS for more information on this ISO process).
**CO₂ TRANSPORTATION – SYNOPSIS AND OUTLOOK**

Safely and reliably transporting CO₂ from where it is captured to a storage site is an important stage in the CCS process. Transportation of CO₂ and other gases is already a reality, occurring daily in many parts of the world. The total transportation distance that would be covered by the 75 LSIPs currently under development and in operation is around 9000 km. More than 80 per cent of these projects are looking to utilise onshore pipelines, in particular in the US and Canada, where a wealth of experience in CO₂ transportation already exists.

The growth of a CO₂ EOR pipeline infrastructure in North America over the past decades may provide some important lessons for new common user CCS infrastructure development. The construction of so called ‘trunk lines’ connecting one or two LSIPs with a proven storage formation could enable subsequent (smaller) projects to come online more easily. In order to better facilitate the development of this new CO₂ transportation infrastructure, there are a few areas that require further attention, including:

- development of appropriate (international) standards and design codes to further promote safe and efficient operation of CO₂ transport infrastructure;
- development of innovative financial and commercial structures for CO₂ networks and hubs to:
  - accommodate numerous partners and their priority access within a network;
  - obtain financing for assets that will initially be ‘oversized’ in anticipation of future volumes of CO₂ being added to the network;
- validation of detailed thermodynamic modelling of CO₂ streams containing impurities.

Most of the items listed above in relation to the development of CO₂ transport infrastructure have been met by other major transport infrastructure programs. Notably, integrated transport networks have been financed and constructed in virtually every country to move fluids, solids, or waste materials safely.

Opposite: Atmospheric testing. Photo courtesy of CO2CRC.
8

STORAGE

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8.1 INTRODUCTION

Injection of CO₂ into sandstones of the Utsira Formation in the North Sea began in 1996 as part of Statoil’s Sleipner Project which has now stored over 13 Mt CO₂. In Algeria, the In Salah Gas Project has been injecting CO₂ into the Krechba Formation since 2004 with over 4 Mt CO₂ stored. These projects have used a wide range of monitoring techniques and have demonstrated that it is possible to safely manage the injection of CO₂ into geologic reservoirs. Oil companies have been injecting CO₂ into ageing oil fields to enhance the recovery of oil (CO₂ EOR) since the 1970s, and there are now more than 130 such operations, mainly in North America. Most companies, for economic reasons, recycle the injected CO₂ which results in the CO₂ being effectively stored permanently within the oil reservoir. The Weyburn Oil Field in Saskatchewan, Canada, for example, has now stored in excess of 18 Mt CO₂. Thus the technologies and operational aspects of injecting and storing CO₂ in geologic formations are established processes. Storing CO₂ captured from industrial processes in geologic formations is also the component in the CCS chain that presents some of the greatest project challenges. Each geologic storage site is unique and must be screened and extensively characterised, taking years and millions of dollars before a decision can be made to proceed with a commercial project. Geologic storage can also represent the most important public perception challenge and the greatest long-term financial liability associated with a CCS project.

8.2 OVERVIEW OF STORAGE

Progress is being made globally in the deployment of large-scale geologic storage of CO₂. For example, injection of CO₂ commenced late in 2011 into a deep saline reservoir at the Illinois Basin – Decatur Project, the first saline injection program in the US. The first statement of fitness for purpose and conditional regulatory approval has been awarded to the storage development plan for Shell’s Quest project, that will proceed with targeting a deep saline reservoir in Alberta, Canada. In Europe, the ROAD project received a positive opinion by the EC concerning its planned storage site in an offshore depleted gas field – the first such opinion applied for under the CCS Directive. Additionally, the Peterhead CCS project received an
agreement for lease of Goldeneye, a depleted gas field 65 miles northeast of the Scottish coast. Advanced evaluation programs are ongoing in Australia to identify onshore and offshore storage targets in Western Australia, Victoria, and Queensland. The potential of storing CO₂ through EOR as a means of CCS is growing in interest outside of the traditional regions in North America to areas such as Latin America, the Middle East, and, increasingly, China. Standards regarding geologic storage have been developed in North America and have undergone the first steps in transitioning to the ISO. Regional assessments that may help accelerate storage demonstration are in progress in Australia, North America (including Mexico), Brazil, Asia, South Africa, and Europe.

Ultimately, all types of geologic storage – deep saline reservoirs, depleted oil and gas formations, and CO₂ EOR – are needed to reduce atmospheric emissions of CO₂ from industrial processes (Figure 59). The majority of planned and operational projects are currently in OECD countries, with a significant shortfall in non-OECD regions. To help develop and deploy CCS to the scale required, more must be done to improve knowledge of the subsurface in the vicinity of large CO₂ emitters to improve development time for future commercial CCS projects.

**FIGURE 59 Status of current and planned storage projects**

![Bar chart](image)

**Roadmap Targets**

A review of the current global portfolio of operational and announced CO₂ geologic storage projects (Geogreen 2011) addressed an ambitious challenge to meet internationally stated deployment objectives for CCS projects. Most considerations of the Global CCS Institute-supported review inclines toward the target envisaged by G8 Leaders in 2008 of having CCS broadly deployed by 2020, and the 2009 IEA CCS Roadmap goal of 100 projects by 2020. Although the IEA Roadmap is evolving, there is a significant challenge to identify enough bankable storage sites by 2015–17 so that CCS projects can be operational by 2020.

Bankable storage sites are those that are sufficiently advanced in characterisation to support final investment decisions in advance of site construction, commissioning, and operations. The Geogreen study indicated that it can take between 4–12 years to reach bankable status when evaluating deep saline reservoirs or depleted oil and gas fields. Lead times for projects using CO₂ EOR can be much less, as little as 1–3 years, although these opportunities are, at present, more geographically restricted. Although much of the effort is focused on data acquisition and technical evaluation of a proposed site, the time related to licensing and addressing environmental regulations is also significant. The availability of legacy geologic information on the prospective site will have a large influence on the time and cost required to reach a final investment decision. Additionally, the gap from achieving bankable status to commencement of operations (encompassing construction and commissioning) can be three years or longer. Thus, to reach 2020 deployment targets, storage sites must reach bankable status around 2015–17.
The Geogreen review examined announced and operational projects involving deep saline formations or depleted oil and gas fields and identified 54 technically feasible bankable candidate sites. Of these, the review suggested 24–30 could potentially reach bankability status in time to be operational by 2020. Non-technical issues such as funding or public perception, while not included in this workflow, may at least double the failure rate and further reduce the number of bankable sites. Therefore, the estimated number of bankable sites is optimistic, and while there may be sufficient deep saline formations or depleted oil and gas field projects announced to foreshadow broad deployment of commercial-scale operating projects by 2020, achieving this goal is far from certain. Moreover, the projected number of bankable or operating projects falls far short of the 2009 IEA Roadmap requirements of 100 projects by 2020.

Including CO₂ EOR projects in this portfolio could markedly improve the status of CCS deployment (Figure 60). In this scenario, however, the CO₂ must be anthropogenic and appropriate monitoring procedures to address storage requirements must be implemented. By considering suitable CO₂ EOR projects the number of bankable projects by 2018 increases as much as 75 per cent, with 100 sites potentially operational by 2028. CO₂ EOR may also reduce the need for public funding of CCS projects in the near term, but currently opportunities are mainly within North America although interest is growing in many other regions including Europe, China, South America, and the Middle East.

**FIGURE 60 Ability to meet CCS Roadmap targets**

Source: Geogreen (2011).
Progress in saline reservoir storage

NORTH AMERICA

In areas of North America, rocks of Cambrian age have emerged as a target of choice for saline reservoir storage projects including the Illinois Basin – Decatur Project, Shell’s Quest Project in Alberta, and the Aquistore Project in Saskatchewan that will store CO₂ captured from SaskPower’s Boundary Dam coal-fired power plant. The storage reservoirs chosen by these projects are in sandstones that accumulated on the submerged margins of the North American craton more than 500 million years ago (Runkel et al. 2007). The sands formed laterally extensive veneers or blankets over the continental margins and now are preserved as sandstones within regions such as the Alberta, Williston, Illinois, and Michigan basins. Generally the sandstones directly overlay dense igneous and metamorphic basement rocks equivalent to the rocks observed at the surface in the Precambrian or Canadian Shield, and the topography on this surface greatly influenced the deposition of the sediments that are reflected in their reservoir characteristics today. Because the Cambrian sandstones are generally at the base of the sedimentary succession they can be overlain by up to several kilometres of sedimentary rocks that commonly contain abundant seals and barriers to vertical fluid movement. Their great depth, generally favourable reservoir characteristics, large estimated storage capacity, numerous seals to retain injected CO₂, and general lack of alternative economic use make the basal Cambrian sandstones highly attractive targets for large-scale storage of CO₂.

The potential importance of the Cambrian strata for CO₂ storage in parts of North America (Figure 61) has driven a bi-national study involving characterisation of the Cambro-Ordovician saline aquifer system supported by federal governments of the US and Canada. The project involves several state and provincial research organisations led by Alberta Innovates–Technology Futures, the Energy and Environmental Research Center in North Dakota, and several other consortia members. In the Northern Plains–Prairie Region (that is, the Alberta and Williston basins not including the Illinois and Michigan basins), the basal Cambrian aquifer system extends over 1.1 million km². In the deeper parts of the Alberta and Williston basins the Cambrian aquifer system is more than 4 km deep and salinities can be over 300,000 mg/L (for comparison, the ocean is about 32,000 mg/L). Hauck et al. (2012) estimated the regional-scale storage capacity of this single aquifer at 85 Gt in Canada alone, with the potential to support other large-scale storage projects in addition to Quest and Aquistore.

FIGURE 61 Distribution of Cambrian sedimentary rocks in North America

Source: Modified after Runkel et al. (2007).
ILLINOIS BASIN – DECATUR PROJECT

In November 2011, continuous injection of CO₂ began into Cambrian sandstones over 2 km deep near Decatur, Illinois, as part of the Illinois Basin – Decatur Project (IBDP) directed by the Midwest Geological Sequestration Consortium (MGSC), one of seven US regional partnerships. Overall the project is managed by the Illinois State Geological Survey and, significantly, is the first million-tonne demonstration of carbon storage in the US. The injection will take place over three years (ca. 300,000 tpa) using CO₂ captured from fermentation processes used to produce ethanol at Archer Daniels Midland Company’s (ADM) corn processing complex at Decatur, Illinois.

Although the US$96 million funding for this demonstration project was received in 2007, research and data acquisition for the project began in 2003, again underscoring the time requirement for developing a storage program. The Illinois State Geological Survey performed the regional characterisation that eventually led to selection of the Decatur site. The Cambrian Mt Simon Formation is the most widespread saline reservoir in the Illinois Basin and covers two-thirds of Illinois and parts of western Indiana and western Kentucky. The CO₂ storage capacity of the Mt Simon Formation in the Illinois Basin is estimated at between 11 to 151 Gt (NACSA 2012), and in the Michigan Basin it is around 29 Gt (Barnes et al. 2009), whereas overall in the Midwest area it is estimated at between 23 to 355 Gt depending on the efficiency factor used (Medina et al. 2011). Characterising the Mt Simon reservoir and the overlying shale seals (the primary seal being the Eau Claire shale) has been part of ongoing research to finalise the decision to proceed with injection at IBDP. The injection well was drilled in 2009 and provided data to help confirm the suitability of the site. In 2010 a seismic survey was conducted, along with drilling of a geophysical monitoring well and a pressure and fluid sampling (verification) well. Schlumberger Carbon Services provided management on the design and construction of all wells associated with the storage and deep monitoring parts of the project. After the fluid sampling well was drilled, two rounds of fluid sampling were performed to determine pre-injection reservoir conditions. In addition, the IBDP has developed one of the most extensive environmental monitoring and subsurface monitoring programs of any storage site. The IBDP includes an extensive outreach program, has held several workshops, and hosted visitors from around the world to learn from this project.

ILLINOIS INDUSTRIAL CCS PROJECT

The Illinois Industrial CCS Project (Illinois ICCS Project) is a larger-scale demonstration building on what was learnt from the IBDP and involving many of the same proponents. The Illinois ICCS Project has entered the construction phase and is designed to inject 1 Mtpa CO₂ into the Mt Simon Formation beginning in 2013 for about 2.5 years. The injection site is within several kilometres of the IBDP and will use many of the monitoring and surveillance methods employed at IBDP. After injection into the Mt Simon saline reservoir is complete, CO₂ capture is expected to continue for EOR operations.

QUEST CCS PROJECT

Quest is a fully-integrated CCS project designed to capture, transport, and store about 1.08 Mtpa of CO₂ for 25 years in the Basal Cambrian Sands of North-Central Alberta, Canada. The project is operated as a joint venture by Shell Canada, Chevron, and Marathon Oil. The CO₂ will be captured from three steam reformer units at the Scotford Upgrader near Fort Saskatchewan, Alberta. The CO₂ will be compressed and transported by pipeline to the storage site about 50 km northeast, although due to routing the pipeline itself will be about 84 km long. The CO₂ will be injected into the Cambrian sandstones at about 2 km depth using 3–8 injection wells. The sandstones at this depth contain very saline water which has a concentration of approximately 200,000 mg/L.

Geologically, the Basal Cambrian Sands are broadly analogous to the Mt Simon Formation of the IBDP in that they represent deposits resulting from a global Cambrian transgression that produced very similar sequences of tidally influenced sheet sandstones. These sandstone packages are typically less than about 100 m thick but are texturally and mineralogically mature – that is, they are made of grains of a uniform size and shape and are dominantly quartz. These are generally positive characteristics for reservoir rocks.

The Quest subsurface work has developed a comprehensive storage development plan driven by an expansive, systematic risk-management process. From the earliest conception of a storage opportunity to the status of reaching maturity for the final investment decision in September 2012 has taken about nine years, with focused effort since 2008. Development of the geologic model for Quest is in its fourth generation and the progressive evolution of these models has involved data acquisition programs that included drilling three data appraisal wells, performing 2D and 3D seismic surveys, obtaining high-resolution aeromagnetic survey data, and conducting numerous laboratory measurements and simulation exercises.

The Quest project has been subject to numerous internal technical and joint venture reviews as well as several independent peer reviews. In 2011, DNV awarded Shell and its Quest project the world’s first certificate of fitness for safe CO₂ storage. This has been viewed as additional confirmation that the project meets rigorous storage standards. In July 2012, Quest received conditional approval from Alberta’s Energy Resources Conservation Board. This approval was an important consideration in the final investment decision to proceed with the storage project and commence injection in 2015.
AQUISTORE PROJECT

The Aquistore Project is also evaluating the storage potential of basal Cambrian strata in western Canada near SaskPower’s Boundary Dam Power Station which is undergoing a retrofit for CO₂ capture. The Cambrian Deadwood Formation is the basal Cambrian unit in the area (Figure 62) and is a dominantly sandstone sequence that is about 3.3 km deep near the power plant. The Aquistore Project, managed by the Petroleum Technology Research Centre, Regina, Saskatchewan, completed drilling an injection/evaluation well in mid-2012 to obtain cores from the Deadwood Formation and overlying seals to extract essential geologic, petrophysical, and hydrogeologic information for model and simulation development, as well as to calibrate geophysical data and obtain baseline reservoir conditions. The well will eventually test injectivity and is designed to inject up to 2000 t/day of CO₂ after a potential pipeline tie-in from the Boundary Dam Power Station. Other site investigations have included performing baseline monitoring surveys, including a 30 km² 3D seismic survey and installing a permanent geophone array over 12 km². Groundwater and soil gas surveys are also in progress with a second well for observation and monitoring planned to be drilled in late 2012. An injection test will be scheduled soon after completion of the monitoring well.

FIGURE 62 Core photos of Cambrian Deadwood Formation in Saskatchewan exhibiting cross-bedded sand grains and good porosity

Source: Petroleum Technology Research Centre, Regina, Saskatchewan, Canada.

EUROPE

There are numerous European initiatives around CCS projects and they involve research consortiums to large-scale commercial considerations of single sites and hubs and networks. The EU GeoCapacity (2009) study, which developed out of the EU Framework Programme 6 for Research and Technological Development, determined a conservative estimate of 116 Gt storage capacity in European onshore and offshore aquifers and hydrocarbon fields. This capacity potentially represents more than 60 years of CO₂ storage from European large-point source emitters (Figure 63).

NORWAY

About 25 per cent of the storage capacity in Europe is located offshore of Norway (EU GeoCapacity 2009). Two of the largest operating saline reservoir storage projects in the world, the Sleipner and Snøhvit projects, are located in the Norwegian sector of the North Sea and are operated by Statoil. The largest offshore aquifers in Norway are the Utsira–Skade Formation aquifer with 15.8 Gt storage capacity and the Byrne–Sandnes Formation aquifer with 13.6 Gt capacity. The Utsira Formation is used by the Sleipner Project which is among the best studied geologic storage sites in the world. Another saline reservoir, the Johansen–Cook Formation has less capacity at 1.8 Gt, but is being investigated for storage potential by Gassnova because of its good reservoir and seal properties (Norwegian Storage Atlas, NPD 2011). Initiatives of the CO₂ Storage Atlas published by the Norwegian Petroleum Directorate are discussed later.
FIGURE 63 Map of European sedimentary basins

Source: EU GeoCapacity 2009.

SPAIN

The EU GeoCapacity (2009) project determined that Spain had the highest onshore storage capacity of all European countries with a conservative estimate of 14,000 Mt in combined onshore and offshore deep saline reservoirs. In December 2010 Spain also became the first European country to transpose the CCS Directive 2009/31/EC. Most of the storage capacity is in deep saline aquifers of the main sedimentary basins (Duero, Ebro, Guadalquivir, and Tajo basins). The Duero Basin in particular is of interest as it has an extension of approximately 50,000 km2 and is the largest Cenozoic basin on the Iberian Peninsula.

The OXYCFB 300 Compostilla Project, led by a consortium of ENDESA, CIUDEN, and Foster Wheeler, in the north of Spain is currently characterising the Cretaceous Utrillas Formation, a deep clastic reservoir in the Duero basin. The project is also examining storage potential of a deep Triassic reservoir in the Ebro Basin. The study has investigated a number of sites for its commercial project storage site and for its Storage Technology Development Center/Pilot (TDP). Construction has begun for the TDP in Hontomín, a location in the Duero basin that will start injecting CO2 in 2013 into Cretaceous carbonates. Commercial operations are planned to begin in 2015 with injection of 1.1 Mtpa for approximately 30 years. Extensive data acquisition campaigns have already taken place, including obtaining baseline data beginning in 2010. An impressive range of monitoring technologies has been examined for feasibility and implementation at the sites, in at particular the Hontomín site. Public engagement initiatives include a visitors information centre with real-time information displays.

POLAND

The EU GeoCapacity study in conjunction with a four year study by the Polish Geological Institute – National Research Institute identified Mesozoic rocks of Northern and Central Poland (in the Polish Lowlands) to have very favourable conditions for geologic storage of CO2. These deep onshore saline reservoirs represent approximately 85 per cent of Poland’s storage capacity with a potential for more than 1760 Mt.

Storage site selection for the Belchatów project started in 2009 and was completed in February 2012 with the Wojszyce structure chosen for Phase II site characterisation. At the end of Phase II FID will be made by Polska Grupa Energetyczna. Beginning in 2017, the project plans to inject 1.8 Mtpa into Jurassic Pliensbachian sandstones after testing injection in 2016. These strata comprise fluvial, deltaic, and nearshore deposits and have a Toarcian-aged sealing unit.
ROMANIA

The Pannonian Basin Province covers much of Central East Europe, underlying mainly parts of Hungary, Romania, and Croatia. Total storage capacity in deep saline aquifers of Romania was estimated at 7500 Mt by the EU GeoCapacity project. The Pannonian Basin is characterised by a system of Cenozoic basins, and is the area of primary petroleum exploration with CO₂ EOR pilots beginning in the region during the 1960s.

The Getica CCS Demonstration project is located in the Getic depression, a 50–100 km wide basin containing more than 6 km of late Cretaceous to Tertiary sediments. The Tertiary deposits are being investigated for CO₂ storage and are mainly sandstones, conglomerates, and sands known to have good reservoir properties; the average porosity is approximately 14 per cent and the permeability is between 50 to 100 mD. The Getica team initially screened 11 potential sites and has narrowed this down to two sites with reservoirs in the Neogene Sarmatian for further investigation. The project intends to begin injection of 1.5 Mtpa CO₂ in 2015. The three project partners – CE Turceni SA, SNTGN Transgaz SA, and SNGN Romgaz SA – are currently establishing a legal entity to run the project.

FRANCE

France has three large sedimentary basins hosting major deep aquifers and petroleum resources: Aquitaine, Paris, and the South-East Basin, with a CO₂ storage capacity estimated at 7922 Mt by the EU FP6 GeoCapacity project. The Paris Basin is the largest covering 180,000 km², and contains sedimentary rocks representing over 248 million years of deposition from the Triassic to the Pliocene. France Nord, a 54 million EUR project funded 40 per cent by French energy agency ADEME and 60 per cent by industrial partners was designed to study the feasibility of a CCS pilot in the Centre-North part of the basin, matching sources and possible sinks. The project was concluded in early 2012.

The ULCOS-BF project is located in the eastern Paris Basin and is a large-scale demonstration led by ArcelorMittal and supported by a consortium that includes most EU integrated steel producers, some mineral groups, and a number of energy producers and technology suppliers. Pre-screening has identified two possible suitable storage sites in Lorraine in several deep clastic formations. Injection testing is planned to start in 2014 with the objective to store 700,000 tpa in a deep saline reservoir.

The well-known Lacq Pilot CCS project is an industrial demonstration that has been storing CO₂ in a depleted gas reservoir since 2010 in a Jurassic dolomite reservoir. This project, operated and funded by Total, is located in the Aquitaine basin in a region with a long history of oil and gas production and natural gas storage in aquifers.

GERMANY

Regional deep saline formations are present in the Northern part of Germany, both onshore and offshore. The Federal Institute for Geosciences and Natural Resources (BGR) has completed regional storage capacity assessments (e.g. in the region where the Jänschwalde project is located) as well as a publicly available storage catalogue for Germany completed in 2011. The CO₂ storage capacity potential of deep saline geologic structures (traps) in investigated areas covering most of Northern Germany onshore and offshore is estimated at 6.3–12.8 Gt (90–10 per cent probability) or 9.3 Gt (50 per cent probability) in 408 geologic storage structures.

BGR is currently leading the Geo-Scientific Potential of the German North Sea project in cooperation with research institutions, public authorities, and industry partners. The five year project involves the acquisition and provision of basic geoscientific information supporting a sustainable development of the German North Sea, and is to be completed at the end of 2013. The results of the project will be made accessible for the private, business, and research sectors through the internet. The information will be an essential contribution towards spatial planning, sustainable economic use, and protection of the marine environment of the North Sea.

The well-known Ketzin project in Northern Germany, led by the German Research Centre for Geoscience, has demonstrated safe storage of CO₂ in the Stuttgart Formation since 2008. The Stuttgart Formation contains mainly sandy channel-facies rocks with good reservoir properties that alternate with muddy flood-plain facies rocks of poor reservoir quality. This demonstration project has been a major source of scientific knowledge to the global CCS community.

UNITED KINGDOM

The UK has the highest number of European storage projects under development, with six projects in Identify, Evaluate, or Define stage; all plan to store CO₂ offshore in the North Sea in either depleted hydrocarbon fields or deep saline reservoirs. CO₂ EOR is being considered by at least one of the projects. Characterisation of sedimentary basins in the North Sea has been driven by oil and gas exploration. Onshore storage potential in the UK is considered small, but storage capacity in deep offshore saline aquifers was estimated at 14,935 Mt (conservative estimate 7100 Mt) by the EU GeoCapacity (2009) project. The conservative storage capacity in offshore hydrocarbon fields is estimated at 7300 Mt. Note the above values do not include the Northern and Central North Sea offshore basins as storage capacity had not yet been estimated in 2009, but could
be large. The UK Energy Technology Institute (ETI) carbon storage capacity appraisal, expected to be available online in late 2012, will give an updated assessment of storage locations and capacity.

Although the North Sea has been the focus of the first storage sites for UK projects, the Irish Sea also has a large potential storage capacity and is surrounded by many large-scale CO₂ emitters in eastern Ireland, Northern Ireland, west Scotland, northwest England, and southern Wales. The calculated CO₂ storage capacity in the oil and gas fields of the East Irish Sea Basin is approximately 1047 Mt. Additional storage potential exists in newly discovered fields where data is not yet in the public domain, and in non-hydrocarbon-bearing structures in the Ormskirk Sandstone. Storage capacity of these structures is estimated to be 630 Mt (Kirk 2006). Further storage capacity work is being carried out by the Geological Survey of Ireland and the British Geological Survey.

UK HUBS AND CLUSTERS

The South Yorkshire and Humber CCS cluster in the UK is designed around capture of CO₂ from fossil fuel fired power plants and other Industrial sources in the region and its geologic storage in reservoirs of the southern North Sea. The long-term aim of the cluster is to capture around 40–60 Mtpa of the CO₂, representing approximately 10 per cent of the UK’s annual CO₂ emissions. Current proposed CCS projects in the region are Don Valley (2Co), White Rose (Drax) and North Killingholme (C.Gen). The Teesside low carbon CCS project, although further north, could also possibly feed into this cluster. Storage options, while preliminary, are being evaluated by National Grid Carbon, a subsidiary of National Grid and include saline reservoirs and oil and gas reservoirs. 2Co are working with Talisman Energy on CO₂ EOR and CO₂ storage in the North Sea.

ROTTERDAM CO₂ HUB

The port of Rotterdam, through the Rotterdam Climate Initiative (RCI) aims to become a hub channelling CO₂ from industrial sites in Northern and Eastern continental Europe and redistributing it to storage locations in the North Sea in depleted (and depleting) oil and gas fields or deep saline aquifers. In 2010 the RCI, funded in part by the Global CCS Institute, commissioned TNO to identify potential storage locations to assist planning infrastructure requirements. Neele et al. (2011) provided an overview and ranking of potential storage sites that were potentially available by 2015, when some of the first CCS projects in the area could become operational. Options for later development were also explored.

The TNO reports indicated that the best initial options for geologic storage are in offshore, depleted gas fields. The study focused on geologic formations in the P and Q blocks of the Dutch part of the North Sea that which contain over 60 oil and gas fields, and deep saline reservoirs generally less than 100 km offshore. A cluster of small gas fields identified as P18 had sufficient storage capacity and injectivity to accept between 1–1.6 Mtpa CO₂ from sources in the Rotterdam region expected to arise in the period 2015–20. A factor in this choice is that the site must be ready for injection by 2015. The P18 cluster, and the principal storage location for the ROAD CCS project, is about 20 km offshore and has a storage capacity of nearly 40 Mt. Gas production is still occurring in the fields but will taper off (depending on the individual field) from 2015 onwards. A new insulated pipeline will be built with a planned capacity of 5 Mtpa to allow for additional partners and scale-up.

Because there is a finite amount of storage capacity in the depleted gas fields of this region, Neele et al. (2012) evaluated additional storage options, including saline reservoirs on the Dutch Continental Shelf, to allow for potential further CCS development associated with the hub. The initial capacity estimates of these saline reservoirs are promising, but will need further assessment as data on these locations is limited at present. This lack of data and infrastructure, however, will mean that injection cannot be initiated until the reservoirs can be adequately characterised, work that will take a number of years.

AUSTRALIA

The Gorgon Injection Project in Western Australia will be the largest carbon storage project in the world when operational. The project intends to inject up to 4 Mtpa CO₂ into sandstones of the Dupuy Formation beneath Barrow Island. The CO₂ will be separated from natural gas produced from the giant offshore Gorgon, Janz, and Io gas fields that each contain variable amounts of associated CO₂. The project has developed a robust uncertainty management plan and undergone the largest environmental impact assessment in Australian history. Progressing the storage component to reach final investment decision in 2009 took more than six years and involved a dedicated subsurface team of geoscientists, engineers, and regulatory support personnel. The injection component alone to this massive project is estimated at AU$2 billion. The project is preparing for injection in 2015.

AUSTRALIAN HUBS

In Australia, Flagship Projects have also been adopting a hub model. In the state of Victoria, the CarbonNet project is evaluating storage opportunities in the offshore Gippsland Basin. The storage target would likely be in shoreface or barrier bar sandstones of the Latrobe Group that have excellent reservoir qualities. Options include depleted oil and gas fields and saline reservoirs. The Lake Entrance Formation provides a regional top seal of marls, mudstones, and marly limestones. The
In Alberta, Canada, the provincial government is performing a detailed review of the existing regulatory framework as it applies to 
storage in underground formations. The CSA Z741 standard may serve as a seed document for the geologic storage component. 

Expected that the scope of this committee will include all standards related to CO2, including capture, transportation, and 
with all aspects of CO2 storage, including site characterisation, well design, injection rates, monitoring, long-term liability (and 
assessment in CCS. It will provide recommendations to the Minister of Energy in late 2012. These recommendations will deal 
discussed in more detail in Chapter 4, but it addresses aspects of closure criteria, stakeholder engagement, and the role of risk 
regulatory framework assessment is 

Presently, more anthropogenic CO2 is being stored through CO2 EOR than by any other method (around 25 per cent of CO2 
in Chapter 9. 

Interest in CO2 EOR as a method of permanent storage of anthropogenic CO2 has increased markedly over the past several 
years, mainly because it presents a viable business case for integrated CCS without the need for a GHG policy or a price for 
carbon. Sustained high oil prices make CO2 EOR more attractive for operators and thereby increase demand for CO2, which 
may, in turn, increase infrastructure development and spur improvements in capture technologies. There have been a number 
of publications produced during the past several years considering CO2 EOR potential for CCS, such as the National EOR 
others. The Global CCS Institute is also undertaking a multifaceted study on CO2 EOR as a CCS mechanism that is summarised 
in Chapter 9. 

Presently, more anthropogenic CO2 is being stored through CO2 EOR than by any other method (around 25 per cent of CO2 
supply for EOR projects use anthropogenic CO2). The largest current anthropogenic CO2 injection projects globally are EOR 
operations such as at Weyburn, Saskatchewan (2.4 Mtpa not including recycle) and the Salt Creek Field, Wyoming (around 
2 Mtpa). With more than 130 CO2 EOR operations in existence, albeit mostly in North America, there is demonstrably greater 
community acceptance of EOR as a long-standing, familiar industrial activity over other types of geologic storage. But the 
opportunity for CCS associated with CO2 EOR is being recognised more widely as Brazil, Mexico, the Middle East, and China 
are all involved in field pilot and demonstration programs, and countries in Southeast Asia are advanced in evaluating potential 
operations. Interestingly, Europe has some of the world’s longest running CO2 EOR operations as Hungary began pilot studies 
in the 1960s and initiated field-scale CO2 injection in the Budafa Field in 1972, the same year injection began at SACROC 
in Texas. Offshore potential in the North Sea has been well studied, although European onshore EOR opportunities are more 
restricted. However, recognition of the role CO2 EOR may play in CCS was indicated in a speech by Günther Oettinger, the EU 
Commissioner for Energy, in Brussels on 12 December 2011, in which he stated “the only existing and short term realistic use 
for large amounts of CO2 is EOR” (Oettinger 2011, p. 3). 

Storage standards and regulations

Work on the Canadian Standards Association (CSA) Z741 – Geological Storage of Carbon Dioxide began in 2010 and is 
expected to be publically available in the fourth quarter of 2012. The CSA Z741 standard addresses only aspects of geologic 
storage of CO2 and not capture and transportation. The technical content of the standard has been completed, including 
receiving and responding to more than 500 comments received during the public feedback period. 

The ISO has convened Technical Committee 265 (TC 265) to examine CO2 capture, transport, and geologic storage. It is 
expected that the scope of this committee will include all standards related to CO2, including capture, transportation, and 
storage in underground formations. The CSA Z741 standard may serve as a seed document for the geologic storage component. 

In Alberta, Canada, the provincial government is performing a detailed review of the existing regulatory framework as it applies 
to CCS projects, and that has very specific implications towards storage activities. This regulatory framework assessment is 
discussed in more detail in Chapter 4, but it addresses aspects of closure criteria, stakeholder engagement, and the role of risk 
assessment in CCS. It will provide recommendations to the Minister of Energy in late 2012. These recommendations will deal 
with all aspects of CO2 storage, including site characterisation, well design, injection rates, monitoring, long-term liability (and 
the liability transfer from the proponent to the Crown), and the establishment of a post-closure stewardship fund. 

In Australia, the Global CCS Institute, with the endorsement of the Department of Resources, Energy and Tourism and through 
the assistance of the CarbonNet project, has sponsored an examination into the future development of a nationally consistent 
technical framework for the measurement, monitoring, and verification of geologically stored CO2. Preliminary workshops with 
stakeholders in Australia identified considerable support for such a national, voluntary framework.
Regional capacity assessments

GLOBAL

There has been much work performed during the past several years on regional storage assessments – coordinated by geologic surveys and research organisations in Europe, North America, South America, and Australia – that have increased confidence in the feasibility of geologic storage of CO₂ (Figure 64). At present, however, there is no uniform international methodology to estimate CO₂ storage capacity. There are numerous technical parameters that may be considered in defining a storage resource, but storage potential can also involve political and social factors. To address this situation, the IEA has organised national geologic surveys to recommend a common method applicable globally for estimation of storage capacity. Results from this work have led to an IEA proposal for choosing from a continuum of existing methodologies depending on whether the requirements are for basin-wide estimates, individual traps and structures, or if policy constraints are significantly involved (Brennan et al. 2012).

FIGURE 64 Map of regions having storage capacity assessment initiatives

MULTI-NATION

The Nordic CCS Competence Centre (NORDICCS) has initiated a Nordic CO₂ storage atlas designed to help identify potential CO₂ storage sites in the European Nordic region. The atlas will be publicly available through the internet and present data in a geographical information system (GIS). The system will permit a visual overview of CO₂ storage options and will provide access to storage site data. Capacity estimates of possible storage sites should be improved by using test scenarios and modelling storage processes incorporating pressure build-up data and seals properties (NORDICCS 2012).

In May 2012, the North American Carbon Storage Atlas (NACSA) was released by Natural Resources Canada (NRCan), the Mexican Ministry of Energy (SENER), and the US DOE. Coordinated by the North American Carbon Atlas Partnership (NACAP), the atlas provides an overview of CCS potential across North America. The research and data that forms this atlas indicates there is at least 500 years of underground CO₂ storage capacity in North America. Low-range estimates indicate there is 136 billion tonnes of storage potential in oil and gas fields (excluding Mexico), 65 billion tonnes in coalfields, and 1.7 trillion tonnes in saline reservoirs (NACSA 2012). Mexico has also released a Mexico-specific and slightly modified version in Spanish.

NATIONAL

The Norwegian Petroleum Directorate (NPD) published a CO₂ Storage Atlas in late 2011 at the request of the Ministry of Petroleum and Energy. The atlas provides an overview of the Norwegian portion of the North Sea and identifies areas with favourable containment characteristics for long-term geologic CO₂ storage. In addition, the atlas (NPD 2012) provides estimates of the capacity for geologic storage.
The evaluation of all relevant geologic formations in the Norwegian sector used a comprehensive database built from over 40 years of petroleum exploration experience. The atlas is free to access through the Norwegian Petroleum Directorate website (NPD 2012).

The UK ETI funded a national assessment of CO₂ offshore storage capacity that began in 2009. Results of the UK CO₂ Storage Appraisal Project (UKSAP) will be available through a web-enabled GIS database together with a CCS system modelling toolkit currently in preparation (ETI 2009).

Australia is funding a four year National CO₂ Infrastructure Plan to accelerate the identification and development of offshore CO₂ storage sites. Four offshore basins are under evaluation and pre-competitive data acquisition by Geoscience Australia, primarily by using existing 2D and 3D seismic surveys and conducting some new ones. The basins and project completion dates are: Petrel Sub-Basin, offshore of the Northern Territory, by 2013; Browse Basin, offshore of Western Australia, by 2015; Vlaming Sub-Basin, offshore of Western Australia, by 2014; and Gippsland Basin, offshore of Victoria, by 2015 (Department of Resources, Energy and Tourism 2011).

Brazil is also preparing a storage atlas for release in 2012 in Portuguese, with the Global CCS Institute supporting its translation and distribution in English.

8.3 STORAGE CHALLENGES

In most respects, the technical procedures around geologic storage of CO₂ can be regarded as mature technologies. For decades, activities such as drilling wells, subsurface mapping, fluid injection, reservoir management, and many monitoring methods have been performed safely and successfully with a high degree of accuracy. Yet storage can be project limiting. If no suitable site can be identified within a region within a reasonable time, there will be greatly increased costs, extensive delays, or even no integrated project. Therefore:

- it is essential that storage site characterisation begin as soon as possible in the consideration of any CCS project. There is no shortcut to site characterisation;
- storage evaluations must consider potential impacts or interactions with other basin resources;
- public concerns of risk associated with CCS are generally around aspects of storage. The perceived risk of leakage and induced seismicity are among the biggest challenges in CCS; and
- most remaining issues regarding regulations for CCS are storage-related, particularly the issue of long-term liability.

Basin resource interaction

Effectively all large-scale CCS projects will use geologic storage in sedimentary basins which may contain a variety of resources, including conventional and unconventional oil and gas, coal, coal seam gas, mineable minerals, and groundwater for industrial, agricultural, and human use. Other, and perhaps generally less obvious, resources include pore space for disposal of oil field brines or other industrial wastes, storage of natural gas, and for the exploitation of geothermal energy. Some resources still undeveloped or marginally economic today could potentially become more valuable as commodity prices change or technologies for extraction are developed. By injecting large quantities of CO₂ into the subsurface there exists potential for resource conflict or impact with future resource use.

Identifying potential resource conflicts is an important part of characterising storage sites. Resource management systems, likely at basin scale, are important for regulators, other industries using the basin resources, and the public. Much like risk management, resource management will be highly site-specific and resource assessments will influence the choice of storage sites, impact the storage capacity and operating parameters, and inform the design of monitoring plans. In addition, geomechanical effects associated with injection of CO₂ that may impact other resource development, or conversely other resource extraction that may potentially impact storage integrity, must be considered. Varma et al. (2011) have produced an extensive review of aspects of basin resource management associated with carbon storage. This document presents a workflow to assist with resource assessment of potential storage locations which includes identifying and locating known and potential resources, evaluating the geomechanical and geologic regime for security of storage, investigating injection options for risk reduction, and developing monitoring and mitigation strategies.
The EC recently initiated a two year project, the European Geological Data Infrastructure scoping study (EGDI-Scope), that further demonstrates the growing importance of subsurface resource management on a regional scale. The consortium carrying out the study includes the Geological Survey of the Netherlands (TNO), the British Geological Survey (BGS), the French Geological Survey (BRGM), the Geological Survey of Denmark and Greenland (GEUS), and EuroGeoSurveys, which is the umbrella organisation of the national geologic surveys of Europe. EGDI-Scope intends to improve broad understanding of social and economic challenges which include sustainable use of energy, water, and mineral resources and mitigating climate change through storage of GHGs.

Risk management of geologic storage of CO$_2$

Risk assessment is an essential activity during the selection and qualification of sites for long-term storage of CO$_2$ and for the development of a risk management strategy. While geologic uncertainties or risks are highly site-specific, the main perceived risks are of potential leakage, induced seismicity and ground displacement, and their potential impact on health, environment, resources, and value. Primary risks around storage that may affect project feasibility are the timely identification of a suitable storage site and public acceptance.

Storage-related risk assessments and risk management processes have matured as more projects approach final investment decisions, a stage at which detailed operational plans that describe MMV programs must be provided. Projects in development have benefited significantly from knowledge dissemination of risk management plans and MMV programs from operational or near-operational projects, such as Sleipner, the IEAGHG Weyburn–Midale CO$_2$ Storage and Monitoring Project, In Salah, and the Gorgon Injection Project. It is notable that many of the smaller R&D projects in particular have contributed to monitoring expertise through deployment of a wide range of technologies, including at Otway, Frio, Nagaoka, Lacq-Rousse, Ketzin, Cranfield, and a number of tests in the US Regional CO$_2$ Partnership program.

At the end of 2011 the UK Department of Energy and Climate change released the FEED study of the ScottishPower Consortium’s Longannet CCS project and E.ON UK’s Kingsnorth CCS Project. This material includes risk assessments and mitigation studies and makes available many reports to all CCS project developers and other interested parties to disseminate the lessons from these FEED studies. Risk registers identified the top 50 risks and assessed them as to whether they were active or closed. The five highest scoring demonstration risks specific to CCS reported by the ScottishPower Consortium were:

- key project consents not obtained for program or in line with expectations;
- technology scale-up challenge;
- adverse public reaction to project;
- challenges of operating with CO$_2$; and
- offshore transportation system sensitivities to variable flow rates of CO$_2$.

In Canada, the Quest CCS project (FID achieved in 2012 and operational start in 2015) has a risk-based MMV plan which is central to the project’s risk management framework. It fully integrates extensive storage characterisation, monitoring design, regular evaluation, and performance reviews to build active safeguards and control responses and feed the project’s communication.

The Norwegian company DNV initiated the CO$_2$ Risk Management (CO2RISKMAN) joint industry project in mid-2011 to develop a publicly available guidance document which will help the emerging CCS industry deliver effective risk management, particularly around safety and environmental hazards associated with handling CO$_2$ in a CCS operation. The project should be complete in mid-2012 and cover all phases of a CCS system from concept and selection to operation and cessation, as well as addressing hazard management for all links in the CCS. The project has involved various types of stakeholders (industries and specialists, regulators, risk management specialists) to define a common basis for more effective communication and consultation among all CCS stakeholders regarding the management of risk. This work will complement the Best practices for risk analysis and simulation for geologic storage of CO$_2$ published by NETL (2011a) and the Assessment of the major hazard potential of carbon dioxide (CO$_2$) published by the UK Health and Safety Executive (Harper et al. 2011).

The European project ECO$_2$ intends to examine risks with storage of CO$_2$ below the seabed in marine ecosystems and aims to provide a best practice guide for monitoring sub-seabed storage by 2015 (ECO$_2$, 2011). State-of-the-art monitoring techniques will be applied at offshore storage sites and locations of natural CO$_2$ seeps in the North, Barents, and Mediterranean seas. Experimental work and numerical simulations will augment these field studies with the goal of detecting and quantifying the fluxes of formation fluids, natural gas, and CO$_2$ from storage sites. Importantly the project will transfer this knowledge into a risk management and communication framework with an evaluation of the costs of leakage, monitoring, and mitigation measures.
PROVIDING COMMUNICATORS WITH ADEQUATE INFORMATION

Storage risk management includes the related processes of public communication and crisis management. Technical risk management ideally aims to avoid having to manage any crisis, but projects need to be prepared to deal with situations related to misinformation, lack of understanding, or potential incidents. Because these situations may exaggerate the perceptions of risks, they can seriously affect or even result in the cancellation of projects. Providing accurate and timely technical information to project communicators is an important role for the storage team (Bradbury et al. 2011).

Issues may also arise that impact CCS more broadly than those directly related to an individual project. For example, in mid-2012 the US National Research Council (NRC 2012) and Zoback and Gorelick (2012) released papers that discuss the potential of seismicity induced by large-scale injection of CO2 into the subsurface. This topic has been studied previously and is evaluated in all site characterisation processes. Whereas the CCS community views the expansive NRC report as a balanced study, the Zoback and Gorelick paper attracted far more media and public attention by using the phrase ‘earthquake triggering’ compared with the NRC’s term ‘induced seismicity’. Numerous individual scientists and scientific organisations, all very familiar with CCS, are in general agreement that the statements in the Zoback and Gorelick paper about storage capacity and associated seismicity reach questionable conclusions. It is an ongoing challenge for the technical CCS community to provide factual, understandable, and timely responses to all stakeholders around issues associated with CO2 storage.

LONG-TERM STORAGE LIABILITY

In most areas, projects still report long-term storage liability as a hindrance to progressing CCS. Liability issues relating to post-closure CO2 storage centre on the size of the storage area and the length of time over which CCS projects operate. Geologic features and decommissioned wells comprise the containment system and there is uncertainty in assessing long-term behaviour of CO2 within this regime and with the methods of identifying and valuing possible impacts to the environment. There is even further uncertainty in the sharing of responsibilities and financing of potential damage remediation between operators and governments.

Considerable work has been conducted in the area of life cycle risk management of CO2 storage – such as the EC Guidance documents 1–4 for the Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide and DNV’s CO2QUALSTORE (2009) and CO2RISKMAN (2012), among others. The general perception is that progress has been made on the technical and economic aspects of post-closure CO2 storage, whereas the legal aspects and overarching regulatory frameworks related to long-term liability remain largely unsolved.

Long-term liability and its transfer from the project proponent to the state is directly addressed by the Mines and Minerals Act, Carbon Sequestration Tenure Regulation (Bill 24) in Alberta, Canada. This act stipulates that monitoring of a CCS site with comparison to predictive models will be performed and reported on at regular intervals throughout the project. This activity will continue for a period (in the order of 10 years) after injection has been terminated, and if monitoring results support predictions, liability transfer to the state will occur. During the injection period, the proponent will contribute to a ‘stewardship fund’ which will be used by the state for MMV and decommissioning activities on an ‘as needed’ basis.
8.4

PROGRESSING STORAGE PROJECTS

Knowledge transfer

Progressing CCS projects and CO₂ storage in general can be accelerated by transferring knowledge and experience gained from existing projects, large or small, to other projects in various phases of development. In particular, many of the smaller research programs involving injection have contributed significantly to development of monitoring capabilities, characterisation criteria, and refining modelling and simulation tools. The coordination of technical needs and fostering the transfer of findings among research and industrial communities is of paramount importance to the broader CCS community.

Although many of the technologies involved in storage are mature, there are still numerous uncertainties associated with characterising deep saline formations, modelling and predicting long-term behaviour of CO₂ in the subsurface, and monitoring and verification procedures at the large spatial and temporal scales involved in CCS. Targeting specific topics and supporting research in these areas is one mechanism the Global CCS Institute pursues, both independently and in association with technically focused agencies such as the IEAGHG GHG R&D Programme, CO2CRC, and others. For example, the Global CCS Institute currently sponsors targeted work to describe and catalogue relative permeability analyses for use in dynamic simulation, and supports a study on options for remedial techniques in the subsurface. Findings from these studies, along with other project-specific reports supported by the Institute, are available on the Institute’s website.

The development of standards, such as the CSA Standard Z741 – Geological Storage of Carbon Dioxide and emerging work by the ISO on CCS, may provide additional confidence to both proponents and regulators in many jurisdictions to proceed with planning of CCS projects. Guidelines and best practices emerging from existing research and commercial projects are also highly instructional in formulating screening and characterisation strategies and with developing risk management plans to inform operations and monitoring activities. Lessons from these storage activities can provide many insights to progress future CCS projects more rapidly.

Ultimately, capacity development by transferring knowledge through reports, webinars, and workshops is critical. The Global CCS Institute is active in all these areas as well as having a strong focus on providing workshops and courses on storage and CCS in emerging economies.
Most anthropogenic CO\textsubscript{2} currently being geologically stored is associated with CO\textsubscript{2} EOR.

To be considered CCS, CO\textsubscript{2} EOR must demonstrate that the storage of injected anthropogenic CO\textsubscript{2} is permanent. Regulations and policy are required to transition from CO\textsubscript{2} EOR to CCS.

Current CO\textsubscript{2} EOR activities contribute to technical and scientific knowledge and public confidence around CCS.

CO\textsubscript{2} EOR is an important commercial driver in some regions, and also supports some CCS demonstration activity.

CO\textsubscript{2} EOR presents important opportunities for CCS demonstration in the near term.

9.1 INTRODUCTION

Injecting CO\textsubscript{2} into mature oil fields has been a method used for enhancing oil production for about 40 years. Enhanced oil recovery (EOR) refers to a suite of techniques that can be applied to reservoirs with declining oil production to maintain or improve production. Most fields considered for EOR have already undergone primary production – in which the natural reservoir pressure brings the oil to surface – and secondary production methods, usually by injecting water to restore reservoir pressure. Using CO\textsubscript{2} for EOR (CO\textsubscript{2} EOR) has proven successful in rejuvenating oil production in many maturing oil fields and extending their productive lives by decades – the degree of improvement in production is highly dependent on site-specific reservoir characteristics and oil composition, and not all oil fields are amenable to CO\textsubscript{2} EOR.

Of the more than 130 CO\textsubscript{2} EOR projects in operation globally, the considerable majority take place in North America and of these, about half are in a geologic setting known as the Permian Basin in West Texas. There are other commercial CO\textsubscript{2} EOR operations ongoing in Canada, Turkey, and Hungary, and pilot projects scattered even further afield. The historical development of CO\textsubscript{2} EOR has largely been constrained by the availability of inexpensive CO\textsubscript{2}. In the US, large naturally occurring accumulations of CO\textsubscript{2} (N-CO\textsubscript{2}) are found in geologic reservoirs such as McElmo Dome, Doe Canyon Deep, and Sheep Mountain in Colorado and Bravo Dome in New Mexico, sources from which the CO\textsubscript{2} can be produced relatively inexpensively. CO\textsubscript{2} produced by human activities, such as those associated with extraction or burning of fossil fuels or other industrial process, is considered anthropogenic CO\textsubscript{2} (A-CO\textsubscript{2}) and is also used for CO\textsubscript{2} EOR. Because A-CO\textsubscript{2} must be separated or captured using physical and chemical processes it is generally more expensive and historically less available than N-CO\textsubscript{2}. A-CO\textsubscript{2}, however, is now becoming increasingly recognised as an economically viable option as more operators globally are interested in CO\textsubscript{2} EOR and geologic (N-CO\textsubscript{2}) sources are not always accessible. In North America more than 6500 km of pipelines transport CO\textsubscript{2} for use in CO\textsubscript{2} EOR operations to produce around 300,000 bbl of oil per day. The expected supply of CO\textsubscript{2} in 2012 for EOR in North America is 66 Mtpa of which over 25 per cent is A-CO\textsubscript{2}. More anthropogenic CO\textsubscript{2} is injected by operating CO\textsubscript{2} EOR projects than by any other storage option for CCS (Figure 65).

This chapter presents the role CO\textsubscript{2} EOR may play in CCS (along with some of the technical and legal aspects of CO\textsubscript{2} EOR relative to carbon storage) and describes the economic, commercial, and regulatory landscape influencing these operations.
POTENTIAL ROLE OF CO\textsubscript{2} EOR IN CCS

CO\textsubscript{2} EOR has long been of interest to the CCS community as an opportunity for developing technical knowledge and for study of large-scale field deployment of CO\textsubscript{2} injection. Increasingly, however, it is being viewed as a likely means of advancing CCS deployment more broadly. This is largely because CO\textsubscript{2} EOR can provide or support a business case for the capture and delivery of CO\textsubscript{2}, thereby fostering development and improvement in capture methods and ultimately lowering their associated costs. In turn this may expand infrastructure and distribution networks to access additional storage sites, which will lead to gains in scientific and technical knowledge around aspects of geologic storage including risk management, monitoring and verification, and modelling and simulation of the subsurface behaviour of CO\textsubscript{2}.

Natural gas processing, the production of ammonia and ethanol, ethylene plants, and coal gasification all produce high concentrations of CO\textsubscript{2} as part of their standard industrial processes and have a comparatively low cost of capture. These low-cost anthropogenic sources of CO\textsubscript{2} are those typically used currently for EOR, and are serving as vanguards for the development of CCS as an integrated solution to carbon storage. Outside the US, A-CO\textsubscript{2} is the largest source of CO\textsubscript{2} for EOR. In the US, projects under construction and planning since 2010 have greater growth in A-CO\textsubscript{2} than development of natural sources, and thus A-CO\textsubscript{2} is expected to become increasingly important in the next decade. Current CO\textsubscript{2} prices for EOR in the US are typically US$10–40/tonne (Godec 2011) and revenues from its sale can cover capture costs from low-cost anthropogenic sources. For CCS projects with relatively higher capture costs, such as power generation, revenue from CO\textsubscript{2} sales can cover some, but not all, of the additional costs. In this way CO\textsubscript{2} EOR can become an important element toward CCS development activity, particularly in North America but also in Europe, Latin America, the Middle East, and China.

Nonetheless, there are differences between a generic CO\textsubscript{2} EOR operation and a CO\textsubscript{2} EOR operation targeting the storage of A-CO\textsubscript{2}, including:

- anthropogenic CO\textsubscript{2} must, clearly, be used as the source, as transferring natural CO\textsubscript{2} from one geologic reservoir to another (the oil field) does not reduce emissions overall; and
- monitoring and verification activities currently associated with CO\textsubscript{2} EOR are applied to optimise oil production, and not to establish baselines or demonstrate conformance and permanence of storage.

The mechanisms involved in the EOR process do result in permanent geologic storage of CO\textsubscript{2} but in the absence of policy or other financial benefit, CO\textsubscript{2} EOR sites will not be operated for CO\textsubscript{2} storage. Most individual fields offer considerably more capacity for carbon storage potential than utilised in normal production operations, and a GHG policy would provide incentives for operators to store more CO\textsubscript{2}.
How does it work?

Injection of CO₂ for EOR is a well-established technology used to increase oil production in many mature fields. Oil fields suitable for CO₂ EOR have some similar characteristics, although a wide variety of reservoir types can be effectively used. As stated previously, oil fields undergoing CO₂ EOR have typically gone through primary and secondary phases of production and, in general, if the field responded favourably to a water-flood and if more than 25 per cent of the original oil remains in the reservoir, the field is a promising candidate for CO₂ EOR. Hovorka and Tinker (2010) provide an accessible technical overview of the CO₂ EOR process.

**FIGURE 66** Schematic diagram of a water-alternating-gas (WAG) miscible CO₂ EOR operation

CO₂ EOR usually targets reservoirs greater than 800 m deep as the pressure and temperature at these depths maintains the CO₂ in a dense or supercritical state. After CO₂ injection has begun it can take months or more than a year before breakthrough occurs and the injected CO₂ begins to be produced along with oil. The produced CO₂ is separated from the oil, collected, compressed, and re-injected into the reservoir. Ideally, as much purchased CO₂ as possible is produced with the oil as this reflects effective reservoir sweep, but importantly re-injection or recycling reduces the need to purchase additional CO₂. With time, the amount of recycled CO₂ progressively increases in an EOR operation so that the need for newly-purchased CO₂ is reduced until at some point the operation may be able to rely almost entirely on recycled CO₂ (Figure 67). Eventually, most of the injected CO₂ becomes permanently contained within the reservoir in unconnected pores, trapped on mineral surfaces, or dissolved in immobile oil and is no longer available to the EOR cycle. This trapping or retention of CO₂ is continuously occurring while CO₂ is being injected and recycled and is considered incidental storage. Industry experience indicates incidental trapping will eventually involve up to 90–95 per cent of purchased CO₂ over the project life (Melzer 2012). The remaining CO₂ not incidentally trapped is also permanently contained and distributed within the reservoir, either dissolved in unproduced mobile oil or undissolved as dense CO₂ so that effectively all the injected CO₂ is retained within the subsurface. Melzer (2012) provides a clear and detailed description of this geologic storage mechanism.
Associated storage

CO₂ EOR is a demonstrated commercial process that can be applied to many existing oil fields to address declining oil production and is associated with permanent geologic storage of CO₂. In the present operating environment, in which there is no incentive to inject additional CO₂ beyond that needed for profitable oil recovery, the associated carbon storage can be considered incidental to the normal operating procedures as described above. Other storage scenarios that may be envisioned within CO₂ EOR include incremental storage, in which either additional CO₂ is injected into the reservoir during the EOR operations (beyond that required to optimise profits) or through injecting additional CO₂ post EOR operations. Both of these will require changes to reservoir management, monitoring techniques, and additional expense for the surplus CO₂. In addition, CO₂ can be injected into non-oil-bearing strata as a buffer for balancing supply with injection requirements during operations.

CO₂ EOR storage opportunities globally

The recently released North American Carbon Storage Atlas (NACSA 2012) indicates that about 136 Gt of CO₂ storage potential exists in Canadian and US oil fields (Mexican fields were not included). This is a significant volume of storage potential, and although more capacity is estimated for saline formations, CO₂ EOR operations currently represent more CO₂ injection than any other uses of CO₂. They additionally provide a business case to develop and improve CO₂ capture facilities and transport infrastructure more broadly, and provide existing opportunities for scientific and technical learning around long-term storage.

Although CO₂ EOR production from North America currently represents about 90 per cent of the world’s production, globally there are many areas with suitable fields. In Europe, Tzimas et al. (2005) and Gozalpour et al. (2005) indicated that the North Sea oil fields offer the greatest potential as many are, without implementing tertiary methods such as CO₂ EOR, nearing the end of their productive lives. Lack of low-cost CO₂ and high capital expenses have limited development in Europe, but potentially there is an incremental 8 billion barrels in the UK, Norwegian, and Danish sectors that would result in about 5 Gt of CO₂ storage (Tzimas et al. 2005). Onshore European opportunities for CO₂ EOR appear mainly limited to the Pannonian Basin region of Croatia, Romania, and Hungary where CO₂ EOR was deployed in the 1970s. Interest in CO₂ EOR is also high in the Middle East with several national oil companies pursuing commercial agreements for CO₂ purchase. In China, national oil companies also are aggressively investigating the potential of CO₂ EOR, having demonstrated success in pilot operations by CNCP at the Jilin oilfield for several years (Jin et al. 2012, ARI 2009). In Brazil, some of the offshore fields in the Santos basin are expected to produce more than 10 Mtpa of CO₂ and CO₂ may be reinjected into the reservoir to boost production. Mexico and Indonesia are also considering CO₂ EOR as an option for their declining onshore and offshore fields.
Support for CO₂ capture

Presently about 75 per cent of global CO₂ use for EOR is from natural accumulations of CO₂ in geologic reservoirs, the use of which cannot be considered to mitigate GHG emissions (as it would not have been emitted without extraction for specific use in EOR). The A-CO₂ sources typically used for EOR produce relatively high concentrations of CO₂ that can be captured at relatively low cost. These lower cost A-CO₂ sources include:

- fermentation at ethanol plants;
- separation of CO₂ from hydrogen production at ammonia plants;
- processing of natural gas to remove associated CO₂;
- separation of CO₂ at ethylene oxide plants; and
- gasification of coal.

In contrast, there are high-cost sources of CO₂ that produce high volumes of CO₂ at low concentrations which must first concentrate CO₂, thereby incurring significant additional costs. Examples of higher-cost A-CO₂ sources include:

- fossil fuel-based electricity generation;
- refineries;
- cement manufacture; and
- iron and steel manufacture.

Although the full cost of CO₂ from high-cost sources is greater than CO₂ EOR producers are willing to pay, there are a number of government-supported CCS projects around the world which are targeting EOR as an important component in their overall business cases to cover part of the cost of capture (Table 18).

**TABLE 18 LSIPs in Define or Execute stages involving power generation and intending to supply CO₂ for EOR**

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>STAGE</th>
<th>PROCESS</th>
<th>CO₂ MTPA</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Dam</td>
<td>Execute</td>
<td>Sub-critical coal-fired</td>
<td>1.0</td>
<td>Canada</td>
</tr>
<tr>
<td>Kemper County</td>
<td>Execute</td>
<td>Integrated gasification combined cycle</td>
<td>3.5</td>
<td>United States</td>
</tr>
<tr>
<td>Tenaska Trailblazer</td>
<td>Define</td>
<td>Super-critical coal-fired</td>
<td>5.75</td>
<td>United States</td>
</tr>
<tr>
<td>NRG Energy Parish</td>
<td>Define</td>
<td>Sub-critical coal-fired</td>
<td>1.5</td>
<td>United States</td>
</tr>
<tr>
<td>HECA</td>
<td>Define</td>
<td>Integrated gasification combined cycle</td>
<td>2.0</td>
<td>United States</td>
</tr>
<tr>
<td>HPAD</td>
<td>Define</td>
<td>Other</td>
<td>1.7</td>
<td>United Arab Emirates</td>
</tr>
<tr>
<td>Don Valley</td>
<td>Define</td>
<td>Integrated gasification combined cycle</td>
<td>4.75</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Texas Clean Energy</td>
<td>Define</td>
<td>Integrated gasification combined cycle</td>
<td>2.5</td>
<td>United States</td>
</tr>
</tbody>
</table>

The Kemper County IGCC project intends to capture 3.5 Mtpa CO₂ beginning in 2014 and the SaskPower Boundary Dam retrofit project plans on capturing 1 Mtpa in early 2014; both projects intend to sell CO₂ for EOR. Both coal projects have received government funding to pay for the cost of demonstrating CO₂ capture: Kemper County (US$705 million) and Boundary Dam (US$305 million). The sale of CO₂ for EOR is an important source of revenue for these projects. The Texas Clean Energy project also has a contract to sell CO₂ for EOR from its fertiliser operations and receives support as well (US$663 million). The value of CO₂ sales to these projects can be substantial, and complements government support.

The contractual price of CO₂ for these projects is not public. Historically, CO₂ prices have ranged between US$10–40/tonne (Godec 2011). Assuming a price of US$25/tonne of CO₂, the total value to a project selling 1 Mtpa over 20 years would be around US$287 million (at a 6 per cent real discount rate). Selling more CO₂ or receiving a higher price would result in increased value to a project.
INFLUENCING FACTORS ON CO\textsubscript{2} EOR AS CCS

Market and price for CO\textsubscript{2}

A key driver for the interest from CCS projects in EOR is the revenue stream that can be delivered. Five of the eight operating LSIPs sell CO\textsubscript{2} to CO\textsubscript{2} EOR operators. These are fully commercial endeavours at prevailing CO\textsubscript{2} prices with the revenue covering the capture and transport costs from low-cost sources, such as the natural gas processing, synfuels, or fertiliser sectors, and has developed along with the broader US EOR market over the past 40 years.

CO\textsubscript{2} EOR production is linked to the price of oil, and rising oil prices have increased the demand for CO\textsubscript{2}. In response, the number of active CO\textsubscript{2} EOR projects rose from 78 in 2002 to more than 130 in 2012. The price of CO\textsubscript{2}, strongly influenced by regional constraints in supplying CO\textsubscript{2}, also increased with rising demand during this period.

The EIA (2012) and IEA (2011a) each project that oil prices will continue to increase over the next decade, increasing the demand for CO\textsubscript{2} and leading to increased CO\textsubscript{2} supplies. In the US the supply of CO\textsubscript{2} is expected to increase by 50 per cent by 2015 relative to 2010 production levels, and could potentially double by 2020 (Figure 68) (EIA 2012). More than half this growth will come from A-CO\textsubscript{2} which will become increasingly important during the following decade (DiPietro et al. 2012).

Growth in oil output may lag behind growth in use of CO\textsubscript{2} because high oil prices encourage operators in existing fields to inject CO\textsubscript{2} even when rates of production are lower than previously targeted rates of production. The average rate of use of CO\textsubscript{2} in the US is estimated to be 0.5 tonnes of CO\textsubscript{2}/barrel of oil in 2011 (Bloomberg 2012). This is an increase from 0.3–0.4 t CO\textsubscript{2}/barrel of oil for some projects as described by earlier studies (Gozalpour et al. 2005, Godec 2011).

With increasing pipeline investments to relieve supply constraints, together with additional A-CO\textsubscript{2} supply sources being developed, it is expected that over the medium term CO\textsubscript{2} prices will be set by these low-cost anthropogenic sources. Until 2020, and in the absence of coherent GHG policies in the US, there is little financial impetus to develop higher cost anthropogenic sources of CO\textsubscript{2} for EOR other than in demonstration projects with government support unless effective GHG mitigation policies are introduced.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig68.png}
\caption{Projected US supply of CO\textsubscript{2} for EOR by source}
\end{figure}

\begin{itemize}
\item Natural CO\textsubscript{2}
\item Gas plants
\item Other low-cost anthropogenic CO\textsubscript{2}
\item High-cost anthropogenic CO\textsubscript{2}
\end{itemize}

Source: DiPietro et al. (2012) and projects in the Define stage of the Global CCS Institute’s Asset Lifecycle Model (Appendix C).
Benefits of CO₂ EOR for government support of CCS development

Most government-supported demonstration projects of CO₂ capture currently under construction in North America intend to sell CO₂ for EOR. This is an important source of revenue for the demonstration project and reduces the amount of government support needed to make the project financially viable. A more difficult benefit to quantify in using captured CO₂ for EOR is additional government revenue. Generally, oil recovery from CO₂ EOR is about 10–20 per cent higher than without enhanced methods. Therefore, policies that increase the supply of A-CO₂ and expand CO₂ EOR production, increase government revenue from royalties, corporate income, and oil production taxes.

The cost of government subsidies supporting CO₂ capture for EOR can potentially be partially or completely offset by growth in government revenue from increased oil production. Based on this, the National Enhanced Oil Recovery Initiative (NEORI 2012) has proposed a production tax credit to support CO₂ capture for EOR; NEORI projects that the cost will be completely offset by an increase in other government revenue.

The NEORI proposed tax credit would be provided through a competitive bidding process in a series of tranches: a pioneer tranche for commercial-scale, ‘first mover’ projects, followed by two subsequent tranches, one for electric power and one for the industrial sector when the technology is more mature. The industrial tranche would include sub-tranches for both lower-cost and higher-cost CCS technologies. Though funding would be provided over four decades, greater support would be targeted in earlier years so that total yearly support peaks in 2024. NEORI (2012) estimates that a full take-up of its policy would directly support the storage (with appropriate monitoring and reporting) of approximately four billion tonnes of CO₂ over 40 years.

Though public policies implemented in other sectors might contribute similar increases in income and sales tax revenue, CO₂ EOR programs generate additional revenue from government royalties and severance taxes from increased oil production.

With increasing concern about near-term and long-term government budgets, government expenditures to support the development and demonstration of CO₂ capture (and associated monitoring, measuring, and verification technologies) compete with other programs for scarce government funds. In demonstrating net positive benefits to the community from government funding, CO₂ capture and storage demonstration projects linked to CO₂ EOR have the advantage that there is the potential for government expenditures to be partially (or even completely) offset by increases in government revenue from increases in oil production.

Contracting for CO₂

Contracts for CO₂ sales from N-CO₂ generally reflect the large body of precedents developed for the sales of natural gas. Typical terms of such contracts include commitments by the buyer and seller stating base and maximum quantities, quality specifications, banking and make-good provisions, and terms from less than five years up to 15 years. Payment terms vary from volume-based under non-firm contracts to take-or-pay arrangements for firm contracts. Contracts of less than a year generally have no adjustment to the agreed contract price, whereas longer term contracts typically have semi-annual or quarterly adjustments to the price of CO₂. These may incorporate an agreed floor price combined with a linear escalation of the CO₂ price above that floor in accordance with the oil price (Veld and Phillips 2009).

The terms and conditions of contracts developed for firm sales of N-CO₂ would appear to meet the requirements for A-CO₂. As noted above, such contracts can be long term and include take-or-pay commitments and payments on termination. Given the high capital costs and long-life nature of the capture assets, industrial and power CCS projects typically require long terms and revenue certainty.

The following three issues need to be addressed to extend to A-CO₂ the principles for the sale of N-CO₂:

1. risk issues around interruption and the potential impact this can have on EOR operations (e.g. field de-pressurisation);
2. future environmental obligations; and
3. sharing of the value of emission reduction carbon credits and/or voluntary emission reductions.

A further key difference is the impact on A-CO₂ projects of changes in EOR operations over time as more recycled CO₂ is utilised. For N-CO₂, shifts in demand (such as ramping production up or down to accommodate fluctuations in injection rates) are readily accommodated by natural reservoirs. However, for A-CO₂ such demand shifts are difficult to accommodate and, given the economic gap facing A-CO₂ projects, plants want all of the CO₂ captured to be sold and not vented.

The key implication of this is that ‘single source, single sink’ is an inadequate model for the development of anthropogenic sources of CO₂. The needs of both the CO₂ supplier and the EOR operator are better delivered by ‘multiple source, multiple sink’ network arrangements that allow better balancing of supply and demand.
These issues are part of the negotiating framework between buyers and sellers used to justify either a discount (due to risks around interruption and environmental obligations) or a premium (due to sharing in future carbon value) to prices for anthropogenic sources of CO₂. They are also part of the reason that when significant N₂-CO₂ sources are available A-CO₂ can prove difficult to sell to oil producers.

**Well-characterised legal and regulatory regimes**

A long history of activity, in a number of jurisdictions, has resulted in a well-characterised system of law and regulation for the injection of CO₂ as part of EOR operations. This is particularly true of North America, where oil companies in the US and Canada continue to inject large volumes of CO₂ under the auspices of their existing legal and regulatory frameworks applying to oil and gas.

The US provides the most complex model for the regulation of EOR activities, although it affords EOR operators a clearly defined system of law and regulation, as well as distinct roles and responsibilities for federal and state-level regulators. Predicated upon historic experience, the resulting combination of commercial law, property law, and regulations addressing injection activities, it provides a refined system which governs the sale and acquisition of CO₂, the transportation of CO₂, the construction of pipelines, ownership and access rights to pore space, authorisations to inject CO₂ and conduct EOR operations; and post-closure abandonment procedures and responsibilities.

A similar methodology for the regulation of CO₂ EOR activities has also been employed by federal and provincial regulators in Canada. Several key distinctions do exist, however, most notably with regard to subsurface mineral and petroleum rights which in Canada tend to be more often owned by provincial governments than private individuals.

In Europe, where there has been less CO₂ EOR activity, there is less regulatory experience. CO₂ EOR activities in Hungary and in the North Sea have been regulated under existing oil and gas law and regulation. Much of the regulatory focus in Europe remains upon the design and implementation of legislation for the storage of CO₂ as a climate change mitigation activity.

**Emergence of CCS-specific law and regulations**

In recent years there has been widespread development of CCS-specific legislation, which has sought to incentivise and remove barriers to the technology, as well as regulate the contingent processes associated with storage. The EU (and its Member States), Australia, Canada, and the US have all enacted legislation to regulate the entire CCS process or discrete aspects of it. Whereas approaches have ranged from stand-alone frameworks to amendment of existing petroleum or resource legislation, all have sought, by providing regulatory certainty, to establish CCS as a legitimate technology for reducing CO₂ emissions into the atmosphere.

The EU, through its Storage Directive (Directive 2009/31/EC), has adopted one of the most comprehensive examples of CCS-specific legislation by creating a permitting framework which applies traditional methods of pollution control and removes obstacles to the technology. Amendments to the EU’s ETS allow for CO₂ captured and stored in accordance with the Storage Directive, to be treated as ‘not emitted’ for the purpose of the EU ETS. Accordingly, operators will not be required to surrender allowances where emissions are captured and stored under the terms of the Storage Directive. The Directive’s recitals state that EOR is ‘not in itself included in the scope of the Directive’, however, its provisions on environmentally safe storage are applicable where EOR is ‘combined with geologic storage’.

The situation in North America differs greatly from that in Europe, with no dedicated national regulatory frameworks for CCS in either the US or Canada. In Canada, the provincial governments of Alberta, Saskatchewan, and British Columbia have all addressed, to some extent, the policy and regulatory environments for CCS. The most detailed regulatory regime has been developed in Alberta, where the introduction of the *Carbon Capture and Storage Statutes Amendment Act 2010* clarified issues relating to pore-space access and introduced requirements around the long-term liability of stored CO₂. This was further amplified by the *Carbon Sequestration Tenure Regulation Act 2011*, which clarified issues with respect to areas, monitoring and verification plans, durations, and closure for both Evaluation Permits and Carbon Sequestration Leases.

In the US, a number of states have developed legislation aimed at facilitating and permitting CO₂ storage. The legislation includes, in some instances, regulatory mechanisms for verifying and certifying the quantities of CO₂ that may be stored during particular phases of the EOR process, and provisions around storage site closure and post-closure. It is clear however, that for many of these states, these developments are decisively aimed at incorporating captured CO₂ into the EOR process, which in some instances includes ensuring the ability to re-use stored CO₂.
9.4

CHALLENGES TO CO₂ EOR AS CCS

Life-cycle analysis

Anthropogenic CO₂ used and trapped within an EOR reservoir represents abated emissions, but questions have been raised about whether it reduces GHG emissions on a project life-cycle basis. This is primarily because CO₂ EOR involves producing oil. Although energy is consumed and CO₂ produced in the CO₂ EOR process, it is the emissions associated with the combustion of the resulting refined petroleum products that can tip the balance from abatement to increased emissions overall. If CO₂ EOR just displaces other oil supplies, and does not change the level of petroleum product consumption, CO₂ EOR reduces emissions. For an example of a study that assumes no change in oil consumption see Faltinson and Gunter (2010). See Jarmillo et al. (2009) for a study which compares life-cycle emissions from oil production from CO₂ EOR relative to other sources of oil.

The extent to which oil production from CO₂ EOR is exactly offset by a reduction in other sources of oil supply depends on the impact CO₂ EOR has on global oil consumption and associated change in the market price of oil. A lower oil price will be required to increase consumption. But a lower price of oil would reduce total oil supply from other suppliers as marginal projects became uneconomic. That is, even as oil consumption increases, the change in consumption is less that the incremental production of CO₂ EOR as other supplies of oil decline in response to lower prices.

Based on recent estimates of the responsiveness of consumption and production to oil prices changes (e.g. Baumeister and Peersman 2011), the increase in consumption is likely to be between 17–67 per cent of the increase in production resulting from CO₂ EOR with a median increase of 50 per cent. That is, given the demand and supply response, each barrel of oil produced from CO₂ EOR most likely displaces half a barrel of oil from other production sources resulting in a net increase in oil consumption of half a barrel.

Given this range of likely consumption increases due to each barrel of CO₂ EOR production then it is likely that there is a net reduction in emissions when A-CO₂ is used as the source given the average efficiency of CO₂ EOR production. This analysis includes accounting for the emissions associated with recycling the CO₂ and refining the oil into petroleum products. Nonetheless, in certain cases, if production of oil is very high for a given amount of injected CO₂ it is possible for net emissions to be positive at a project level. Although defining the boundaries of a project is critical to correctly account for life-cycle emissions from EOR, even including the energy and CO₂ costs incurred in the cleaning, compression and transport of the CO₂, an unpriced good that would otherwise be released to the atmosphere still results in negative life-cycle emissions on average.

CO₂ availability

Low-cost CO₂ supply is often limited in quantity and restricted geographically, and not always available near appropriate oil fields. Projects can support pipelines several hundred kilometres long if the volume of delivered CO₂ is large enough to achieve economies of scale, but longer lengths can be prohibitively costly for a single site. Rising oil prices and energy security concerns of the late 1970s and early 1980s increased US interest in expanding CO₂ EOR production, but a lack of low-cost nearby CO₂ prevented its development. During the mid-1980s, construction of pipelines hundreds of kilometres long connected natural CO₂ sources in Colorado and New Mexico to the Permian Basin, and this drove a rapid expansion in CO₂ EOR projects (Bradley 2011). In Canada, the Weyburn CO₂ EOR project was large enough to support construction during the late 1990s of a 320 km pipeline from a coal gasification plant across the border in North Dakota. Developments in the rest of the world such as in Hungary, Turkey, Brazil, Mexico, and China are typically linked to low-cost CO₂ supplies near suitable oil fields.
High-cost anthropogenic CO₂ sources need more than EOR alone

For CCS projects associated with the power, steel, and concrete industries the cost of capture technology is significant and is still primarily at the demonstration stage. In addition, such projects face increased operating and maintenance costs and an ‘energy penalty’ by implementing CO₂ capture.

For example, Tenaska, the main proponent of a 600 MW net supercritical pulverised coal-based power station project in Texas, US (the ‘Trailblazer Project’), has stated that for these type of projects the addition of a carbon capture plant adds about 30 per cent to capital costs, approximately 10 per cent to operating and maintenance costs, and reduces net electrical output by about 25 per cent of what would otherwise be available for sale (Tenaska 2011).

Although the evidence to date from projects in the US and Canada is that sales of CO₂ for EOR, while helpful, are not enough in isolation to close this gap, it is noteworthy that the government-supported Kemper County IGCC and SaskPower Boundary Dam projects are proceeding with capture and intended sales of CO₂. As described previously, the current demand vs. supply dynamics are unlikely to support high-cost capture until around 2020.

In conjunction with other support measures, sales of CO₂ for EOR can provide a range of benefits to such high-cost projects, such as:

- contributing towards closing the commercial gap;
- mitigating integration risk between capture, transport, and storage elements of the CCS chain; and
- mitigating the risk in relation to cost and timeframe (which can be 5–10 years or more and hundreds of millions of dollars in cost) to develop a suitable greenfield deep saline formation to the level of certainty required for FID.

Source: Data supplied by Ventyx, United States Department of Energy’s National Energy Technology Laboratory and National Sequestration Database and Geographic Information System, modified by the Global CCS Institute.
Legal and regulatory challenges

The opportunities for CO₂ EOR operations using A-CO₂ to transition to full CO₂ storage projects are tempered by the legal and regulatory regimes which have emerged around the two distinct processes. Where adequate policy settings and economic drivers exist, policymakers and regulators must consider the adequacy of their legal and regulatory environment to enable and encourage a transition.

ENABLING A TRANSITION WITHIN THE LAW

Regulators seeking to enable a transition from EOR activities to full-scale geologic storage must consider the extent to which a legal and regulatory regime governing CO₂ EOR may also support the injection and storage of A-CO₂. Consideration of the scenarios in which CO₂ may be stored, together with the legal and regulatory regimes that govern them, reveals that a number of legal barriers to the integration of the two activities remain.

It is important that the legal and regulatory framework accurately identifies property rights involved in each storage scenario. The rules should also address competing uses of the subsurface and provide a mechanism to resolve potential conflicts.

One example of potential conflict may arise in jurisdictions where pore space occupied by a mineral is not available for CO₂ storage unless the rights to that mineral are also acquired. It may be necessary to amend laws to allow for the acquisition of property rights or owner consents across the various storage scenarios. Issues around property rights associated with storage are alleviated somewhat in jurisdictions where ownership of pore space has been vested in the State. In these instances, the determination of resource management and priority of use will become increasingly important for government.

Presently in the US, CO₂ storage during CO₂ EOR operations is viewed by the EPA as presenting a lower risk than other storage operations mainly because of the pressure management provided by the concurrent injection of CO₂ and extraction of reservoir fluids (including the oil and recycled CO₂). During the basic storage model in which CO₂ is stored during normal EOR operations, the EPA determined that the Class II wells regime would continue to apply. Where there is proposed incremental storage with the aim of maximising CO₂ storage, the EPA suggests this will ‘likely’ increase risk and that an operator should determine whether a Class VI well permit is required. Given that various factors may affect the risk profile of a particular operation, it is important for the regulatory framework to be appropriately adapted to the risk profile presented.

Some regulatory frameworks for CCS require a high degree of assurance that injected CO₂ will not return to the atmosphere. In contrast, for EOR a similar high level of documented scrutiny has not been employed. Meeting the permanence requirements expected for CCS under some regulatory frameworks may require additional monitoring and accounting protocols for CO₂ EOR relative to current practices, but not likely more onerous than for sequestration sites using saline formations.

Post-closure liability has proved particularly significant during the design and implementation phases of many of the new regulatory models for CCS. Where there is the likelihood of potential damage to third parties, potentially occurring far into the future, policymakers may choose to ensure that some sort of industry-funded compensation scheme is available. It is unclear how costly the schemes would be and during the early years of CCS development whether it is possible to create a large enough pool of funds to sufficiently spread the risk among participants. This may lead to costs that discourage participation of commercial EOR operators. Many operations are presently within jurisdictions that have orphan well schemes (which are much more limited in scope). Policymakers may also wish to create a stewardship entity for storage sites to address potential incidents over an extended period that may exceed the lifetime of private companies or even of nations. However, the cost and complexity of trying to establish and fund such a stewardship entity may prove prohibitive; consequently, shorter time frames or more limited responsibilities for the stewardship entity may ultimately need to be accepted.

In developing CCS regulations, it is desirable to require CCS and CO₂ EOR operators to undertake actions which significantly lower the expected risk of leaks and to make them liable for costs due to leaks if they fail to undertake these actions. Increasing requirements to avoid leaks and liability for leaks necessarily increases the cost to operators. Where the costs of transitioning from CO₂ storage during EOR operations to dedicated storage are greater than the anticipated benefits, the transition will not occur. Policymakers will need to consider the issues of costs and benefits in crafting liability rules that they deem appropriate under the circumstances.
STATUS OF CO₂ EOR AS CCS

The intent or objective of CCS is the long-term isolation of CO₂ in the deep subsurface as a means of managing the risks of global climate change. At present, CO₂ EOR operations in North America and in other oil basins in Eastern Europe, the Middle East, South America, and China are injecting anthropogenic CO₂ into maturing oil reservoirs where the CO₂ is likely to be permanently stored. The capacity for storage in these fields, while significant, is less than that available in saline reservoirs and, by itself, less than required for CCS to mitigate CO₂ emissions to the atmosphere.

Additionally, for CO₂ EOR projects to be recognised as CCS, certain regulatory thresholds will need to be met, including levels of reporting regarding monitoring, measurement, and verification requirements. There are no current overarching regulations or guides regarding the transition of a CO₂ EOR project into a dedicated storage project. However, CO₂ EOR offers benefits to the body of knowledge needed to implement CCS, including useful experience in handling and injecting CO₂, modelling, predicting its behaviour in the subsurface, and demonstrating effective monitoring methodologies.

CO₂ EOR may also create a revenue stream for the project proponents, since demand for CO₂ EOR is driven by high oil prices which create incentives to increase the supply of oil. Although there may be a willingness to pay a high price for CO₂ when oil prices are high, the price will primarily be determined by the availability of supply sources. Over the next decade the CO₂ price is expected to be determined by low-cost CO₂ sources. CO₂ prices alone will be insufficient to support relatively high-cost projects associated with electricity or iron and steel.

CCS requires credible long-term climate change policies to enable investment in both demonstration and deployment, particularly for the majority of large-scale, relatively high-cost sources of CO₂ emissions. When credible GHG mitigation policies are introduced, then CO₂ EOR can accelerate the development of a broad-scale CCS industry – since CO₂ EOR effectively brings forward the revenue stream required to support large-scale CCS projects, leading to earlier deployment than if the only driver was climate policy. In the absence of GHG policy, CO₂ EOR is unlikely to lead to additional geologic storage beyond what the commercial CO₂ EOR market delivers.

CO₂ EOR is supporting projects today, but it will not lead to a CCS industry by itself. CO₂ EOR does offer benefits to the demonstration and deployment of CCS, and it adds to the body of knowledge needed to implement CCS broadly. This includes the development of numerous materials, technologies, and industrial best practices that should be directly transferable to the large-scale commercial adoption of CCS across the global power and industrial economies. Overall, CO₂ EOR is likely to have a substantial role in the next decade supporting CO₂ storage and development of capture technology. Its role will diminish in future decades as the need to store much larger volumes of CO₂ will require the use of dedicated storage such as saline aquifers.

Opposite: Photo courtesy of Cenovus Energy.
PUBLIC ENGAGEMENT

10

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Public engagement and communication is increasingly recognised as a fundamental project management component for most CCS demonstration projects.

All communication and engagement activity around a CCS demonstration project should be designed to build and reinforce trust between a developer and key stakeholders.

Effort is required to improve understanding of CCS technology and its wider low-emission energy context.

The term ‘public engagement’ is used generically to describe multiple areas of stakeholder interaction – from dealings with key influencers over project progress (such as regulators and local site communities) to interaction with a more broadly defined public, including media and environmental NGOs. For all but a few CCS projects based in isolated locations, key stakeholder lists can be long and varied.

High-profile examples of the effects of organised public opposition in Europe, in combination with increased sensitivity to public spending following the GFC, means that proponents of CCS demonstration projects must become more adept at understanding and engaging with key stakeholders. The topic of public engagement is therefore growing in international significance.

For the 2011 project survey, the Global CCS Institute sought specific information from project proponents regarding their progress in the creation and execution of public engagement strategies. The 2012 project survey further developed these themes to examine the type of communities that CCS projects are dealing with, the communication and engagement tools that projects have found successful, key areas of concern voiced by stakeholders, the current levels of satisfaction with the project’s community data, and public engagement strategies as risk-mitigation tools.

In this chapter, interesting trends in the 2012 project survey data are identified and reflected on in the context of best practice lessons emerging from early demonstration projects and applied social research.

Short case studies are used to highlight two themes that consistently emerge from project feedback and social research: the need to improve understanding of CCS and energy more generally, and the importance of building and maintaining trust as a fundamental success factor in any public engagement strategy.

10.1 EMERGING TRENDS IN PUBLIC ENGAGEMENT

Most public engagement best practice guidance will cite the importance of understanding the local context of a site and tailoring activities and messages to meet those specific needs.

This site specificity makes it notoriously difficult to monitor trends in public engagement activity for CCS demonstration projects, however, with this caveat in place, the responses to 2012 project survey highlight some potential focus areas which largely correlate with key areas of learning emerging from social research data and early CCS demonstration experience.
Public engagement recognised as a key component of project management

Early demonstration projects have consistently shown the value of both early stakeholder engagement and of embedding communication/engagement expertise within a project management team from the outset of a project (Ashworth et al. 2010a). The ROAD Project in Rotterdam, the Netherlands, cites the integration of stakeholder management expertise in their project team as the first key lesson that can be taken from their current successful public outreach process (Kombrink et al. 2011). The UK’s Peterhead Project also recognises the value of a wide skill-set in a CCS project team:

“Given the importance of managing stakeholder engagement for a CCS project, we made sure that we had communication expertise integrated into our project management team from a very early stage. It is really important to have broader social and political viewpoints represented when making important project decisions.”

George Clements, Development Manager, SSE, Peterhead CCS Project, UK.

Evidence from early CCS demonstrations and also from other large industrial projects have shown that announcing project plans before engaging with local communities and other affected stakeholders and familiarising them with the project contributes to significant conflict between stakeholders (Russell and Hampton 2006).

Growing recognition of the importance of managing stakeholder communication and engagement is evident from the 2012 project survey results in which a high percentage of projects (in all but the earliest Identify phase of the project lifecycle) have, or are in the process of developing, a public engagement strategy (Figure 70).

However, the survey results also highlight that a relatively large fraction (13 of the 56 LSIP respondents) report that their CCS project did not require a public engagement strategy. These results are largely explained by projects citing remote geographic locations, successful achievement of necessary permissions, or projects located on privately-owned land.
Demonstrations still confined to areas of low population

To examine this trend further, the 2012 project survey sought to better understand the types of communities that CCS demonstration projects are impacting on globally; it asked project proponents to describe the different communities impacted by their CCS project (Figure 71).

**FIGURE 71** Community descriptions by overall asset lifecycle stage

From the 52 projects that responded, not a single project was being planned in a highly populated residential area, and of all the projects currently through FID and into the Execute or Operate phase of the project lifecycle, only two had to deal with communities from moderately populated residential areas. The vast majority of the advanced projects were based in relatively remote locations with limited community impacts.

While such projects have little to teach in terms of their processes for community engagement, the existence of eight projects that are actually capturing, transporting, and storing CO₂ (in quantities totalling around 23 Mtpa) provides a strong message for those involved in CCS public engagement regarding the reality of CCS demonstration and the potential impact of this technology on future global CO₂ emissions.

Altogether, exactly half of the responding projects reported dealing with largely industrial communities (local communities based in industrialised areas that were familiar with construction and industry processes), but given the complex, often geographically diverse stages of the CCS process, it was not surprising that many project respondents also cited dealings with farm communities and moderately populated areas as well.

Despite the complexities of dealing with multiple community types, the majority of project respondents still ranked their local communities as presenting relatively low levels of public engagement risk – 71 per cent of responding projects ranked their local communities as presenting a low level of public engagement risk.

Interestingly, 38 per cent of responding projects currently in the Evaluate, Execute, and Define phases of the project lifecycle reported communities which presented a medium or high risk, while all of the responding projects in the early Identify stage and those in the actual Operation phase of the project lifecycle considered their communities to present a low level of risk. This result supports anecdotal evidence derived from discussions with projects in these intermediate phases of project development, which suggests that these periods are crucial in terms of the efforts required to reduce and manage public engagement risk.
Public engagement as a risk-mitigation strategy

Lessons emerging from both social research and early CCS demonstration experience highlighted the critical role of communication and public engagement as a project risk mitigation function (Bradbury et al. 2011). To explore this further, the survey asked projects that had, or were developing, a public engagement strategy to assess the suitability of their current community data and engagement strategies as tools for understanding, anticipating, and mitigating public engagement risk (Figure 72).

FIGURE 72 The extent to which projects consider consultation activities with impacted local communities are sufficient for anticipating and mitigating public engagement risk

Over half of the responding projects expressed confidence in their current engagement and communication activities. That is, they felt they were either sufficient or on track to anticipate and mitigate public engagement risks in their local communities. These results seem to support the general trend, where projects are taking a more sophisticated approach to public engagement activities.

The 2012 project survey results also reveal a substantial number of projects reporting dissatisfaction with both their understanding of local communities and their current levels of engagement. Best practice consistently reiterates the importance of gaining a sound understanding not just of a project’s stakeholders, but of the wider social context in which a potential project is expecting to operate.

Understanding a project’s social context should form a fundamental part of a project’s initial risk assessment process. The subsequent creation of a public engagement strategy is ideally a positive, proactive, trust-building exercise, but in project management terms many projects find it useful to badge the strategy as a detailed risk mitigation strategy that requires monitoring and management like any other project risk (Bradbury et al. 2011).

The Toolkit for Social Site Characterisation (Wade and Greenberg 2011) and its Communication and Engagement Toolkit (Ashworth et al. 2011) both offer an array of practical tools to assist project developers to gain a better understanding of their local communities and stakeholders.
Social research highlights a number of key areas that projects should consider exploring to understand a project’s social environment.

- **Local economic conditions:** What are the major industries employing people in the community? Is the base more service-oriented or industrial? How is the economic health of the community and the region? What is the tax base? What are local energy costs?
- **Local empowerment:** How established are local property owners? Does the community feel that it has a voice in making decisions that impact the community? Are there positive or negative examples of these? What is the community experience with industry or environmental concerns?
- **Underlying views:** What are the local views and experience relating to climate change, coal-based energy, renewable energy, coal mining, drilling, oil production, natural gas storage, and emissions trading? Is there a local history of royalty payments for mineral or other property rights?
- **Environment:** Has the community experienced environmental damage in the past? How was it resolved?

To help shape engagement approaches, the research is meant to identify both positive and negative impacts to a project, but it can also influence a project’s technical design and planning elements. This social site information will only be useful if it is truly integrated into the overall project planning and management of a project.

*Note: Adapted from Wade and Greenberg (2011, p. 17).*

A preference for face time

In order to gain a better picture of the kind of public engagement activity that projects around the world are engaged in, the Global CCS Institute asked all 2012 project survey respondents that had, or were developing, a public engagement strategy to identify the engagement methods they found most helpful in their local communities (Table 19).

<table>
<thead>
<tr>
<th>Engagement methods responding projects found most helpful with local communities (multi-select answers)</th>
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<tbody>
<tr>
<td>ANSWER</td>
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<tr>
<td>Face-to-face meetings</td>
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<tr>
<td>Formal consultation events</td>
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<tr>
<td>Media</td>
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<td>Communications material</td>
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<td>Site visits</td>
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<td>Websites</td>
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<td>Education programs</td>
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Reported project experience, social research (Itaoka et al. 2012, Reiner et al. 2006 and de Best-Walshober et al. 2008), and large-scale public opinion surveys, such as the EC Eurobarometer (Eurobarometer 2011), and the Canadian and Albertan perceptions of CCS survey (TransAlta 2011) all indicate that large segments of the population have very little knowledge of CCS and issues related to low-carbon energy more generally. Social science research confirms that when people are missing information or direct experience with a particular risk or issue, they will seek information from sources around them – from friends or other trusted sources of information (Wade and Greenberg 2011, Rowe and Wright 2012).

Given this context, it is perhaps not surprising that all of the respondents cited face-to-face meetings of some form as the most helpful methods of engaging with local communities. Site visits also ranked particularly highly, along with media coverage and communication materials.
A number of respondents clarified that they were using the full suite of engagement tools, but tools such as websites, posters, and leaflets were created as support materials to enhance face-to-face interaction with stakeholders.

“In the end it’s about the people behind the monoliths. It’s about personal contact, you have to be sensitive and that means you have to invest time and money and effort. In our experience if people get the impression you have good intentions and that you are willing to listen you will be successful.”

Marc Kombrink, Director Stakeholder Management, ROAD, the Netherlands.

Storage risks top the list of community concerns

Results from a comparison study of four international large group workshops designed to inform stakeholders about CCS and other climate issues (held in Australia, the UK, Canada, and the Netherlands), found that participants’ perceptions of CCS tended to focus on the perceived risks and uncertainties associated with the technology. Workshop participants in each country raised questions around CCS safety, the likelihood of unplanned leaks of CO₂, and the likelihood of CO₂ remaining safely stored for long periods of time, but other areas of questioning spanned a host of wider economic and social concerns (Ashworth et al 2012).

The 2012 project survey results echo these findings. The survey asked projects for feedback on their most frequently raised stakeholder concerns. The health, safety, and environmental impacts of onshore CO₂ storage topped the project survey list, closely followed by health, safety, and environmental concerns regarding onshore transportation of CO₂. The next most reported concerns were around the cost/benefit of CCS and potential impacts to community property values.

These findings undoubtedly point to the need for those trying to communicate the benefits of CCS to be able to provide accurate information on key technical topics such as the properties of CO₂, CO₂ behaviour underground, and CO₂ behaviour in its different phases of transportation. However, social research and emerging project experience indicates that allaying public concerns around future CCS demonstration projects involves much more than a simple provision of facts, or a beautifully crafted scientific argument. It is not simply about what is communicated, but how it is communicated.

To help with the delivery of technical project information, a number of recent CCS demonstration projects such as ROAD, Getica CCS, Compostilla and Longannet have reported great success in providing communications training for their project’s technical staff.

“We have found that just providing a basic level of communication training to the technical staff on our project greatly improved their confidence and ability to interact with a wider array of stakeholders. We have worked hard to make sure that our project staff can hold dialogs and present in a balanced way – explaining both the benefits and potential risks of CCS technology, using language their audience can understand! Having technical staff able to present in public has brought real credibility to our outreach and education work.”

Gloria Popescu, Head of Knowledge Sharing and Communication at the Romanian Institute for Studies and Power Engineering (ISPE), Getica CCS, Romania.

Multiple sources of risk research (on CCS but also on more established topics such as nuclear power and genetically modified crops) confirm that the ‘general public’ assess risk based on a range of factors, not just probabilistic assessments or empirical facts (Bradbury et al. 2011). This more expansive approach to risk assessment becomes particularly evident in the case of evolving technologies like CCS that are still in the demonstration and learning phase of development. Risk communication in this kind of uncertain environment relies very heavily on establishing trust between the communicator and stakeholder.

CSIRO’s comparison of five international CCS projects (Ashworth et al. 2010a) found that the projects that were framed as research projects and were aligned to research organisations were more readily accepted than those initiated or fronted by a private company. Projects led by private companies that have been well received – despite not being aligned to specific research projects – tend to have either framed their project as part of a responsible approach to business as usual (CO₂ EOR projects in North America), or they have gone to great lengths to demonstrate the knowledge-sharing public good components of the project.
It’s all about the economy

The people who endorsed us talked about it (CCS) being a vital tool in the battle against climate change. I don’t think that that kind of argument worked at a local level, within the local community, they didn’t care. We would bring it up and they would say ‘oh that’s nice for us’.

Norm Sacuta, Director of Communication, Weyburn, Canada.

Framing a project and creating the messages and resources to communicate its value should be a fairly site and stakeholder-specific process. A strong project communication/engagement strategy will take the time to consider interested, affected, and influential stakeholders impacted by the project, and then frame their message to address questions like: What is the value of the project? Why is it taking place here? Why should I care about this? How will this directly impact me?

The experiences emerging from many of the early demonstration projects is that multiple ways of framing a project are required. For example, the potential of CCS to make a critical contribution to lowering the world’s carbon emissions is an important context for early, high-level engagement activities, but local communities affected by a CCS demonstration show very little interest in the importance of CCS for lowering their nation’s carbon emissions. Instead, messages around sustainable job creation and skill development opportunities are likely to be more relevant.

A clear trend emerged from responses made by all 10 projects that answered a request for information on the benefits that projects were communicating to local stakeholders. All mentioned some kind of economic benefit including future-proofing traditional local industries, creating new jobs and skills, development opportunities, improving access to CO2 for EOR-related projects, and general improvements to a region's energy-related infrastructure.

This focus on the potential economic benefits that a project might bring a region or community has become increasingly evident as larger numbers of CCS demonstration projects have started moving from the ‘identify phase of the project life-cycle into the Evaluate and Define phases and have had to undertake more direct interaction with communities impacted by CCS demonstration.

This ‘direct’ or ‘human’ approach supports one of the key recommendations of the international research team that compared the communication and outreach practices of five early CCS projects. The team emphasise the importance of first identifying, and then clearly articulating, the local benefits of a project; communications should be designed to address stakeholders’ needs, not push out generic information (Ashworth et al. 2010a).

10.2

PUBLIC ENGAGEMENT SUCCESS FACTORS

There is a wealth of public engagement-related resources designed to support CCS project proponents and other interested stakeholders with the design and implementation of a CCS engagement and communication strategy (Ashworth et al. 2010a, Ashworth et al. 2011, European CCS Demonstration Project Network 2012, NETL 2009, CATO-2 2008 and WRI 2010).

Through collaborations with CCS demonstration projects, CSIRO, and a network of international social researchers, the Global CCS Institute’s knowledge platform now contains over 50 different public engagement and communication knowledge products – including an internationally trialled and peer-reviewed toolkit with supporting resources (Ashworth et al. 2010a, Ashworth et al. 2011, Wade and Greenberg 2011 and Bradbury et al. 2011).

Encouragingly, respondents to the 2012 project survey indicated a strong uptake of the available international resources, in support of their existing in-house and project-specific guidelines. The gradual release of early demonstration project lessons and experience is helping to improve the relevance of public engagement best practice and guidance.

Researchers, such as the European-funded SiteChar group (SiteChar 2011), are now beginning to monitor and report on projects as they deploy these best practice guides, capturing lessons that will improve processes and fast-track learning for future project proponents.

By consolidating the best current social research with the experiences and emerging lessons from early CCS demonstrations, it is possible to identify a number of factors common to projects with successful public engagement programs (Table 20).
## Table 20: Public engagement and communication: common success factors

<table>
<thead>
<tr>
<th>SUCCESS FACTOR</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td><strong>Shared vision</strong></td>
<td>Alignment and shared vision across key government bodies (national, state, local) and development teams</td>
</tr>
<tr>
<td>From case studies like Barendrecht, Jänschwalde, and the Carson Project in California, examples are seen of misalignment between different levels of government proving exceptionally difficult for projects. Visible conflict at these levels erodes public confidence and provides a gap to be filled by groups with inaccurate, but well-articulated and damaging views on CCS. At the same time, the majority of Canadian projects have benefitted from tightly aligned and supportive provincial, state, and federal governments and partnership with the US Government.</td>
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</tr>
<tr>
<td>This need for alignment is not exclusive to governments. CCS projects with a consortium of partners have emphasised the importance of all parties presenting consistent, unified messages on the need for, and description of, a CCS project (including the funding bodies and governments involved) and of presenting CCS as a ‘complete chain’ solution to avoid detractors being able to break it down and challenge its constituent parts.</td>
<td></td>
</tr>
<tr>
<td><strong>Core communications function</strong></td>
<td>Communication/engagement experts embedded in project team from project outset</td>
</tr>
<tr>
<td>Successfully deployed projects have almost always integrated communication and engagement expertise into the earliest project plans to ensure that, along with technical details, social, economic, and political factors are adequately represented when important decisions are being made.</td>
<td></td>
</tr>
<tr>
<td><strong>Social context considered</strong></td>
<td>Social context genuinely considered during project site selection and throughout the project's design and implementation phases</td>
</tr>
<tr>
<td>Projects invest large resources, in time and money, into selecting a site based on geologic and technical suitability. Often these selections do not adequately consider the social context of the site. For example, in Barendrecht, although the location was deemed suitable to address technical aspects of the project, it became apparent after the project location was announced that consideration of the possible social constraints had not been factored into the choice of the onshore storage site (ECN 2010).</td>
<td></td>
</tr>
<tr>
<td><strong>Early engagement</strong></td>
<td>Time and effort invested at the outset of a project to interact with, and truly understand, stakeholders</td>
</tr>
<tr>
<td>The timing of a project’s community engagement has been shown to have a decisive influence on the acceptance of a project. Early engagement with local affected communities, regulators, interested academics, environmental NGO groups, local councils, industry bodies, etc. has emerged as the best approach to facilitate meaningful participation and to instil a sense of empowerment within the community (Ashworth et al. 2010a).</td>
<td></td>
</tr>
<tr>
<td><strong>Targeted framing and messaging</strong></td>
<td>Carefully considered and targeted messaging or framing of the project</td>
</tr>
<tr>
<td>Both what and how messages are communicated will have a significant impact on the way a project is perceived and ultimately deployed.</td>
<td></td>
</tr>
<tr>
<td>Project messaging and stakeholder mapping must also be flexible and evolve and adapt as times, perceptions, and demands change.</td>
<td></td>
</tr>
</tbody>
</table>

> It is important to recognise that a project’s stakeholder list will change and grow as the project progresses. It is essential to continually analyse input and information to identify additional stakeholders who should be engaged.

*Tenaska Traiblazer, Texas (Tenaska 2010, p. 6).*
<table>
<thead>
<tr>
<th>SUCCESS FACTOR</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible project implementation strategy</td>
<td>Having the ability to adapt solutions to meet stakeholder concerns</td>
</tr>
<tr>
<td></td>
<td>Flexibility in project implementation, whether allowing time for informal discussions before project announcements, or identifying multiple options for storage or pipeline sites, provides greater opportunity to involve community stakeholders in some project decision making (Ashworth et al. 2010b).</td>
</tr>
<tr>
<td></td>
<td>“At Quest, we demonstrated our commitment to responding to community input by making a total of 30 changes to our initial pipeline route in order to take account of community feedback. Upfront community consultation had tangible benefits for our project, with mostly positive responses from the community during our public hearing.”</td>
</tr>
<tr>
<td></td>
<td>Len Heckel, Business Opportunity Manager, Shell Canada Energy, Quest project, Canada.</td>
</tr>
<tr>
<td></td>
<td>This can be a difficult process to manage and requires close integration between technical, project management, and engagement staff. However there is strong evidence from CCS projects and other analogous industries that where stakeholders can be involved in some decision-making processes and can see the impact their involvement has had on project outcomes, trusting partnerships begin to emerge and are usually highly fruitful (Bradbury et al. 2011).</td>
</tr>
<tr>
<td></td>
<td>Even if design flexibility is difficult, it is important that all decision-making processes and timelines are still made explicit to stakeholders to elicit trust in the transparency of the decision-making processes.</td>
</tr>
</tbody>
</table>

**Note:** Listed success factors are adapted from Ashworth et al. (2010a).
Building trust

The common factor at the root of all these success factors is the practice of building trust. Essentially, all communication and engagement activity around a CCS demonstration project should be designed to build and reinforce trust and understanding between a developer and their stakeholders – that is why public engagement work must start early, and demonstrate commitment, consistency, respect, and honesty.

If CCS is being cast, in some circles, as the Cinderella of future low-carbon energy technologies, then the Spanish Government-funded City of Energy Foundation (CIUDEN) might just have the right magic spell to be considered its fairy godmother. There was no royal ball, but the Compostilla Project did manage to engage local communities to such an extent that the project in the Spanish village of Hontomín is now celebrated and considered part of the local community.

CIUDEN was created by the Spanish Government to support research, development, and demonstration of advanced clean coal technologies, as well as drive social and economic regeneration in the mining region of El Bierzo in Northwest Spain, and by extension to improve technology development at a national level.

On the Compostilla Project, CIUDEN works in partnership with the project coordinator and Spain’s leading electricity company, Endessa, and boiler technology provider, Foster Wheeler. Like a number of other successful CCS demonstration projects worldwide, the Compostilla Project coordinates most of its education and outreach work through the consortium research partner, in this case CIUDEN.

From planning through to execution, CIUDEN’s engagement activities for the first phase of the Compostilla Project were a textbook example of best practice public engagement and communication. Activities included:

- comprehensive social site characterisations and stakeholder identification processes carried out at every phase of the project;
- an outreach strategy and communication plan developed to target different levels of stakeholders from local communities through to policy makers and media;
- engagement expertise fully integrated into the project management through a ‘communication panel’ of both communication and technical staff from all three consortium partners, as well as representatives from academia and the media;
- tailored messaging and communication material to specific audiences;
- project staff trained in communication and engagement; and
- running of a proactive outreach and education campaign, both with a presence at local events and by organising tours, site visits, and other events at the project site and learning centre.

Moving into the industrial phase of the project, problems started to emerge. The project had to engage with a different community when it scaled up for the next phase (moving from the storage test site in Hontomín to the industrial storage site in Sahagun). It had undergone a change of leadership (from CIUDEN to the project co-ordinators Endessa), and it was starting a permitting process during a time of political uncertainty due to national elections.

When some local permits were denied and environmental NGOs started to leaflet communities against fossil fuels and CCS, the Compostilla team had to regroup and take immediate action.

It emerged that the project had started to undertake geological assessments prior to any meaningful public engagement in the community to explain what the project was about. The mistrust this created was compounded by the public face of the project moving to a large power generator rather than the research scientists from Hontomín.

CIUDEN’s communication lead, Monica Lupion, reflects on the lessons learned by the Compostilla Project at this juncture.

“You’re asking people to accept something they don’t know very much about, and that you yourself are saying is a new technology, will always, in the end, come down to a matter of trust. There was nothing wrong with Endesa, it is simply that in the current economic climate there’s a distrust of big business.”
The project’s original communication reformed and embarked on an intensive community engagement campaign. Says Lupion:

“We knew we were coming to the problem late, but we felt we still had time to undertake proper engagement and start winning back that trust – before opposition became too big to handle and people’s opinions became too entrenched. We needed to be dynamic and take an innovative approach, not just sit there and say “we’ll do it this way, because this is the way we’ve always done it”.

The group held multiple visits and open days at the City of Energy museum, with staff handpicked for their communication ability with different stakeholder groups. These were social events with wine and snacks, to encourage people to take an interest in what is a really important regeneration project for this area of Spain.

Lupion is clear that all the communication activity that they undertook to recover this phase of the project was about providing an honest assessment of the facts in a manner that builds mutual respect.

“Our job was just to explain the facts about CCS in a way that people can understand. We made sure we had plenty of third-party advocates such as academics at the meetings who could explain things in everyday terms. The theory says you need everyone’s permission – you don’t. But you do need everyone to see that you are listening to their concerns.”

Permits to continue the geological survey for Spain’s full chain CCS project, Compostilla, were awarded, and at the end of 2011 the activities in the area restarted. Local media hailed it as a great step forward. The decision about the technical viability of Sahagun as a site for CO₂ storage is expected in December 2012, before the FID of the Compostilla Project.

10.3

IMPROVING UNDERSTANDING OF CCS

Although the CCS industry is demonstrating a growing recognition of the importance of engaging with communities and other interested and influential stakeholders, multiple public opinion surveys and workshop results have shown that CCS remains a relatively unknown quantity with the wider public (Itaoka et al. 2012, Reiner et al. 2006 and de Best-Waldhober et al. 2008). Despite its potential to make a substantial impact on future CO₂ emissions (IEA 2012b), CCS suffers from something of an image problem: it is not a renewable energy technology and therefore is not as palatable for political sound bites; it is not a single piece of technology that can be easily packaged and encapsulated in nice imagery; its relationship with fossil fuels creates an uneasy tension with environmental activists; it is easily confused with extraction technologies such as CSG; and an understanding of the relative cost and risks associated with CCS in comparison to other low-carbon technologies requires a level of scientific literacy and familiarity with complex energy markets.

Research emerging from a CSIRO-led international study into people’s perceptions of CO₂ and the implications for their acceptance of CCS, highlights a fundamental lack of knowledge about the basic properties and behaviour of CO₂ among the general public (including its role in anthropogenic climate change) (Itaoka et al. 2012). The results of interviews and focus groups held in Japan, the Netherlands, and Australia revealed a tendency to perceive CO₂ negatively as toxic and harmful. Common misperceptions shared by survey respondents included the belief that CO₂ had qualities similar to air pollution or soot and that it could be flammable or explosive.
Among the key recommendations in the report is a reminder to those communicating about CCS not to assume prior knowledge.

Many members of the public still require basic information on climate change, CCS, and their relationship to CO2 emissions. Awareness of these topics does not directly imply knowledge, as for example, more participants indicated having heard of CCS than did actually understand what it is.

Itaoka et al. (2010, p. 10).

There is also a recommendation to consider the sources and style of information being presented on CCS, recommending a softer, education-based approach for harder-to-reach stakeholders.

Additional CCS education and outreach campaigns should be planned through less formal mechanisms. Given a correlation between trust in informal sources and poorer understanding of CCS, sole reliance on formal information and communication sources (i.e., public sector organisations, local government, national newspapers, and scientists) may not reach the people with the poorest understanding of CCS, who instead place their trust in NGOs, friends, and the internet.

Itaoka et al. (2012, p. 10).

Cambridge University’s recent survey of current global CCS communication highlighted that there had been improvements since the last survey in 2008, but that there is still a technical bias in most communication, with little attention to the socio-economic issues around CCS deployment (Corry and Reiner 2011).

The Cambridge survey findings also supported a CSIRO study into CCS education materials available worldwide, acknowledging that while there were a growing variety of online education resources and a few bespoke examples of CCS education materials, very few attempted to create resources that could be meaningfully integrated into a teaching curriculum. Both studies highlighted the need for educational resources created by independent bodies, which included teaching strategies and learning support for teachers, and consider the social, political, environmental, and economic aspects of CCS as well as the technical components.

In August 2012 the Global CCS Institute launched its first set of CCS education materials. Both the primary and secondary school curriculum resources and supporting teacher notes are available to download from the Institute’s website.

The materials were created by CSIRO in response to a global review of publicly available CCS education resources, which exposed a gap in knowledge, with teachers reporting a particular lack of confidence in teaching students about CCS and low-carbon technologies (Colliver et al. 2011).

CSIRO program developer, Angela Colliver, explained:

For teachers to have trust in these resources, it was essential to prove that they were scientifically sound and easily adapted to fit within a school’s existing curriculum activities. These resources use the latest science and inquiry-based learning methodologies to inspire students to do their own research and learn more about climate change and the potential role of low-emissions technologies in a low-carbon future.
The Global CCS Institute resources underwent extensive reviews by scientific and educational experts, as well as classroom trials in both Australian and international schools and use a teaching methodology known as ‘enquiry-based learning’ to encourage students to self-research to form and justify their own opinions. In Australia, the resources were fully integrated into CSIRO’s sustainability program for schools, ‘CarbonKids’.

Although the resources were specifically mapped to fit the Australian national curriculum, they are easily transferable to most modern curricula. The Global CCS Institute is currently developing plans to trial an international support system for educators looking to incorporate CCS resources into their national or regional curricula.

FIGURE 73 Year 6 students from St Anne’s School, Western Australia, demonstrating CCS using household items.

A number of challenges remain for public engagement around CCS, and most are inextricably linked to the challenges facing CCS development more generally. These are improving understanding of CCS and the need to consider low-carbon technologies in a future energy mix, making the business case for CCS at both a local and national level, and providing tangible demonstration experience to improve industry, government, and public confidence in both the commercial and technical viability of the technology.

However, it is encouraging that best practice guidance, rooted in actual demonstration experience, is beginning to emerge. It is even more encouraging that projects appear to be using at least elements of this guidance to improve the sophistication and quality of their public engagement and communication strategies.

Just as public engagement strategies have to be flexible and evolve as situations change, it is essential that effort is undertaken to monitor and capture learning from demonstration projects currently using best practice guidance to engage with stakeholders. Only by maintaining this continual loop of knowledge-sharing can we improve and adapt public engagement activities and ultimately improve public understanding of CCS and its crucial role in a low-carbon energy future.
APPENDIX A: 2012 PROJECTS SURVEY

A.1 Overview of data analysis process

Since 2009, the Global CCS Institute has maintained a comprehensive database on CCS projects in order to quantify progress made towards CCS demonstration. Historically, the Institute’s dataset on LSIPs has been compiled from an annual project survey completed by lead project proponents. This survey monitors projects’ progress through the asset lifecycle. It is supported by primary research undertaken by the Institute’s Australian, North American and European offices, with results retained for proprietary analysis and displayed in summary form on the Institute’s public website and within its Global Status of CCS reports.

For 2012, the Institute has improved data quality and relevance to more accurately understand and report on project demonstration and movement. At the time of publication, the Institute had received survey returns from 75 per cent of surveyed projects. This demonstrates a high level of direct engagement with projects around the world and forms an empirical basis for analysis. For those projects that did not complete the survey this year, previously collected and publicly available data was used for analysis purposes.

A key element to these improvements was the adoption of a statistical framework driving stronger process and control through survey efforts, and creating the appropriate supporting structures to reinforce this.

There are five phases to the Institute’s framework.

1. **Development phase**: during which planning for the conduct of the survey and the topics on which information is to be collected are determined.

2. **Collection phase**: covers those activities undertaken up to and including the lodgement of the completed survey forms from projects.

3. **Processing phase**: covers the capture of responses on survey forms and representation in Institute systems.

4. **Analysis/Dissemination phase**: the key objective is to produce a statistical package which can inform annual reporting on overall development of CCS projects and their respective contributions toward demonstration.

5. **Evaluation phase**: evaluation activity brings together all phases to assess performance in preparation for the following year/s.

This sequence provides the Institute with the ability to adopt a repeatable process with the necessary supporting structures in place.

In addition to this, the Institute undertook a series of interviews with projects in 2012 and gratefully acknowledges instructive discussions with Green Hydrogen, Getica CCS, ROAD, South West Hub, Don Valley, Peterhead, and Quest.
A.2 Reconciliation of LSIPs with 2011 Status Report

Table A1 outlines the major changes that have occurred amongst the LSIPs since the *Global Status of CCS: 2011* report was published in October 2011.

TABLE A1 Reconciliation of LSIPs with those presented in the *Global Status of CCS: 2011* report

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>LSIP</th>
<th>CAPTURE CAPACITY</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Newly-identified projects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Datang Daqing Oxyfuel Combustion CCS Demo Project</td>
<td>&gt; 1 Mtpa</td>
<td>New build super-critical coal-fired power plant generating electricity and heat, with oxyfuel combustion CO\textsubscript{2} capture. Operation is expected to start in 2015.</td>
</tr>
<tr>
<td></td>
<td>Datang Dongying Carbon Dioxide Capture and Storage Project</td>
<td>1 Mtpa</td>
<td>New build 1000 MWe coal-fired power generation plant. The plant will use one of Alstom’s CO\textsubscript{2} capture technologies.</td>
</tr>
<tr>
<td></td>
<td>Ji Lin Oil Field EOR Project</td>
<td>&gt; 0.8 Mtpa</td>
<td>New build natural gas processing plant. Operation is expected to start in 2015.</td>
</tr>
<tr>
<td></td>
<td>Shanxi International Energy Group CCUS Project</td>
<td>&gt; 2 Mtpa</td>
<td>New build super-critical coal-fired power plant with oxyfuel combustion CO\textsubscript{2} capture.</td>
</tr>
<tr>
<td></td>
<td>Shen Hua Ningxia Coal to Liquids Plant Project</td>
<td>2 Mtpa</td>
<td>New build coal-to-liquids plant.</td>
</tr>
<tr>
<td>Europe</td>
<td>Caledonia Clean Energy Project</td>
<td>TBA</td>
<td>New build IGCC power plant with post-combustion CO\textsubscript{2} capture and use of CO\textsubscript{2} for EOR. Operation is expected to start in 2015.</td>
</tr>
<tr>
<td></td>
<td>Sargas Green Power Plant Malta</td>
<td>1.2 Mtpa</td>
<td>New build fluidised bed boiler power plant that would capture around 1.2 Mtpa of CO\textsubscript{2} from two 180 MWe modules for use in EOR.</td>
</tr>
<tr>
<td></td>
<td>Industrikraft Möre AS Norway</td>
<td>1.4 Mtpa</td>
<td>New build natural gas-based power plant scheduled to begin operations in 2016.</td>
</tr>
<tr>
<td>United States</td>
<td>NRG Energy Parish CCS Project</td>
<td>1.5 Mtpa</td>
<td>Retrofit of post-combustion capture technology at a coal-fired power plant in Texas. The CO\textsubscript{2} will be used for EOR. An air permit application was filed in September 2011, an EIS process is underway, and the FEED is continuing. Operation is expected to start in 2015.</td>
</tr>
<tr>
<td><strong>Projects removed from LSIP listing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia/New Zealand</td>
<td>Browse Reservoir CO\textsubscript{2} Geosequestration Project</td>
<td>3 Mtpa</td>
<td>Removed from the Institute’s LSIP listing in August 2012, after receiving confirmation the project had been put on hold.</td>
</tr>
<tr>
<td></td>
<td>Coolimba Power Project</td>
<td>2 Mtpa</td>
<td>Removed from the Institute’s LSIP listing in May 2012, after receiving confirmation no further investment would be made into the project.</td>
</tr>
<tr>
<td>Canada</td>
<td>Project Pioneer</td>
<td>1 Mtpa</td>
<td>Cancelled in April 2012, due to the revenue from carbon sales and the price of emissions reductions being insufficient to fund the project.</td>
</tr>
</tbody>
</table>

*continued on page 174*
<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>LSIP</th>
<th>CAPTURE CAPACITY</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Longannet Project</td>
<td>2 Mtpa</td>
<td>Cancelled in December 2011 following announcement by the UK Department of Energy and Climate Change that it would not fund the construction of the CO₂ capture facilities.</td>
</tr>
<tr>
<td></td>
<td>Peel Energy CCS Project</td>
<td>2 Mtpa</td>
<td>Put on hold in June 2012, citing the economic slowdown and uncertainties around public funding.</td>
</tr>
<tr>
<td></td>
<td>Vattenfall Jänschwalde</td>
<td>1.7 Mtpa</td>
<td>Cancelled in October 2011, citing the lack of government support and the absence of a clear legal framework.</td>
</tr>
<tr>
<td>United States</td>
<td>Good Spring IGCC</td>
<td>1 Mtpa</td>
<td>Removed from the LSIP listing in May 2012, after the project was reconfigured as a natural gas-fired plant without CO₂ capture due to the lower price of natural gas compared to coal.</td>
</tr>
<tr>
<td></td>
<td>Sweeny IGCC Power Project</td>
<td>5 Mtpa</td>
<td>Cancelled in April 2012 following the split of ConocoPhillips Company (oil and gas exploration and development) and Phillips 66 Company (midstream operations, refining and power generation).</td>
</tr>
</tbody>
</table>

**Project progress**

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>LSIP</th>
<th>CAPTURE CAPACITY</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Don Valley Power Project</td>
<td>4.75 Mtpa</td>
<td>Moved to Define in February 2012 following the appointment of financial and legal advisers, and the choice of the capture technology provider.</td>
</tr>
<tr>
<td>United States</td>
<td>Air Products Steam Methane Reformer EOR Project</td>
<td>1 Mtpa</td>
<td>Moved to Execute as it started construction in August 2011 – the new build hydrogen plant is expected to begin operation in 2012.</td>
</tr>
<tr>
<td>Canada</td>
<td>Quest</td>
<td>1.08 Mtpa</td>
<td>Moved to Execute following the announcement by Shell Canada on 5 September 2012 that it would proceed with the construction of the project.</td>
</tr>
<tr>
<td></td>
<td>Swan Hills Synfuels A ’In-Situ Coal Gasification/Power Generation Project’</td>
<td>1.2–1.4 Mtpa</td>
<td>Moved to Define, as a detailed FEED study is under way and a capture technology provider has been selected, while negotiations for the off-take of CO₂ are at the advanced stages.</td>
</tr>
</tbody>
</table>

**Other key changes**

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>LSIP</th>
<th>CAPTURE CAPACITY</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia/New Zealand</td>
<td>Surat Basin CCS Project</td>
<td>1 Mtpa</td>
<td>Planned CO₂ capture capacity was revised down to 1 Mtpa from 2.5 Mtpa.</td>
</tr>
<tr>
<td>China</td>
<td>Shenhua/Dow Chemicals Coal to Chemicals Plant Project (Yulin)</td>
<td>2.5 Mtpa</td>
<td>Planned CO₂ capture capacity was revised down to 2.5 Mtpa from 5 Mtpa.</td>
</tr>
<tr>
<td>Europe</td>
<td>Sleipner CO₂ Injection</td>
<td>1.1–1.2 Mtpa</td>
<td>Volume of CO₂ captured and injected will be expanded to 1.1–1.2 Mtpa in 2014, with the addition of 0.1–0.2 Mtpa of CO₂ from the gas produced from the Gudrun field, currently under development.</td>
</tr>
<tr>
<td></td>
<td>Green Hydrogen</td>
<td>0.5 Mtpa</td>
<td>Primary CO₂ storage option was changed from EOR to an offshore depleted gas field.</td>
</tr>
</tbody>
</table>
### A.3 Surveying of non-LSIPs

Apart from surveying LSIPs, in 2012 the Institute trialled an expansion of its survey to include some projects that do not fall into the definition of an LSIP. This may be continued in future surveys in recognition of the strong and valuable contribution to CCS that smaller, mid-sized or non-integrated projects make. The Institute gratefully acknowledges survey participation by:

- Miranga CO₂ Experimental Site;
- Jilin Oil Field EOR Project (Phase 1);
- Shanghai Shidongkou 2nd fired power plant;
- Sinopec Shengli oil field EOR Project (pilot);
- Shenhua Ordos CTL Project (pilot phase);
- HuaNeng GreenGen IGCC Project (Pilot CCS);
- Langfang IGCC Co-Generation Power Plant CCS Project;
- Peabody/Hua Neng Xilinguole Coal to Chemicals Project;
- Lacq Pilot CCS project;
- Tomakomai CCS Demonstration Project;
- Nuon Buggenum pre-combustion capture pilot (CO₂ Catch-Up);
- Technology Centre Mongstad (TCM);
- CO₂ Capture and H₂ Production Pilot at Puertollano IGCC;
- Hontomin Plant of R&D on CO₂ Storage; and
- Southern Company and MHI Plant Barry Demonstration Project.
APPENDIX B: ASSET LIFECYCLE MODEL

B.1 Asset Lifecycle Model

The Asset Lifecycle Model represents the various stages in the development of a project, small or large, as it moves through planning, design, construction, operation and closure. There are different systems available to define project stages, sometimes using different terminology, but all effectively use a similar lifecycle model. This framework (Figure B1) reflects the decision points in a project lifecycle where developers either decide to continue to commit resources to refine the project further (gateways) or assess that future benefits will not cover the expected costs.

FIGURE B1 Asset Lifecycle Model

Source: from WorleyParsons 2009, modified by Global CCS Institute.
A project is considered in ‘planning’ when it is in the Identify, Evaluate or Define stages and is considered ‘active’ if it has made a positive FID and has entered construction (Execute stage) or is in operation (Operate stage). As a project progresses through each stage, the level of definition increases with an improved understanding of the scope, cost, risk and schedule of the project. This approach reduces the uncertainty surrounding the project while managing upfront development costs.

In the Identify stage, a proponent carries out early studies and preliminary comparisons of alternatives to determine the business viability of the broad project concept. For example, an oil and gas company believes that it could take concentrated CO₂ from one of its natural gas processing facilities and inject and store the CO₂ to increase oil production at one of its existing facilities. To start the process the company would conduct preliminary desktop analysis of both the surface and subsurface requirements of the project to determine if the overall project concept seemed viable and attractive. It is important that the Identify stage considers all relevant aspects of the project (stakeholder management, project delivery, regulatory approvals and infrastructure as well as physical carbon capture and storage facilities). Before progressing to the Evaluate stage, all the project options that meet the overall concept should be clearly identified.

In the Evaluate stage, the broad project concept is built upon by exploring the range of possible options that could be employed. For the oil and gas company this would involve exploring:

- which of its facilities, and possibly even facilities of other companies, might be best placed to provide the concentrated CO₂ for the project;
- possible pipeline routes that could be utilised from each of these sites and even alternative transport options such as shipping if relevant; and
- which oil production field is suitable for CO₂ injection based on its proximity to the concentrated CO₂, the stage of oil production at the field and other site factors.

For each option the costs, benefits, risks and opportunities would be identified. The Evaluate stage must continue to consider, for each option, all relevant aspects of the project (stakeholder management, project delivery, regulatory approvals, infrastructure as well as physical carbon capture and storage facilities). At the end of this stage, the preferred option is selected and becomes the subject of the Define stage. The preferred option must be sufficiently defined. No further key options are to be studied in the Define stage.

In the Define stage, the selected option is investigated in greater detail by carrying out feasibility studies and preliminary FEED. For the oil and gas company this would involve determining the specific technology to be used, the design and overall costs for the project, the permits and approvals required and the key risks to the project. In addition, it involves undertaking a range of activities such as focused stakeholder engagement processes, seeking out finance or funding opportunities and tendering for and selecting an engineering, procurement and contracting supplier.

At the end of the Define stage, the level of project definition must be sufficient to allow for a FID to be made. The level of confidence in costing estimates should be ±10–15 per cent for overall project capital costs and ±5–10 per cent for project operating costs. Collectively, the Identify, Evaluate and Define stages can take between 4–7 years. Development costs to reach a FID can be in the order of 10–15 per cent of overall project capital cost depending on the size, industry and complexity of the project.

In the Execute stage, the detailed engineering design is finalised. The construction and commissioning of the plant occurs and the organisation to operate the facility is established. Once completed, the project then moves into the Operate stage.

In the Operate stage, the CCS asset is operated within regulatory requirements and maintained and, where needed, modified to improve performance.

In the Closure stage, the CCS asset is decommissioned to comply with regulatory requirements. The site is rehabilitated for future defined use and resources are allocated to manage post-closure responsibilities.
# APPENDIX C: 2012 LSIPs

Table C1 presents the detailed list of the LSIPs that were included in the analysis for the *Global Status of CCS: 2012* report. The 2012 LSIP number correlates with the world map of LSIPs (Figure 9) and regional maps (Figure 12, Figure 13 and Figure 14) presented in Chapter 2.

<table>
<thead>
<tr>
<th>LSIP NO. 2012</th>
<th>OVERALL ASSET LIFECYCLE STAGE</th>
<th>PROJECT NAME</th>
<th>DISTRICT</th>
<th>COUNTRY</th>
<th>INDUSTRY</th>
<th>CAPTURE TYPE</th>
<th>TRANSPORT TYPE</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Operate</td>
<td>Val Verde Natural Gas Plants</td>
<td>Texas</td>
<td>United States</td>
<td>Natural gas processing</td>
<td>Pre-combustion (gas processing)</td>
<td>Onshore to onshore pipeline</td>
</tr>
<tr>
<td>2</td>
<td>Operate</td>
<td>Enid Fertilizer CO₂-EOR Project</td>
<td>Oklahoma</td>
<td>United States</td>
<td>Fertiliser production</td>
<td>Pre-combustion</td>
<td>Onshore to onshore pipeline</td>
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<tr>
<td>3</td>
<td>Operate</td>
<td>Shute Creek Gas Processing Facility</td>
<td>Wyoming</td>
<td>United States</td>
<td>Natural gas processing</td>
<td>Pre-combustion (gas processing)</td>
<td>Onshore to onshore pipeline</td>
</tr>
<tr>
<td>4</td>
<td>Operate</td>
<td>Sleipner CO₂ Injection</td>
<td>North Sea</td>
<td>Norway</td>
<td>Natural gas processing</td>
<td>Pre-combustion (gas processing)</td>
<td>Direct injection</td>
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<tr>
<td>5</td>
<td>Operate</td>
<td>Great Plains Synfuel Plant and Weyburn-Midale Project</td>
<td>Saskatchewan</td>
<td>Canada</td>
<td>Synthetic natural gas</td>
<td>Pre-combustion (gas processing)</td>
<td>Onshore to onshore pipeline</td>
</tr>
<tr>
<td>6</td>
<td>Operate</td>
<td>In Salah CO₂ Storage</td>
<td>Wilaya de Ouargla</td>
<td>Algeria</td>
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<td>Pre-combustion (gas processing)</td>
<td>Onshore to onshore pipeline</td>
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<tr>
<td>7</td>
<td>Operate</td>
<td>Snøhvit CO₂ Injection</td>
<td>Barents Sea</td>
<td>Norway</td>
<td>Natural gas processing</td>
<td>Pre-combustion (gas processing)</td>
<td>Onshore to onshore pipeline</td>
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<td>8</td>
<td>Operate</td>
<td>Century Plant</td>
<td>Texas</td>
<td>United States</td>
<td>Natural gas processing</td>
<td>Pre-combustion (gas processing)</td>
<td>Onshore to onshore pipeline</td>
</tr>
<tr>
<td>9</td>
<td>Execute</td>
<td>Air Products Steam Methane Reformer EOR Project</td>
<td>Texas</td>
<td>United States</td>
<td>Hydrogen production</td>
<td>Post-combustion</td>
<td>Onshore to onshore pipeline</td>
</tr>
<tr>
<td>10</td>
<td>Execute</td>
<td>Lost Cabin Gas Plant</td>
<td>Wyoming</td>
<td>United States</td>
<td>Natural gas processing</td>
<td>Pre-combustion (gas processing)</td>
<td>Onshore to onshore pipeline</td>
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<td>11</td>
<td>Execute</td>
<td>Illinois Industrial Carbon Capture and Storage Project</td>
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<td>United States</td>
<td>Chemical production</td>
<td>Industrial separation</td>
<td>Onshore to onshore pipeline</td>
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<td>12</td>
<td>Execute</td>
<td>Alberta Carbon Trunk Line (ACTL) with Agrium CO₂ Stream</td>
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<td>Canada</td>
<td>Fertiliser production</td>
<td>Pre-combustion</td>
<td>Onshore to onshore pipeline</td>
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<td>13</td>
<td>Execute</td>
<td>Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project</td>
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<td>Canada</td>
<td>Power generation</td>
<td>Post-combustion</td>
<td>Onshore to onshore pipeline</td>
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<tr>
<td>14</td>
<td>Execute</td>
<td>Kemper County IGCC Project</td>
<td>Mississippi</td>
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<td>Pre-combustion</td>
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<td>15</td>
<td>Execute</td>
<td>Gorgon Carbon Dioxide Injection Project</td>
<td>Western Australia</td>
<td>Australia</td>
<td>Natural gas processing</td>
<td>Pre-combustion (gas processing)</td>
<td>Onshore to onshore pipeline</td>
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<td>TRANSPORT DISTANCE</td>
<td>PRIMARY STORAGE OPTION</td>
<td>CAPTURE CAPACITY</td>
<td>YEAR OF OPERATION</td>
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<td>TRANSPORT ASSET LIFECYCLE STAGE</td>
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<td>132 km</td>
<td>Enhanced oil recovery</td>
<td>1.3 Mtpa</td>
<td>1972</td>
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<td>225 km</td>
<td>Enhanced oil recovery</td>
<td>0.68 Mtpa</td>
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<td>Commercial agreement EOR</td>
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<tr>
<td>190 km</td>
<td>Enhanced oil recovery</td>
<td>7 Mtpa</td>
<td>1986</td>
<td>Operate</td>
<td>Operational transport</td>
<td>Commercial agreement EOR</td>
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<tr>
<td>0 km</td>
<td>Offshore deep saline formations</td>
<td>1 Mtpa (+0.2 Mtpa in construction)</td>
<td>1996</td>
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<td>Operational transport</td>
<td>Operating storage facilities</td>
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<tr>
<td>315 km</td>
<td>Enhanced oil recovery</td>
<td>3 Mtpa</td>
<td>2000</td>
<td>Operate</td>
<td>Operational transport</td>
<td>Commercial agreement EOR</td>
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<tr>
<td>14 km</td>
<td>Onshore deep saline formations</td>
<td>1 Mtpa</td>
<td>2004</td>
<td>Operate</td>
<td>Operational transport</td>
<td>Operating storage facilities</td>
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<td>152 km</td>
<td>Offshore deep saline formations</td>
<td>0.7 Mtpa</td>
<td>2008</td>
<td>Operate</td>
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<td>Operating storage facilities</td>
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<tr>
<td>256 km</td>
<td>Enhanced oil recovery</td>
<td>8.5 Mtpa (5 Mtpa in operation + 3.5 Mtpa in construction)</td>
<td>2010</td>
<td>Operate</td>
<td>Operational transport</td>
<td>Commercial agreement EOR</td>
<td>8</td>
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<tr>
<td>101–150 km</td>
<td>Enhanced oil recovery</td>
<td>1 Mtpa</td>
<td>2012</td>
<td>Execute</td>
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<td>Commercial agreement EOR</td>
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<td>Not specified</td>
<td>Enhanced oil recovery</td>
<td>1 Mtpa</td>
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<td>Commercial agreement EOR</td>
<td>9</td>
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<tr>
<td>1.6 km</td>
<td>Onshore deep saline formations</td>
<td>1 Mtpa</td>
<td>2013</td>
<td>Execute</td>
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<td>Constructing storage facilities</td>
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<tr>
<td>240 km</td>
<td>Enhanced oil recovery</td>
<td>Up to 0.59 Mtpa (initially 0.29 Mtpa)</td>
<td>2014</td>
<td>Execute</td>
<td>Design of pipeline</td>
<td>Commercial agreement EOR</td>
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<tr>
<td>100 km</td>
<td>Enhanced oil recovery</td>
<td>1 Mtpa</td>
<td>2014</td>
<td>Execute</td>
<td>Design of pipeline</td>
<td>Advanced negotiations EOR</td>
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<td>75 km</td>
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<td>3.5 Mtpa</td>
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<td>Execute</td>
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<td>7 km</td>
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<td>3.4–4.1 Mtpa</td>
<td>2015</td>
<td>Execute</td>
<td>Construction of pipeline</td>
<td>Constructing storage facilities</td>
<td>14</td>
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continued on page 180
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<th>INDUSTRY</th>
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<th>TRANSPORT TYPE</th>
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<td>Quest</td>
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<td>Hydrogen production</td>
<td>Pre-combustion</td>
<td>Onshore to onshore pipeline</td>
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<td>Define</td>
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<td>Kansas</td>
<td>United States</td>
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<td>Pre-combustion</td>
<td>Onshore to onshore pipeline</td>
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<tr>
<td>18</td>
<td>Define</td>
<td>Lake Charles Gasification</td>
<td>Louisiana</td>
<td>United States</td>
<td>Synthetic natural gas</td>
<td>Pre-combustion</td>
<td>Onshore to onshore pipeline</td>
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<td>Define</td>
<td>Alberta Carbon Trunk Line (ACTL) with North West Sturgeon Refinery CO₂ Stream</td>
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<td>Canada</td>
<td>Oil refining</td>
<td>Pre-combustion</td>
<td>Onshore to onshore pipeline</td>
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<td>Define</td>
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<td>Abu Dhabi</td>
<td>United Arab Emirates</td>
<td>Iron and steel production</td>
<td>Industrial separation</td>
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<td>Wyoming</td>
<td>United States</td>
<td>Coal-to-liquids (CTL)</td>
<td>Pre-combustion</td>
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<td>Post-combustion</td>
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<td>Define</td>
<td>OXYCFB 300 Compostilla Project</td>
<td>Leon</td>
<td>Spain</td>
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<td>Oxyfuel</td>
<td>Onshore to onshore pipeline</td>
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<td>Porto Tolle</td>
<td>Veneto</td>
<td>Italy</td>
<td>Power generation</td>
<td>Post-combustion</td>
<td>Onshore to offshore pipeline</td>
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<td>25</td>
<td>Define</td>
<td>Rotterdam Opslag en Afvang Demonstratieproject (ROAD)</td>
<td>Zuid-Holland</td>
<td>The Netherlands</td>
<td>Power generation</td>
<td>Post-combustion</td>
<td>Onshore to offshore pipeline</td>
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<td>26</td>
<td>Define</td>
<td>Swan Hills Synfuels A ‘In-Situ Coal Gasification/Power Generation Project’</td>
<td>Alberta</td>
<td>Canada</td>
<td>Synthetic natural gas</td>
<td>Pre-combustion</td>
<td>Onshore to onshore pipeline</td>
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<td>28</td>
<td>Define</td>
<td>Don Valley Power Project</td>
<td>South Yorkshire</td>
<td>United Kingdom</td>
<td>Power generation</td>
<td>Pre-combustion</td>
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<td>Define</td>
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<td>Zuid-Holland</td>
<td>Netherlands</td>
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<td>Industrial separation</td>
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<td>Define</td>
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<td>British Columbia</td>
<td>Canada</td>
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<td>Pre-combustion (gas processing)</td>
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<td>31</td>
<td>Define</td>
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<td>Lorraine</td>
<td>France</td>
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<td>Industrial separation</td>
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<td>Define</td>
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<td>Łódź</td>
<td>Poland</td>
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<td>Post-combustion</td>
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<td>United States</td>
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<td>New Jersey</td>
<td>United States</td>
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<td>YEAR OF OPERATION</td>
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<td>84 km</td>
<td>Onshore deep saline formations</td>
<td>1.08 Mtpa</td>
<td>2015</td>
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<td>Constructing storage facilities</td>
<td>27</td>
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<td>112 km</td>
<td>Enhanced oil recovery</td>
<td>0.85 Mtpa</td>
<td>2013</td>
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<td>Commercial agreement EOR</td>
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<td>4.5 Mtpa</td>
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<td>Design of pipeline</td>
<td>Commercial agreement EOR</td>
<td>17</td>
</tr>
<tr>
<td>240 km</td>
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<td>1.2 Mtpa</td>
<td>2015</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Commercial agreement EOR</td>
<td>18</td>
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<td>Not specified</td>
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<td>0.8 Mtpa</td>
<td>2015</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Advanced negotiations EOR</td>
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<td>Operational transport</td>
<td>Commercial agreement EOR</td>
<td>23</td>
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<td>130 km</td>
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<td>1.4–1.6 Mtpa</td>
<td>2015</td>
<td>Define</td>
<td>Design of pipeline</td>
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<td>120 km</td>
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<td>2015</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Assessing suitability of storage site/s</td>
<td>24</td>
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<tr>
<td>101–150 km</td>
<td>Offshore deep saline formations</td>
<td>1 Mtpa</td>
<td>2015</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Assessing suitability of storage site/s</td>
<td>25</td>
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<tr>
<td>26 km</td>
<td>Offshore depleted oil and gas reservoirs</td>
<td>1 Mtpa</td>
<td>2015</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Constructing storage facilities</td>
<td>28</td>
</tr>
<tr>
<td>51–100 km</td>
<td>Enhanced oil recovery</td>
<td>1.2–1.4 Mtpa</td>
<td>2015</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Advanced negotiations EOR</td>
<td>48</td>
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<td>≤50 km</td>
<td>Enhanced oil recovery</td>
<td>2.5 Mtpa</td>
<td>2015</td>
<td>Define</td>
<td>Operational transport</td>
<td>Commercial agreement EOR</td>
<td>19</td>
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<tr>
<td>425 km for EOR, 175km to alternative saline site</td>
<td>Enhanced oil recovery</td>
<td>4.75 Mtpa</td>
<td>2016</td>
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<td>Design of pipeline</td>
<td>Advanced negotiations EOR</td>
<td>43</td>
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<tr>
<td>26 km</td>
<td>Offshore depleted oil and gas reservoirs</td>
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<td>Define</td>
<td>Design of pipeline</td>
<td>Detailed site characterisation</td>
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<td>35 km</td>
<td>Onshore deep saline formations</td>
<td>2.2 Mtpa</td>
<td>2016</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Detailed site characterisation</td>
<td>29</td>
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<td>51–100 km</td>
<td>Onshore deep saline formations</td>
<td>0.7 Mtpa</td>
<td>2016</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Assessing suitability of storage site/s</td>
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<tr>
<td>101–150 km</td>
<td>Onshore deep saline formations</td>
<td>1.6–1.8 Mtpa</td>
<td>2017</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Assessing suitability of storage site/s</td>
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<tr>
<td>6.4 km</td>
<td>Enhanced oil recovery</td>
<td>3 Mtpa</td>
<td>2017</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Advanced negotiations EOR</td>
<td>36</td>
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<tr>
<td>160 km</td>
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<td>2.6 Mtpa</td>
<td>2017</td>
<td>Define</td>
<td>Design of pipeline</td>
<td>Detailed site characterisation</td>
<td>38</td>
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<th>TRANSPORT TYPE</th>
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<td>Illinois</td>
<td>United States</td>
<td>Power generation</td>
<td>Pre-combustion</td>
<td>Onshore to onshore pipeline</td>
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<tr>
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<td>Design of pipeline</td>
<td>Exploration of prospective sites</td>
<td>New</td>
</tr>
<tr>
<td>101–150 km</td>
<td>Onshore depleted oil and gas reservoirs</td>
<td>1 Mtpa</td>
<td>Not specified</td>
<td>Identify</td>
<td>Not specified</td>
<td>Exploration of prospective sites</td>
<td>69</td>
</tr>
<tr>
<td>≤50 km</td>
<td>Enhanced oil recovery</td>
<td>1 Mtpa</td>
<td>Not specified</td>
<td>Identify</td>
<td>Not specified</td>
<td>Identifying prospective EOR customers</td>
<td>New</td>
</tr>
<tr>
<td>201–250 km</td>
<td>Enhanced oil recovery</td>
<td>1 Mtpa</td>
<td>Not specified</td>
<td>Identify</td>
<td>Not specified</td>
<td>Identifying prospective EOR customers</td>
<td>68</td>
</tr>
<tr>
<td>Not specified</td>
<td>Various storage options being considered</td>
<td>2–3 Mtpa</td>
<td>Not specified</td>
<td>Identify</td>
<td>Not specified</td>
<td>Exploration of prospective sites</td>
<td>New</td>
</tr>
<tr>
<td>201–250 km</td>
<td>Various storage options being considered</td>
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<td>Not specified</td>
<td>Identify</td>
<td>Not specified</td>
<td>Exploration of prospective sites</td>
<td>New</td>
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APPENDIX D: COSTS

D.1 Levelised electricity costs

The levelised costs, in 2010 dollar terms, for different power technologies fitted with CCS range from US$114/MWh for oxyfuel combustion to US$130/MWh for post-combustion capture at a supercritical pulverised coal plant (Figure D1). This represents an increase in costs over non-CCS power plants of around 40 per cent for NGCC and IGCC plants and more than 60 per cent for supercritical black coal plants.

FIGURE D1 Levelised costs of electricity for different capture technologies

The costs for transport and storage are often considered to account for a relatively small share of the total costs of a CCS project, around 5–7 per cent in many cases (Figure D1). This reflects modelling choices often made to transport the CO₂ to high-capacity onshore saline reservoirs with good injectivity that are less than 200 km from the source of the emissions. Transporting the CO₂ a similar distance offshore can double the transport costs and doubling the distance offshore may double that cost again. Storing in off-shore rather than onshore saline aquifers can also double or triple the storage cost (ZEP 2011). While transporting CO₂ is a mature technology and considered relatively low risk, the costs associated with characterising a secure storage site, even a good site, can present challenges to projects. Site characterisation costs must be borne well in advance of any opportunity to recover costs, and have non-trivial levels of risk as the site assessment may indicate the site is not suitable for storage, and another site must be located and the process started again.

Cost studies are often based around building a plant in the US, and translating those studies to other countries or regions often results in even larger increases in costs over unabated fossil fuel plants, reflecting different capital costs as well as different country-specific requirements, including different fossil fuel costs. For example, for CCS plants in the UK, it was recently estimated that incorporating CCS would increase costs by between 75–116 per cent (Parsons Brinckerhoff 2011). Even within a single country, regional factors influencing labour costs or fuel types can change costs for otherwise identical projects. In the US, the difference between labour costs in union versus non-union workforces alone can increase project costs by 20 per cent.
Similarly, there can be significant differences and inconsistencies in the way CCS costs are currently calculated and reported by various authors and organisations (Rubin 2012). The different cost estimates observed in studies often arise due to differences in assumptions regarding technology performance, the costs of inputs, or the methodology used. Nonetheless, in detailed studies such as those prepared by the IEA (Finkenrath 2011), the Global CCS Institute (Global CCS Institute and WorleyParsons 2011), and the National Energy Technology Laboratory (NETL 2011), many of these differences disappear when the assumptions are normalised and a common methodology applied. In these specific studies, the effect of any individual assumption on the estimated levelised cost for power generation is generally 5 per cent or smaller (Global CCS Institute 2011a). In other studies, these effects can often be more pronounced, but at the same time, may lack transparency around key assumptions or methodologies.

Given the importance of CCS as an option for mitigating energy-related CO₂ emissions, efforts to improve and harmonise the methodology for estimating and communicating CCS costs are being undertaken by an international group of experts from industrial firms, government agencies, universities, and environmental organisations. Key agencies involved in cost estimation, including NETL, the EPRI, the IEA, and the Global CCS Institute are engaged in this task in order to improve transparency and understanding.

D.2 FEED studies

The CCS costs studies discussed above make certain assumptions that preclude certain site-specific or project-specific assumptions in order to compare the expected costs of two or more different technologies in a specific application. Technology-leveling assumptions are made so that the true differences in typical plant configurations are highlighted. As such, they are typically poor predictors of specific project costs. The level of accuracy for those technology studies is within the range of ~30 to +50 per cent of project costs, with certainty limited due to the level of design detail undertaken and estimated risk level around the technology and project. Issues relating to contingencies for CCS projects are discussed further below.

In contrast, cost studies for specific projects aim to provide the owner with as accurate an estimate as possible of all the project costs that must be financed. The level of accuracy for project studies reflects the resourcing applied to completing the project design, tendering to equipment suppliers and level of risk analysis undertaken. Performing cost estimates to a high level of accuracy requires a significant amount of engineering detail and effort to assess the lowest cost options for specific locations as well as increased levels of information from equipment providers. For FEED studies, undertaken to provide further definition to the project in order to allow an investment decision to be made, the overall project capital cost is expected to be in the range of ±10–15 per cent with a smaller range for operating cost assessments.

Although a number of project-specific FEED and other studies have been completed in recent years, only a few are in the public domain including:

- Scottish Power’s Longannet project;
- Eon’s Kingsnorth project; and
- ROAD.

The first two projects have been cancelled, as funding – from both anticipated market revenue opportunities and government demonstration programs – was insufficient, while ROAD is currently considering issues around the investment decision. Further, the level of detail publicly available varies. The Kingsnorth project was cancelled in 2010 in the early stages of the feasibility assessment with costs released for the capture, transport and storage facilities. As a result, the information provided from this project has a higher level of uncertainty and less detail regarding specific cost elements. ROAD, reflecting ongoing commercial consideration and confidentiality concerns, has released highly aggregated costs for the capture process. The Longannet project, in development for a lengthy time, has released a detailed FEED study where the cost components reflected a thorough tendering process and a high level of design effort.

As a project capturing a slipstream from an existing power project, the Longannet costs reflect the capture, transport and storage elements only, and so do not include the full costs of establishing a new generation facility incorporating CCS. However, the proposed Longannet demonstration also included costs for new steam and power supplies required for the capture process (rather than drawing on the Longannet plant itself) as well as certain ‘balance of plant’ items that would normally be included in a new build plant.

The investment costs for CCS demonstration projects in the public domain vary significantly, reflecting a number of issues including scale, risk and site-specific considerations (Figure D2). Nonetheless, the published project investment costs appear to differ significantly from (and are usually larger than) the estimates provided in generalised cost studies. However, the costs estimates for most projects tend to provide limited details on what is included or excluded in the cost estimate – what is site specific and what is technology-related. Consequently, it can be difficult to interpret the wide range of investment cost estimates presented in Figure D2. It appears likely that the design cost studies represent a lower bound for projects rather than...
a mid-point estimate. Underpinned by the detailed information provided in the Longannet FEED study, CCS investment costs for a large-scale project are likely to incur a cost at least US$5000–6000 per kW. As demonstration plants are built, it is likely that these costs will be better understood and the range of investment costs narrow as perceptions of risk also changes.

FIGURE D2 CCS investment costs: demonstration projects vs. cost studies

One of the reasons that project-specific costs may vary from design studies relates to the accounting for contingencies, to account either for risk or for unknown but expected costs. Contingencies are included in cost estimates to reflect unknown costs which are omitted or unforeseen due to a lack of complete project definition and engineering effort for a given level of design estimation (NETL 2011). In these cases, this contingency, known as project contingencies decreases with the level of design effort. For mature technologies, such as unabated coal and gas-fired power plants, project contingencies in pre-feasibility studies are considered to be around 10 per cent or less and decline further through a FEED study. In the Longannet FEED study, the contingency associated with the estimates for the transport component was 7 per cent in total (and less for certain elements), reflecting both the real world experience of transporting CO₂ and the maturity of the technology.

The maturity of the technology affects cost estimates because of performance uncertainties associated with the development status of a technology. Usually included as ‘process contingencies’, they are applied to individual technology components within the entire CCS production chain.

In publicly available project studies, it is common for both types of contingencies to be combined and reported as a single number, even if it is provided against components of the CCS process. In the Longannet FEED study, contingencies for the capture process accounted for 20 per cent of the capture costs. This contrasts with the average contingencies used in design studies, such as the Institute/WorleyParsons estimate of 16–18 per cent for the power and capture process. For the storage elements, the share of costs allocated to contingencies in the Longannet project varied across the elements of storage construction (from platform preparation offshore through subsea work and injection wells) averaging 21 per cent across the entire storage chain.
D.3 Cost reduction programs

There are also a number of research programs exploring opportunities to reduce costs. The largest program is the US DOE Fossil Energy Program which funds work by the NETL. Acknowledging in particular the challenges of current capture technologies, the challenges of large-scale demonstrations, and the energy costs associated with capture, the stated goal of this program is to develop advanced capture technologies that achieve at least 90 per cent CO₂ capture with a corresponding cost and energy penalty reduction of 50 per cent compared to current state of the art technologies. Focusing on IGCC and post-combustion capture (including oxyfuel) technologies, the aim is to make several possible improvements in those technologies available for commercial deployment by 2030 (Ciferno et al. 2012). In the case of post-combustion technologies, the target is that the increase in costs above unabated coal power plants is less than 35 per cent.

The UK Government established a Cost Reduction Task Force, led by industry to identify the scope for cost reductions in CCS for fuel and technology components. The approach seeks to establish a partnership between industry and government to bring forward the deployment of CCS. Recognising that the opportunities for cost reductions in capture will only be achieved over the longer term (given the long lead times to construct CCS plants), this process is seeking to gain a commitment from industry on initiatives to reduce cost and to develop advice for Government in identifying the most promising technologies, market frameworks and incentives. The group will report to Government in the second quarter of 2013.
APPENDIX E: POLICY DEVELOPMENTS

E.1 Policy developments by country

E.1.1 AUSTRALIA

In 2010, the Australian Government announced that all new coal-fired power stations would be required to be built CCS Ready, as part of the Cleaner Future for Power Stations election commitment.

In late 2011, the Government’s legislation to introduce a carbon price, the Clean Energy Legislative Package (CELP), was given effect and the CCS Ready policy was subsequently abandoned in favour of market driven investment outcomes. The Victorian Government also made a similar announcement in March 2012 to not proceed with CCS Ready regulations.

The CELP underpins the carbon-pricing mechanism that commenced on 1 July 2012, and that will extend to 30 June 2015. Covering Australia’s top 500 emitters (those producing over 25,000 tCO₂ per year), the price starts at AU$23/tCO₂-e and rises by 2.5 per cent per year in real terms to 30 June 2015.

After 2015, the administratively fixed price will transition to a market-determined price. There is also an independent regulatory compliance and management regime in place.

On 28 August 2012, Australia and the EC announced plans to link their ETS. A full two-way link, by means of the mutual recognition of carbon units between the two cap and trade systems, will commence no later than 1 July 2018. Under this arrangement, businesses will be allowed to use carbon units from the Australian emissions trading scheme or the EU ETS for compliance under either system.

To facilitate the link, the Australian Government will make two changes to the design of the Australian carbon price. These are that:

- the price floor will not be implemented; and
- a new sub-limit will apply to the use of eligible Kyoto units. While liable entities in Australia will still be able to meet up to 50 per cent of their liabilities through purchasing eligible international units, only 12.5 per cent of their liabilities will be able to be met by Kyoto units.

In recognition of these changes and while formal negotiations proceed towards a full two-way link, an interim link will be established, whereby Australian businesses will be able to use EU allowances to help meet liabilities under the Australian emissions trading scheme from 1 July 2015 until a full link is established, no later than 1 July 2018.

The Australian Government also released in late 2011 a draft Energy White Paper called Strengthening the Foundation for Australia’s Energy Future. The Paper outlines the Government’s reform of the domestic energy markets and the carbon-pricing mechanism. A key message in the Paper is that the carbon-pricing mechanism is now the major policy instrument for driving new low-carbon technology deployment.

E.1.2 BRAZIL

Brazil’s principal framework for climate change policy is the 2010 National Climate Change Policy (Decree No. 7390, implementing regulation of Law No. 12187), which sets a nationwide emissions reduction target. The Decree sets a deadline of 15 December 2011 for the major emitting sectors (including power generation) to submit action plans (including targets, actions, performance indicators, and proposed incentives to implement the plans) for emissions reductions. It also indicates that the adopted targets may form the basis for emissions trading.

There is no ETS in Brazil, but as a host country for CDM projects, it is often regarded as one of the main players in the global carbon credit market. A state-wide ETS covering large emitters in Rio de Janeiro was expected to have been signed into law via decree in June 2012 for commencement in January 2013.

At the time of drafting, however, the signing of the decree has been delayed. It is expected that other states will be invited into the consultation process, creating a possibility for the emergence of a national system. The scheme would have covered major emitters from the oil, steel, cement, ceramics, chemical, and petrochemical sectors. The first commitment period will be from 2013 until 2015, with subsequent periods expected to last five years.
E.1.3 BULGARIA

The principal framework for climate change is outlined in the Bulgarian National Energy Strategy until 2020, adopted by the Bulgarian Parliament in mid-2011. The Bulgarian Government estimates that about 9.2 MtCO₂ will be avoided by 2030 through CCS.

Bulgaria abides by the EC’s common emission reduction targets, although trading in Bulgaria was suspended in 2010 and re-launched in early 2011. In early 2012, the EC authorised Bulgaria’s request for the continued free allocation of EU ETS allowances to their power sectors beyond this year (rather than having to purchase them on the open market).

Bulgaria’s climate policy includes supporting, both financially and institutionally, the construction of power plants with facilities for CCS by schemes and mechanisms adopted at the European level.

E.1.4 CANADA

Canada’s policy focus is primarily about providing funding support for projects. Canada agreed to only voluntary emission pledges to 2020 under the UNFCCC, and has indicated that it will not be ratifying a second commitment period under the Kyoto Protocol.

In the third quarter of 2011, the Canadian Government released the text of the proposed regulations titled Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity Regulations. If passed, the regulations would come into effect on 1 July 2015, requiring all existing and new coal-fired units to meet an emissions performance standard equivalent to combined cycle natural gas (set at and fixed at 0.375 tCO₂ per MWh). A temporary exception would be provided for plants that incorporate CCS out to 2025.

The policy includes incentives for early action for existing plants that incorporate CCS prior to having to do so. The comments received and how they were addressed by the Government will be available in a Regulatory Impact Analysis Summary when the final regulations are published in Canada Gazette Part II later in 2012.

Canada is also a key component of the North American Carbon Storage Atlas.

E.1.5 CHINA

China recently became the largest global GHG emitter, as well as arguably one of the largest investors (competing with the US) in clean energy with over US$55 billion in 2010. According to the Lawrence Berkeley National Laboratory, China’s anticipated peak emission point under a 450 ppm scenario will need to be realised between 2025 and 2030.

As reported last year, China has adopted in its 12th Five Year Plan (approved in March 2011) both national energy and carbon intensity targets. These intensity targets have been subsequently allocated on a differentiated basis across provinces where governors and mayors alike are responsible for their implementation and compliance. This emphasises the important role that provincial and local levels have in both the implementation of the national strategy and in the design of sub-national policies.

The national carbon intensity target is set at 17 per cent per unit of GDP by 2015 (relative to 2005) and 40–45 per cent by 2020. It is understood that China announced at the April 2012 MEF that the 2020 target is to be pushed out to 2025.

In May 2012, the energy intensity targets were tightened (from 18–21 per cent below 2010 levels by 2015) and allocated to sectors. Sector-specific energy intensity reduction targets by 2015 include 20 per cent reduction for chemicals and 18 per cent reduction for steel, non-ferrous metals, and petrochemicals.

Over the period 2006–10, it appears China has enacted all the institutional requirements to realise these targets. This includes supporting quite pro-market oriented tools over the next five years (such as pilot emissions trading schemes to commence in 2013 across two provinces and five cities) to reduce emissions.

It is also understood that the NDRC has given the pilot regions the authority to make independent choices on which sectors should be brought into the schemes (but clearly power, steel, cement, chemicals, and non-ferrous metals are likely candidates – also indicating opportunities to support CCS mitigation solutions).

Reports in the public domain suggest that the pilots are unlikely to be launched by 2013, as only Beijing has released (in March 2012) draft rules and regulations of its ETS. Design issues still include which sectors are to be covered. The two provinces of Guangdong and Hubei have publicly indicated this sort of delay.

The NDRC (which acts as China’s regulator for UNFCCC offsets) recently published rules governing China’s future domestic carbon offset market. This is very much in line with China’s preference for project-based market mechanisms, such as the CDM, in the UNFCCC. The offsets, known as Chinese Certified Emission Reductions (CCERs) will be awarded to projects that have received government approval to earn credits under the CDM, but have yet to be registered by the UNFCCC. Projects that have already earned credits under the CDM will not be allowed to produce domestic offsets (to avoid double counting).
This policy direction supplements an already quite extensive suite of demand measures (including a national electricity smart grid) and fiscal and tax regimes including a resource tax, a fuel/energy tax, and potentially a carbon tax. While a carbon tax could be implemented in parallel to an ETS, this policy discussion may be superseded by a cross-over to a national emissions trading scheme by 2015.

Another initiative is the *China Coal Cap* (CCC), announced by the National Energy Administration last year in recognition of having to curtail China’s dependency on coal use (which is the cheapest energy source in the country). The CCC caps coal production at 3.8 billion tonnes by 2015. China produces about 50 per cent of the global supply of coal (with its biggest imports from Australia and Indonesia). Currently 70 per cent of its energy consumption is satisfied by coal, 60 per cent is consumed by the power sector, 15 per cent by metallurgy, and over 10 per cent for cement manufacture.

The CCC is in the process of implementation and could see the national coal cap being implemented through both sectoral (power, metallurgy, cement, chemicals, etc.) and provincial/city caps. China’s high reliance on coal indicates a dependency on CCS to help decouple emissions from economic growth, as well as manage air pollution issues. China is also enthusiastically pursuing both nuclear and renewable energy sources, including binding targets for the latter.

Like many other countries in the world, China has strong reasons to explore, and is sitting on a large supply of non-conventional gas sources (coal bed methane and shale). Some 5 per cent of China’s coal, 20 per cent of its gas, and 55 per cent of its oil is currently imported.

In March 2012, the UNFCCC’s Global Environment Facility and the World Bank awarded China a grant to undertake a Climate Change Technology Needs Assessment (TNA). A report is expected in 2–3 years.

In 2012, the Global CCS Institute also struck a MoU with China’s NDRC to share information on CCS to help it plan to roll out the technology to cut emissions.

### E.1.6 EUROPEAN UNION

The EU’s climate change policy is characterised by strong cooperation with the international community, compliance with the UNFCCC and Kyoto Protocol, and leadership in terms of assuming emission reduction targets and implementing mechanisms.

The EC’s common emission reduction targets include:

- 20 per cent reduction of emissions relative to 1990 by 2020 (or 14 per cent compared to 2005);
- 20 per cent share of renewables in total energy mix by 2020; and
- 20 per cent increase in energy efficiency by 2020.

The EC has committed to move to a 30 per cent emission reduction target if there is a global comprehensive agreement for the post-2012 period (i.e. other developed countries commit to comparable efforts) and developing countries contributions are meaningful.

In early 2012, the EC released a paper on the policy options to drive a 30 per cent emission reduction on 1990 levels by 2020. In essence, a tighter carbon constraint could realise potentially higher revenues to be hypothecated back into low carbon developments due to higher carbon prices.

The key climate change policy instrument for facilitating emission reductions and encouraging low emission technologies is the EU ETS. It covers emitters in the power generation and other energy-intensive sectors such as steel, cement, paper, and chemicals. The third phase is due to start on 1 January 2013 and extends to 2020.

The third phase sees the fixed national emission caps cancelled and replaced by one common ceiling for the whole EU. After this, the target is set to decrease linearly every year over the period up to 2020, in conformity with the set goal of a 21 per cent emission reduction compared to 2005. It will also adopt a market allocation approach (auctioning), replacing the current administrative allocation method. The obligation on power plants will be to purchase on the open market and acquit a quantity of allowance every year equivalent to their verified emissions for the preceding year.

Every member state receives an annual quantity of allowances on the basis of their emission reduction targets. The revenues from the auction sales are collected in the national budgets of the member states and a minimum 50 per cent of these revenues must be used to combat climate change (including for CCS).

There are basically 10 countries that can apply for derogation of this rule. Bulgaria and Romania applied and were granted such derogations for the third phase.

In addition to the revenues raised at national level through auction sales, an additional 300 million allowances have been allocated under the NER300 at the European level for financing demonstration projects for CCS and renewables.
There were 13 CCS proposals received by the European Investment Bank (EIB) under the NER300 program. The EIB has completed its due diligence assessments of these proposals (which are confidential) and must monetise (sell) 200 million of the 300 million allowances (expected by October 2012) prior to making recommendations to the EC on prospective projects. The EIB is on track to do this.

Sales of the NER300 tranche of allowances as at April 2012 stand at around 99 million (about 20 million sold per month). The allowances are for use in phase 3 of the EU ETS. The average price for an allowance is about €8.

E.1.7 EU ETS PHASE III

Starting from the commencement of the third trading period (2013–20), the ETS will implement a new single EU-wide emissions cap. Individual national allocation plans for each EU member state will be replaced by one EU-wide cap on emissions amounting to around 2 billion allowances in 2013. This cap will reduce linearly and annually by 1.74 per cent of the average annual level of the Phase II cap (equalling approximately 37 million allowances each year), with a view to delivering an overall reduction of 21 per cent below 2005 verified emissions by 2020.

Auctions for emission allowances will be held by member states and will be open to any EU installation operator. The associated revenues will be collected in member states’ national budgets, and no less than 20 per cent of these will be used to encourage the use of clean coal technology (including CCS).

Furthermore, the regulations on how the allowances are allocated to individual installations are set by the EU rather than the member states. There will be no free allocation to installations from the energy sector in the third phase, with installations from industry sectors receiving free allocation based on a benchmark approach. This means that fossil fuel fired power plants will have to purchase/pay for the allowances for all the emissions they emit, unless derogations are granted (only a limited number of countries can apply, and to date derogations have been authorised for Bulgaria, Romania, the Czech Republic, Cyprus, Estonia, Lithuania, and Poland – Hungary and Latvia are yet to be decided).

The EC adopted a decision in April 2011 which provides for more than 50 product-related benchmarks for industry sectors. According to EU legislation, the percentage of allowances allocated free of costs will decrease from 80 per cent in 2013 to 30 per cent in 2020. Also, a reduction factor will be applied to all industry sectors if the overall cap is not sufficient to meet the demand for emission allowances (as calculated on the basis of the benchmark model).

E.1.8 FRANCE

The basis of French climate change policy is the EC’s policy framework, including participation in the EU ETS. Climate policy in France has not changed significantly in the past 12 months, with strategies in the Plan Climate (2010) scheduled to run until 2020.

The Government established a working group in mid-2011 to explore scenarios to reduce emissions by 80 per cent by 2050.

E.1.9 GERMANY

Germany abides by the EC’s climate change policy and legislative frameworks, and it participates in the EU ETS. The Government goes deeper than the unilateral emission reduction targets by setting a domestic target to reduce emissions by 40 per cent below 1990 levels by 2020.

In mid-2011, the German Government adopted the Energy Package, which complements the 2010 Energy Concept and defines Germany’s energy policy.

In this policy document, the Government expressed strong support for CCS projects both under the EC’s Energy and Climate Package (CCS Ready) as well as its development in the domestic energy and industrial sectors. It tried doing this through the CCS Act (finally adopted mid-2012 by the mediation committee for the transposition of the EC Directive) but this Act now only allows for CCS on a test basis, restricts the amount of CO₂ to be captured and stored to 1.3 million tonnes a year (up to a maximum of 4 million tonnes), and provides individual states the option to opt out.

E.1.10 INDIA

While India is taking a cautious approach to CCS developments, the central government acknowledges that a lot of India’s energy production for the next 20 years will be coal based. According to India’s 2nd National Communications under the UNFCCC, coal meets 63 per cent of India’s total commercial energy requirement (indigenous reserves are sufficient to meet India’s power needs for at least another 100 years), followed by petroleum products (30 per cent), and natural gas. Nearly 70 per cent of the power requirements in India are presently met by thermal power plants.
When this consideration is added to India’s 450 million people who do not have access to electricity, there seems an even greater need to ensure that CCS is available to countries like India, where the use of coal to generate electricity is expected to dramatically increase, especially since it will remain for some time the cheapest energy source available.

The IEA estimates that India’s emissions rose by 140 MtCO₂-e or 8.7 per cent in 2011 compared to 2010. India’s principal climate change framework is its National Action Plan on Climate Change (NAPCC) 12th Plan period 2012/13–2016/17. This complements the existing Integrated Energy Policy, as well as state governments’ respective State Action Plan on Climate Change (SAPCC).

India has also set up an Expert Group on Low Carbon Strategy for Inclusive Growth to develop a roadmap for low carbon development in prioritised sectors such as electricity, industry, oil, and gas.

The Group released an interim report in May 2011 noting that the implementation of existing policies can achieve an emission intensity reduction of nearly 23–25 per cent by 2020 compared to 2005 levels. It further notes that with external development assistance and technology transfer, a 33–35 per cent emission intensity reduction by 2020 is even possible.

As at the first Quarter 2012, six of the original eight missions envisaged in the NAPCC have been approved, with the Government announcing its intention to introduce a ‘National Mission on Clean Coal Technologies’, including CCS. This will be the ninth mission under the NAPCC, which aims to minimise the emissions arising specifically from coal-fired power plants.

India has a coal levy, for which funds (estimated to be US$500 million over the financial year 2010–11) are hypothecated to a National Clean Energy Fund which will be used for funding research and innovative projects in clean energy technologies.

The 2012 Budget, announced in May, did not carry details on the scale or fate of the fund, simply announcing that imported steaming coal was exempted for the next two years from full customs duty. Bloomberg estimates the fund could yield some US$1.2 billion in 2012.

In addition to this, the IEA estimates that India invested more than US$10.2 billion in clean energy technologies in 2010.

In March 2012, industrial energy efficiency targets (with tradable instruments for over-achieving targets) were announced under the Perform, Achieve, and Trade (PAT) program, for about 480 entities; the program is estimated to save some 30 MtCO₂ per annum. The power sector and steel sectors are expected to drive some 70 per cent of the savings.

The Global CCS Institute is currently working with the Energy and Resources Institute (TERI) on a CCS scoping study, which should be completed in 2012.

Interestingly, India was only one of six parties which submitted views on the UNFCCC’s CCS in the CDM process, which were formally considered in the inter-sessional meeting in May. In it they express support for a permanent global reserve of offsets, equal to 2 per cent of the total number of project offsets generated, to remedy unexpected events from CCS projects.

E.1.11 INDONESIA

Indonesia’s National Council on Climate Change, which has 17 Ministers and is chaired by the President, is in charge of coordinating Indonesia’s climate change policies and international positions. The Council is being supported by a number of Working Groups, including Mitigation, and Transfer of Technology. While the Council is exploring the establishment of a cap and trade mechanism, Indonesia does not seem to have any plans to set up a domestic carbon trading system.

In Indonesia, many of the key initiatives are embodied in decrees rather than legislation, and passed by Ministries rather than Parliament. In late 2011, the President approved a decree that obligates Indonesia to cut its emissions 26 per cent below unchecked levels by 2020, and 41 per cent if the country can secure international funding.

Most of Indonesia’s mitigation efforts are focused on the forestry sector, as the country emits well over 1 billion tonnes of CO₂-e annually from deforestation and burning of peat land (80 per cent of its emissions).

Per capita electricity demand has increased nearly three-fold over the past two decades in Indonesia, spurring its nuclear program to install four nuclear power plants with a combined capacity of 4000 MW by 2025. Along with Australia and South Africa, Indonesia is one of the world’s top coal exporters (although it is planning in 2012 to introduce an export tax on coal).

The climate change decree also provides emission targets for sectors compared to expected emission levels if no further policies are implemented. The energy and transport sector must save 38 to 56 MtCO₂-e.

E.1.12 ITALY

The basis of Italian climate change policy is the EC’s policy framework, including participating in the EU ETS. Climate policy in Italy has not changed significantly in the past 12 months.
E.1.13 JAPAN

The principal framework for developing climate change policy is the 1998 Guideline of Measures to Prevent Global Warming and Climate Change Law Concerning the Promotion of Measures to Cope with Global Warming (Act on Promotion of Global Warming Countermeasures). The principles surrounding the establishment of carbon pricing are underpinned by the National Fundamental Law on Energy (Basic Act on Energy Policy).

To deliver on its UNFCCC obligations, Japan has mostly relied on domestic emission reductions through mitigation and forest carbon-sink measures, as well as purchases of UNFCCC backed units (it is one of the biggest buyers internationally of these tradable units). It is understood that this is because Japan does not currently have adequate scope for GHG emissions reductions through energy conservation or energy efficiency, especially in the industrial sector, as it has been a global frontrunner in these areas since the 1980s.

Japan made it clear at COP 16 that it does not intend participating in the continuation of the Kyoto Protocol post-2012, and as such will no longer be subject to binding emission reduction targets. This is because they see the framework as forcing legal obligations on certain parties only, and to limited effect, and the framework does not involve major GHG emitters such as China, the US, and India. To facilitate its long-term emission reduction target, Japan is expecting to pursue offset opportunities. In addition to the CDM, Japan is proposing a new market mechanism under a post-2012 framework called a bilateral offsets crediting mechanism (BOCM).

A key difference between CDM and the BOCM is that any UNFCCC oversight of the BOCM is minimised to the function of providing guidance for emissions monitoring, reporting, and verification (MRV) and accounting rules. The BOCM will be technology-agnostic and intends to cover a wider range of sectors and activities from transport, waste management, energy efficiency, renewable energy, and also REDD+ projects. Japan also advocates that bilateral cooperation will potentially pave the way for more engagements by developing countries in emission reduction efforts in the future.

The Ministry of Economy, Trade and Industry (METI) and the Ministry of the Environment have commissioned over 100 feasibility studies to identify potential emissions reduction projects which can be implemented.

With Japan as one of the world’s biggest coal importers, coupled with continued power shortages and a curtailing of new nuclear power plants projects, this all seems to further limit its ability to achieve its stated emission reduction target.

A new energy blueprint is expected to be released in late 2012, outlining an aggressive role to play by renewables (some 30 per cent share) and supported by a feed-in tariff regime. The premium prices paid by utilities could be as high as US$0.57c per kWh.

E.1.14 MALAYSIA

Malaysia launched its National Policy on Climate Change in 2010, which provides its overarching policy framework. There have been no substantial policy announcements over the past year. In mid-2011, Malaysia released its 2nd National Communications to the UNFCCC.

Malaysia indicated in its high-level statement at COP 17 (late 2011) that its low-carbon strategy is dependent on multi-sectoral and trans-ministerial initiatives (such as National Green Technology and Climate Change Council, National Climate Change Focal Point, and National Steering Committee on Climate Change).

Delivering its 2020 emission reduction pledge (up to 40 per cent energy intensity per capita compared to 2005 levels) is conditional on technology transfer and access to international finance from developed countries, such as those potentially provided through the Technology Mechanism and the GCF.

E.1.15 MEXICO

The General Law on Climate Change (GLCC) was passed in mid-2012. There is also a permanent Inter-ministerial Commission on Climate Change comprising the Departments of Foreign Relations, Social Development, Environment and Natural Resources, Energy, Economy, Agriculture, and Communications and Transport.

The GLCC demonstrates major progress for Mexico, and leads by example for other countries to address climate change and transition to a low-carbon economy. While this law does not include concrete measures and activities, it consolidates the existing institutional structures (under the Special Programme on Climate Change 2009–2012) and tasks the Commission to encourage the development of a carbon trading scheme.

The Commission will oversee six working groups including the following two: Mitigation and a Mexican Committee for Emission Reduction and GHG Capture Projects.

In a recent submission to the UNFCCC, Mexico supports the establishment of new market mechanisms, as well as possibly sectoral approaches where countries retain sovereign capacity to decide which aspects of its economy are introduced into international markets, and which count as a contribution to the achievement of its own pledges.
It also sets the target for the electricity sector to provide 35 per cent of Mexico’s electricity from clean sources by 2024. Mexico considers CCS an important option in a long-term climate strategy, but outside of the CCS-CO₂ EOR opportunities, there are no direct incentives for coal-related CCS.

Mexico is very much an international leader. Apart from hosting COP 16, it recently hosted the Group of 20 (G20) Summit, as well as a strong advocate for the creation of the Green Climate Fund. It has subsequently submitted a bid (one of six countries) to host it. The Government offered US$500,000 to support administrative expenses of the Secretariat.

To support CCS activities, Mexico, in partnership with the US DOE and Canada, recently released an atlas mapping potential storage capacity in North America. It cites Mexico’s resource as at least 100 GtCO₂, compared with annual emissions of about 205 MtCO₂.

The development of a National CCUS Strategy and Regulatory Framework was identified as a goal in Mexico’s National Energy Strategy 2012–2026, which was presented to the Mexican Congress in April 2012

E.1.16 THE NETHERLANDS

Like other EU member states, the Netherlands operates within the broader framework of the EC climate policy and its emissions targets.

In November 2011, the Government released its Energy Report 2011, recognising not only the inevitability of CCS use (including for gas), but also that the Dutch economy can benefit greatly from being a global leader in CCS. Its major policy focus is to support CCS via demonstration projects.

The Government is only permitting demonstration projects for under-sea storage (not on-shore storage), and is actively pursuing European funding opportunities (such as the NER300) for them. It is also adopting policy measures that encourage CCS as well as setting parameters for conventional fuels.

E.1.17 NEW ZEALAND

In mid-2011, a review panel released its findings on how the NZ ETS (which started in 2009, with liquid fossil fuels, stationary energy, and industrial processes beginning to be covered in 2010) should evolve beyond 2012. A Government consultation paper was released in mid 2012 outlining two proposals. The first limits CERs to 50 per cent fulfilment of the emission reduction obligation and the second proposes auctioning of permits.

The limit on CERs is similar to that of Australia, as the Government accords a high priority to the development of international carbon markets more generally. It is in formal discussions with Australia and Korea. It is interesting to note that only about 2 per cent of total allowances acquitted were sourced from CDM projects (noting that CERs generated from HFC-23 and N₂O projects are not allowed).

NZ has adopted a 90 per cent by 2025 renewable electricity target.

E.1.18 NORWAY

Climate policy in Norway has not changed significantly in the past 12 months, and it continues to rely on its carbon tax on offshore petroleum production installations, along with its membership in the EU ETS, to reduce emissions (even though the country is not a member of the EU it is a member of the European Economic Area Agreement).

The Government released in April 2012 a White Paper on Climate Change Actions. While there are no new national measures, there is an increase to the CO₂ tax rate to about €51/tCO₂, a new technology fund established with up to €6.6 billion by 2016, and the intent to pass a law requiring all new gas power plants to be CCS ready at start-up.

E.1.19 ROMANIA

The basis of Romania’s climate change policy is the EC’s policy framework. Romania also participates in the EU ETS. In early 2012, the EC authorised Romania’s request for the continued free allocation of EU ETS allowances to their power sectors beyond this year (rather than having to purchase them on the open market).

Due to irregularities found in the country’s national GHG emissions inventory, Romania’s eligibility to internationally trade its surplus Kyoto allowances under the Kyoto Protocol’s international emissions trading scheme was suspended in late August 2011.

Romania’s National Emissions Registry underpinning its participation in the EU ETS was also suspended in 2011 by the EC due to unlawfully transferred allowances, and allowed to re-open in March 2012.
E.1.20 RUSSIA


It includes the Ministry for Energy overseeing the:

- development and implementation of pilot projects on the construction and development of industrial exploitation in the field of energy for the capture and disposal of CO₂; and
- implementation of a set of measures to limit GHG emissions from energy generation from fossil fuels.

Russia has refused to take on a second target under the Kyoto Protocol, preferring instead to keep to its voluntary emissions cut pledge made under the Copenhagen Accord in 2009. As such, the fate of its estimated 6 billion surplus of Kyoto credits remains in doubt.

In late 2011, the Government approved a self-imposed cap (300 million) on the number of JI credits it can issue to projects.

E.1.21 SAUDI ARABIA

The principal climate change framework is the Ninth Development Plan, Chapters 14 (Environmental Management) and 26 (oil and gas); the latter indicates a preference for CCS. There has been no substantial change in policy over the past 12 months.

E.1.22 SOUTH AFRICA

Policymaking in South Africa typically starts with the introduction of a Green Paper (a public discussion document) followed by a White Paper (broadly outlining government policy). Although there is no climate change law, there has been a number of Green Papers outlining market-based approaches to facilitating mitigation. The principal framework for climate change is the Vision, Strategic Direction and Framework for Climate Policy (2008). This Policy supports CCS for coal-fired power stations and all CTL plants, and in general power plants that are not CCS Ready should not be approved. The Treasury has also been charged with studying the implementation of a carbon tax by 2018–20. It is expected that this will be considered by the recently formed CCS Interdepartmental Task Team.

In October 2011, it released a White Paper on National Climate Change Response Strategy. It recognises the potential of CCS over the short and medium term in the synthetic fuels industry, and highlights the Carbon Capture and Sequestration Flagship Programme as led by the Department of Energy in partnership with the South African Energy Research Institute. The program includes, among other initiatives, the development of a CCS demonstration plant to store the emissions from an existing high-carbon emissions facility.

It also notes that a portfolio of economic instruments, including carbon taxes and emissions trading schemes and complemented by appropriate regulatory policy measures, are essential to driving and facilitating mitigation efforts and creating incentives for mitigation actions across a wide range of key economic sectors. This will be overseen by the Treasury, and the Departments of Trade and Industry and Economic Development.

In addition to the 2010 Green Paper on a carbon tax, the 2012 Budget states that a revised policy paper on a carbon tax will be published in 2012 for a second round of public comment and consultation. The Government accepts the need to price carbon emissions and the phasing in of a tax instrument for this purpose. A phased implementation of the carbon tax by 2013 is expected, with the price starting at US$15.60/tCO₂e above a tax-free threshold (for most sectors this is 60 per cent) and would increase by 10 per cent until 2019–20.

South Africa also hosted the UNFCCC’s COP 17/CMP 7 in Durban. These climate negotiations achieved the resolution of the inclusion of CCS in the CDM with the finalisation of modalities and procedures, as well as agreement to explore a new legally binding instrument or arrangement for enhanced mitigation in a post-Kyoto world (mostly after 2020).

E.1.23 KOREA

Korea is listed as one of the top 10 largest emitters globally, driven by its energy-intensive economic activity (manufacturing). The central policy platform driving emissions and pollution management, as well as economic development in Korea, is the Five Year National Plan for Green Growth (see the Global Status of CCS: 2011 report for details). Korea, through the Presidential Committee on Green Growth (its central policy making force), has equipped its regulatory institutions to appropriately enforce these policies.

The two major objectives of this Plan are to reduce emissions by 4 per cent below 2005 levels by 2020 (as submitted to the UNFCCC), and to allocate 2 per cent of annual GDP to Green Growth investments and development projects.
The Korean National Assembly recently released the emission profiles of the country's top 150 emitters, showing a 9.1 per cent growth year on year. This is driven by the power, oil refining, and steel sectors.

After what seems much national deliberation, in May 2012 Korea approved the establishment of a cap-and-trade scheme in 2015 (with commitment periods expected to be 2015–17, 2018–20, and 2021–26) as the major enabler of its mitigation efforts. This is in addition to the imposition in 2012 of its Emissions Target Management Scheme (ETMS) (i.e. emission reduction goals on 458 of its largest emitters ranging from factories, buildings, and livestock farms). The expected interplay between the ETMS and the ETS is that facilities producing less than 25,000 tCO₂-e per year (or entities producing 125,000 tCO₂-e per year) will not have obligations under the ETS, but there will be a voluntary opt-in option.

While it could take some months for the ETS design to be finalised (the promulgation of a Presidential Decree is expected by November 2012), it has been indicated that the penalty for non-compliance could be set at three times the prevailing market price (expected to be no more than US$113 per tonne). There may also be a 95 per cent free allocation of permits (and 100 per cent to trade-exposed entities) in the first and second commitment periods, as well as permission for both banking and borrowing from other commitment periods.

There are many key issues still to be decided, however, including: coverage (about 60 per cent of emitters are expected to be included), the emissions caps and reduction targets for each period, the caps on banking and borrowing, and the rules for using international offsets (such as those generated under the CDM). Korea is also reportedly in talks with both Australia and New Zealand to discuss ways of linking their respective emissions trading schemes.

Korea is showing a preference for incentive-based instruments that not only allow national industries to act in their own self-interest but in a way that can deliver efficiently on national objectives.

In a 2012 submission to the UNFCCC on Nationally Appropriate Mitigation Actions (NAMAs), Korea stated that it believed what was lacking in the international climate change agenda was a climate regime that could improve the commercial viability of investments for mitigation, and that if such a regime existed then the market will drive finance and technology to flow to mitigation actions in developing countries.

In addition to market-based instruments, the Government indicated that it will spend US$150 million over the next decade specifically on CCS, and the Ministry of Education, Science and Technology (MEST) recently publicly stated that the Government intends to enhance Korea's R&D efforts in CCS.

Korea is demonstrating international leadership in the climate change policy agenda by being one of two countries shortlisted to host COP 18. While Qatar won the bid, Korea will host a key ministerial meeting in the lead-up to COP 18, which will be instrumental in clarifying the central issues in the weeks before a COP.

Korea has also submitted a bid to host the GCF (one of six countries to do so). It has offered support of US$2 million in 2012 for its start-up and an additional US$1 million per annum until 2019.

### E.1.24 SPAIN

The basis of Spain’s climate change policy is the EC’s policy framework, including participating in the EU ETS. Spain’s National Allocation Plan (holding 2012 emissions to at most 37 per cent of the 1990 base year) ends in 2013. From this date, the EC approach will be adopted.

In late 2011, a Carbon Fund for a Sustainable Economy was established by means of Royal Decree (1494/2011) to buy carbon credits. It is administered by the Secretary of State for Climate Change, and will contribute to the fulfilment of the objectives of reducing emissions taken by Spain with the acquisition of carbon credits. Spain is the second largest buyer of UN offsets under the CDM after Japan.

### E.1.25 SWEDEN

The basis of Sweden's climate change policy is the EC's policy framework, including participating in the EU ETS. Sweden’s National Emissions Registry, underpinning its participation in the EU ETS, was suspended early this year due to security issues and allowed to re-open in March 2012.

Climate policy in Sweden has not changed significantly in the past 12 months, although there have been increases in its energy and CO₂ tax from 2011. Sweden is also developing a carbon neutral by 2050 roadmap, which is expected to be considered by Government at the end of 2012. In 2011, the Government also presented an environmental technology strategy.
E.1.26 TRINIDAD AND TOBAGO

In mid-2011, the Government of Trinidad and Tobago released its National Climate Change Policy. The document highlights that it will increase the use of cleaner technology in all sectors by developing regulatory approaches and technology standards, explore the feasibility of cap and trade schemes within and across emitting entities, and explore CCS and CCUS (among other approaches).

E.1.27 UNITED KINGDOM

In addition to the UK reflecting the broader EC climate policy framework and emissions targets, it has had several instruments directly aimed at achieving emissions reduction since the early 2000s.

The principal long-term framework for managing emissions is the Climate Change Act (2008). The Act enshrines in legislation the UK’s emissions reduction targets (at least 34 and 80 per cent lower than the 1990 baseline for the years 2020 and 2050 respectively), and creates five-yearly carbon budgets (the first four are 2008–12, 2013–17, 2018–22, and 2023–27). It also established an independent Climate Change Committee (CCC) to advise the Government.

In 2010, the CCC released, and the Government responded to, several recommendations dealing with electricity market reform, carbon price floor, and the Emissions Performance Standard (EPS), among other things.

The EPS is currently set at the equivalent of 0.45 kg of CO_2 per kWh. The carbon price floor is aimed at avoiding stranding low-carbon assets due to very low international carbon prices.

The Energy Act 2011 provides for specific CCS incentives to support the construction of four commercial-scale demonstration projects in the UK, and retrofitting additional CCS capacity to these projects should it be required at a future point. It also adopts a CCS Ready policy for new fossil fuel fired power stations.

In late 2011, pursuant to the Climate Change Act, the Government released The Carbon Plan outlining its plans for achieving the first four carbon budgets (2008–27) on a pathway consistent with meeting the 2050 target.

The Plan recognises that by being an early mover in technologies such as CCS (for both fossil fuel and biomass plants), the UK could establish a long-term comparative advantage in growing global markets for these technologies.

As such, CCS forms an integral component of the sectoral plans for both industry and the power sector. The Plan also states that Scotland believes that fossil fuels – with CCS, renewables, and energy efficiency – are the best long-term solutions to its energy security.

Complementing the sectoral plans is the release of the CCS Roadmap titled Supporting Deployment of CCS in the UK.

The roadmap outlines:

- a CCS commercialisation program (£1 billion);
- a R&D innovation program (£125 million);
- continued electricity market reform including long-term feed-in tariffs with ‘contract for difference’ tailored to the needs of CCS power plants;
- development of transport and storage networks; and
- continued international engagement.

In 2012, Scotland released its Electricity Generation Policy Statement which specified that new fossil fuel plants over 300 MW will need to demonstrate CCS readiness (previously it applied only to coal).

E.1.28 UNITED STATES

Despite multiple attempts in recent years, the US has been unsuccessful in passing federal climate legislation. In the absence of a dedicated federal scheme, US climate policy is being pursued through federal regulation under the existing Clean Air Act (CAA) and individual state initiatives.

At the federal level, the US EPA and the Department of Transportation have issued regulations establishing GHG emission standards and corporate average fuel economy standards for light duty vehicles and GHG emissions standards and fuel efficiency standards for medium and heavy-duty engines and vehicles.

EPA has also issued regulations establishing permitting requirements for major stationary sources of GHGs under the New Source Review Prevention of Significant Deterioration (PSD) and Title V Operating Permit programs. PSD (preconstruction) permitting involves a five-step top-down analysis for the Best Available Control Technology (BACT). The permitting guidance identifies CCS as an add-on pollution control technology that is ‘available’ for facilities emitting CO_2 in large amounts and which should be listed as an option at step one of the BACT process for such facilities.
On 27 March 2012 the EPA issued for comment a Rule proposing that new fossil fuel-fired power plants greater than 25 MW (electric) meet an output-based performance standard of 1000 pounds of CO$_2$ per megawatt-hour. New power plants that use CCS would have the option to use a 30-year average of CO$_2$ emissions to meet the proposed standard rather than meeting the annual standard each year. The proposal does not apply to existing units and transitional sources that have PSD permits by the date of the proposal and commence construction within 12 months of the proposal.

Multiple states have established GHG emission targets. California, one of the world’s largest economies, enacted the comprehensive Global Warming Solutions Act in 2006 to reduce GHG emissions through a combination of regulatory and market mechanisms. Under the Act, California established a cap and trade program for major sources with enforceable compliance obligations, beginning with 2013 emissions. California is also partnering with British Columbia, Ontario, Quebec, and Manitoba in the Western Climate Initiative to develop a cap and trade program that transcends national boundaries. The Regional GHG Initiative – a cooperative effort among nine Northeastern and Mid-Atlantic states to reduce GHGs through a market-based cap and trade program – completed its first three year control period in 2011. In addition to GHG specific laws and policies, EIA reports that 30 states and the District of Columbia have enforceable renewable portfolio standards or similar laws.

In the 2013 Energy Budget, the President announced a clean energy standard (CES) is one policy option to be considered for supporting the deployment of clean energy technology (including CCS) and reducing emissions from the electric power sector. This is consistent with his 2011 State of the Union address, where he announced the goal of producing 80 per cent of electricity from ‘clean’ energy sources by 2035.

In addition, the Budget allocates US$276 million for research and development of advanced fossil fuel power systems, CCS, and CCUS.

In March 2012, the Clean Energy Standard Act was introduced which, if passed, will establish a standard for clean energy generation in the US through 2035. The Act provides for CCS facilities.

The US has agreed to only voluntary emission pledges to 2020 under the UNFCCC, and has indicated that, similar to the first commitment period under the Kyoto Protocol, it will not be ratifying a second commitment period either.

The US seems to be placing increasing emphasis on CCUS as a potential path for early-mover CCS adoption.
APPENDIX F: LEGAL AND REGULATION ISSUES

As discussed in Section 4.3 of this report, the following figures provide a breakdown by region of legal and regulatory issues that have been identified by LSIPs in the 2012 project survey as insufficiently addressed in their jurisdictions.

FIGURE F1 Market rules to accommodate CCS outcomes in prevailing market mechanisms

FIGURE F2 Standards to account for cross-border movement of CO₂
FIGURE F3 Remediation activities to be undertaken by the operator in the event of leakage

FIGURE F4 Post-operational transfer of operator’s liability
FIGURE F5 Definition of project boundaries

FIGURE F6 Drafting and implementation of a monitoring plan
FIGURE F7 Selection and evaluation of a storage site

FIGURE F8 CCS activities adequately addressed in pre-existing planning and permitting regimes
APPENDIX G: CCS ACTIVITIES IN DEVELOPING COUNTRIES

Table G1 provides an illustrative list of CCS activities developing countries, as at August 2012.

**TABLE G1 Illustrative list of CCS activities in developing countries**

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>CCS ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>▪ CCS project in operation</td>
</tr>
</tbody>
</table>
| Botswana| ▪ CCS workshops conducted, raising awareness  
          ▪ Study underway which includes:  
            ▪ Initial assessments on role and opportunity for CCS  
            ▪ Undertaking preliminary geologic assessment |
| Brazil  | ▪ Centre of Excellence in CCS R&D has been established  
          ▪ Completed a Geographic Information System (GIS)-based database of CO₂ sources and sinks  
          ▪ Pilot CO₂ injection program underway  
          ▪ Reviewing and refining Brazilian Carbon Geological Sequestration Map (CARBMAP) program |
| China   | ▪ CCS adopted as a key GHG mitigation technology in National Climate Change Program  
          ▪ Numerous domestic R&D initiatives  
          ▪ Efforts underway to assess and characterise CO₂ storage capacity by Chinese Geological Survey  
          ▪ Several pilot projects, e.g. for CO₂ capture and CO₂ EOR  
          ▪ 11 large-scale integrated demonstration projects in the planning stages |
| Egypt   | ▪ Study underway assessing potential for CCS in gas processing and power industry, identifying barriers and environmental impacts |
| India   | ▪ Interest in CO₂ capture for EOR field studies  
          ▪ Indian CCS Scoping Study  
          ▪ Proposed study to carry out a technical feasibility assessment to review and evaluate a range of capture technologies |
| Indonesia| ▪ Study being finalised on potential for CCS as part of South East Asia CCS Scoping Study, including opportunities for deployment and regulatory and economic analysis  
         ▪ Assessment of current CCS R&D activities and technical capacity of the domestic industry to provide support throughout the CCS chain  
         ▪ Workshops on developing a CCS Technology Roadmap  
         ▪ Preliminary studies on CCS and EOR |
| Jordan  | ▪ Study underway assessing potential for CCS in oil shale development strategy and to identify and address legal, regulatory, and financial barriers |
| Kenya   | ▪ Investigating possibility for high-level storage study |
| Kosovo | ▪ Study completed which covers:  
          ▪ Preliminary geologic potential  
          ▪ Capacity-building assessment including legal and regulatory requirements  
          ▪ Workshops and training on CCS technology |

continued on page 206
<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>CCS ACTIVITIES</th>
</tr>
</thead>
</table>
| Mexico       | ▪ CCS identified in Special Program on Climate Change and National Energy Strategy 2012–26  
▪ Country-level preliminary assessment of CO₂ storage potential completed  
▪ Pilot projects being considered, including for CO₂ capture with a focus on EOR |
| Maghreb      | ▪ Study underway to assess the potential for carbon capture on projected and existing power plants in Tunisia, Algeria, and Morocco and for CO₂ geologic storage and transportation at a regional scale |
| Malaysia     | ▪ CCS workshops conducted for raising awareness and discussing key issues  
▪ Scoping study completed on the long-term role for CCS, opportunities for near-term deployment, technical and financial feasibility, and next steps for further investigation  
▪ Capacity-building program developed and activities being implemented |
| Philippines  | ▪ Study being finalised on potential for CCS as part of South East Asia CCS Scoping Study, including opportunities for deployment and regulatory and economic analysis |
| Saudi Arabia | ▪ Identified CCS as an appropriate low emission technology  
▪ Workshops and roundtables held and sponsored on CCS, including on monitoring and storage specifically, challenges and opportunities  
▪ Working towards a EOR-CCS project |
| South Africa | ▪ CCS identified as a priority in national White Paper on National Climate Change Response  
▪ South African Centre for CCS established  
▪ Storage Atlas complete; further basin-specific storage studies underway  
▪ Scoping study for test injection project being developed  
▪ Legal and regulatory review undertaken and further work commenced |
| Thailand     | ▪ Study being finalised on potential for CCS as part of South East Asia CCS Scoping Study, including opportunities for deployment and regulatory and economic analysis |
| Trinidad and Tobago | ▪ CCS Scoping Study, including Legal and Regulatory Review |
| United Arab Emirates | ▪ Three industrial CCS projects in the planning stages (in the hydrogen, steel, and aluminum industries) |
| Vietnam      | ▪ Study being finalised on potential for CCS as part of South East Asia CCS Scoping Study, including opportunities for deployment and regulatory and economic analysis |
### APPENDIX H: US CO₂ PIPELINES

Table H1 provides an overview of the main existing CO₂ EOR pipelines in the US. Chapter 7 discusses a number of LSIPs that could be considered extensions or components of these existing CO₂ EOR pipeline networks in the US.

#### TABLE H1 Exisiting major US CO₂ pipelines

<table>
<thead>
<tr>
<th>PIPELINE</th>
<th>OWNER/OPERATOR</th>
<th>LENGTH (KM)</th>
<th>DIAMETER (IN)</th>
<th>ESTIMATED MAX FLOW CAPACITY (MTPA)</th>
<th>LOCATION (STATE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adair</td>
<td>Apache</td>
<td>24</td>
<td>4</td>
<td>1</td>
<td>TX</td>
</tr>
<tr>
<td>Anton Irish</td>
<td>Oxy</td>
<td>64</td>
<td>8</td>
<td>1.6</td>
<td>TX</td>
</tr>
<tr>
<td>Beaver Creek</td>
<td>Devon</td>
<td>85</td>
<td></td>
<td></td>
<td>WY</td>
</tr>
<tr>
<td>Borger, TX to Camrick, OK</td>
<td>Chaparral Energy</td>
<td>138</td>
<td>4</td>
<td>1</td>
<td>TX, OK</td>
</tr>
<tr>
<td>Bravo</td>
<td>Oxy Permian</td>
<td>351</td>
<td>20</td>
<td>7</td>
<td>NM, TX</td>
</tr>
<tr>
<td>Centerline</td>
<td>Kinder Morgan</td>
<td>182</td>
<td>16</td>
<td>4.3</td>
<td>TX</td>
</tr>
<tr>
<td>Central Basin</td>
<td>Kinder Morgan</td>
<td>230</td>
<td>16</td>
<td>4.3</td>
<td>TX</td>
</tr>
<tr>
<td>Chaparral</td>
<td>Chaparral Energy</td>
<td>37</td>
<td>6</td>
<td>1.3</td>
<td>OK</td>
</tr>
<tr>
<td>Choctaw (NEJD)</td>
<td>Denbury Onshore, LLC</td>
<td>294</td>
<td>20</td>
<td>7</td>
<td>MS, LA</td>
</tr>
<tr>
<td>Comanche Creek (currently inactive)</td>
<td>PetroSource</td>
<td>193</td>
<td>6</td>
<td>1.3</td>
<td>TX</td>
</tr>
<tr>
<td>Cordona Lake</td>
<td>XTO</td>
<td>11</td>
<td>6</td>
<td>1.3</td>
<td>TX</td>
</tr>
<tr>
<td>Cortez</td>
<td>Kinder Morgan</td>
<td>808</td>
<td>30</td>
<td>23.6</td>
<td>TX</td>
</tr>
<tr>
<td>Delta</td>
<td>Denbury Onshore, LLC</td>
<td>174</td>
<td>24</td>
<td>11.4</td>
<td>MS, LA</td>
</tr>
<tr>
<td>Dollarhide</td>
<td>Chevron</td>
<td>37</td>
<td>8</td>
<td>1.6</td>
<td>TX</td>
</tr>
<tr>
<td>El Mar</td>
<td>Kinder Morgan</td>
<td>56</td>
<td>6</td>
<td>1.3</td>
<td>TX</td>
</tr>
<tr>
<td>Enid-Purdy (Central Oklahoma)</td>
<td>Merit</td>
<td>188</td>
<td>8</td>
<td>1.6</td>
<td>OK</td>
</tr>
<tr>
<td>Este I to Welch, TX</td>
<td>ExxonMobil</td>
<td>64</td>
<td>14</td>
<td>3.4</td>
<td>TX</td>
</tr>
<tr>
<td>Este II to Salt Creek Field</td>
<td>ExxonMobil</td>
<td>72</td>
<td>12</td>
<td>2.6</td>
<td>TX</td>
</tr>
<tr>
<td>Ford</td>
<td>Kinder Morgan</td>
<td>19</td>
<td>4</td>
<td>1</td>
<td>TX</td>
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APPENDIX I: REFERENCES AND ABBREVIATIONS


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## ABBREVIATIONS

<table>
<thead>
<tr>
<th>TERM</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>AAU</td>
<td>Assigned amount unit</td>
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<td>A-CO$_2$</td>
<td>Anthropogenic CO$_2$</td>
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<tr>
<td>ADB</td>
<td>Asia Development Bank</td>
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<tr>
<td>ADP</td>
<td>Durban Platform for Enhanced Action</td>
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<tr>
<td>AGR</td>
<td>Acid gas removal</td>
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<td>APEC</td>
<td>Asia Pacific Economic Cooperation</td>
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<td>Ar</td>
<td>Argon</td>
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<td>ARRA</td>
<td>American Recovery and Reinvestment Act</td>
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<td>Ad-hoc working group</td>
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<td>Further Commitments for Annex I Parties under the Kyoto Protocol</td>
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<td>Long-term Cooperative Action under the Convention</td>
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<td>BACT</td>
<td>Best available control technology</td>
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<td>CBM</td>
<td>Coal bed methane</td>
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<td>CCS</td>
<td>Carbon capture and storage</td>
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<tr>
<td>CCSR</td>
<td>CCS ready</td>
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<tr>
<td>CCUS</td>
<td>Carbon capture use and storage</td>
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<td>CDM</td>
<td>Clean Development Mechanism</td>
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<tr>
<td>CEM</td>
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<tr>
<td>CER</td>
<td>Certified Emission Reduction unit</td>
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<td>CfD</td>
<td>Contract for differences</td>
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<td>CH$_4$</td>
<td>Methane</td>
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<td>Conference of the Parties serving as the Meeting of the Parties to</td>
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<td></td>
<td>the Kyoto Protocol</td>
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<td>CO$_2$e</td>
<td>Carbon dioxide equivalent</td>
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<td>COP</td>
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<td>Coal-to-liquids</td>
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<td>Department of Energy and Climate (UK)</td>
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<td>Det Norske Veritas</td>
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<td>Department of Energy (US)</td>
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<td>EB</td>
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<td>European Commission</td>
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<td>EEPR</td>
<td>European Energy Programme for Recovery</td>
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<td>EIA</td>
<td>Energy Information Administration</td>
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<td>Enhanced oil recovery</td>
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<td>Environmental Protection Agency</td>
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<td>Engineering, procurement and construction</td>
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<td>ETS</td>
<td>Emission trading scheme</td>
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<td>Final investment decision</td>
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<td>Global financial crisis</td>
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<td>H₂S</td>
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<td>km</td>
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<td>LCOE</td>
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<td>Mtpa</td>
<td>Million tonnes per annum; million tonnes a year</td>
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Printed on Maine Recycled. Featuring 60% certified recycled (PCW) and 40% certified virgin fibre sourced from responsibly managed forests. Certified carbon neutral by The Carbon Neutral Company. Maine Recycled is manufactured process chlorine free and produced in a facility that operates under world’s best practice ISO 14001 Environment Management System.