IEF Report

IEF- Global CCS Institute Symposia on CCS

Lessons Learned

Report for the 13th IEF Ministerial

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Foreword

This IEF report on CCS technology is a summary of the outcome of the two IEF-Global CCS symposiums held in September 2009 in Beijing, China and June 2010 in Algiers, Algeria. The aim of this series of symposiums was to review key issues related to CCS, disseminate learning, investigate ways to accelerate the development and commercial deployment of CCS technologies, and develop messages to IEF Ministers and other CCS and climate change fora.

This report is based on the background material, working papers, presentations, debates and concluding statements of the two symposiums; additional research work has been also carried out to give further insights on key points of particular interests. This report is however published under the sole responsibility of the IEF Secretariat.

The IEF is thankful to the Global CCS Institute and the Canadian Ministry of Foreign Affairs for their financial support. The IEF is also appreciative to the Energy Research Institute of the National Development and Reform Commission of China and to the Ministry of Energy and Mines of Algeria and Sonatrach for hosting the events, and to Sonatrach for arranging the visit to the In Salah CCS Project.

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1. Executive Summary

Given the projected increase in long-term demand and the prevalence of fossil fuels in the future energy mix, there is an urgent need to improve the environmental sustainability of fossil fuel production and consumption by moving toward low carbon emission technologies. Coordinated and cohesive policies must be implemented and concrete actions taken to curb GHG emissions and any effective global climate-change strategy will require strong participation from the major oil and gas producing and consuming countries.

Carbon capture and storage (CCS) is among the most promising GHG reduction technologies. Its development and deployment offer part of the solution that can contribute, along with energy efficiency and renewable energy, to delivering a sustainable energy future. The deployment of CCS in conjunction with enhanced oil recovery (EOR) in particular, is demonstrating significant potential to contribute towards global emissions reduction and at the same time to enhance global energy security.

A vast number of initiatives and activities are underway to support widespread deployment of CCS technology including CCS research and development, construction of pilot and larger scale CCS demonstration and the development of directives and related regulations across a number of countries.

While CCS technology was viewed as having great potential participants to the symposiums observed that cost, regulatory framework, and public acceptance remain significant obstacles still to be overcome before CCS technology attains commercial viability. The symposia indentified key actions and steps that need to be taken for CCS to become an economically viable and safe sequestration option.

The technologies required for CCS are generally well understood individually; however they have yet to be integrated and applied on a large scale in key sectors such as power generation and oil refining. Implementation of the three steps - CO_2 capture, transport and storage - requires capital investment and additional operating costs.

Current costs levels are the most significant barrier to large scale commercial deployment of CCS. According to existing estimates CCS technologies could increase electricity production costs by 60-100 percent at existing power plants and 25-50 percent at new coal-fired power plants. The most expensive component of CCS is the capture and compression of CO_2 which amounts to 60-80% of the total CCS cost. CCS technology will need significant government support and fiscal incentives if it is to be deployed at commercial scale. This can be done through several means such as cap-and-trade emissions programmes, taxing emissions or direct government subsidies. Funding for near-term demonstration projects is required in order to continue to prove CCS at the commercial scale and to reduce costs. Considering the scale of investment needed, Governments will be required to address the funding gap and to help facilitate private sector investments via public-private partnerships in CCS demonstration.

The decision to include CCS in the Clean Development Mechanism under the Kyoto Protocol now facilitates further reduction in costs by allowing sequestered carbon to be sold as credits on carbon trading markets. The IEF, the Global CCS Institute and other organizations have advocated extensively for the inclusion of CCS into the CDM, as a way to develop CCS. In December, 2010 at the UNFCCC in Cancun, (COP 16), it was announced that CCS projects will now be included under the CDM, a positive step although it might take some time before CCS projects will see any benefit by the CDM, due to lengthy and complex procedures.

Knowledge sharing is one of the major ways to lower the cost and increase the reliability of CCS. Some of the lessons learned that could be shared include those in technology, regulation, business models, financing, plant operations, best practice, and plant management.

One of the key issues discussed by the IEF-GCCSI Symposium series was the need for a comprehensive legal and regulatory framework for CCS. An enabling environment must be in place that provides adequate assurances of acceptable risk to companies and investors. Likewise, governments and citizens need assurance through regulations and controls that CCS activities will not result in any adverse effects. Regulatory frameworks at national and international levels are needed to clarify long term rights, liabilities and institutional structures. In particular, regulations defining the limits of liability for storage need to be established. Some of the major issues that regulation needs to address include the physical properties of site selection, storage methods, monitoring of reservoirs, measuring storage and verification of storage.

During the two IEF-Global CCS Institute Symposia the need to increase public awareness and acceptance was one of the key issues raised by participants. Gaining general acceptance of CCS technologies will be necessary to demonstrating that CCS is a safe and environmentally acceptable option. Currently public awareness of CCS is low which has lead to low acceptance levels of public support for CCS technology to date. CCS stakeholders must address public concerns and perceptions and educate and communicate on large scale CCS deployment. Existing pilot plants, particularly those associated with EOR/EGR; provide good starting points for communicating the feasibility and value of CCS.

The series of IEF-Global CCS symposia represents a significant contribution to enhance international dialogue, cooperation and industry-government collaboration for the reduction of barriers and acceleration of industrial scale CCS.

2. Background

Given the projected long-term demand and dominance of fossil fuels in the future energy mix, there is an urgent need to improve the sustainability of their production and consumption, especially with regard to the associated environmental footprint. Carbon capture and storage (CCS) development and deployment offer a solution that can contribute, along with energy efficiency, to delivering a sustainable energy future.

The 11th IEF Ministerial (Rome, April 2008) concluded that "a sustainable energy future implies efficiency improvements, technological advances in both production and consumption of fossil fuels, and development of alternative low-carbon energy sources". Ministers noted that carbon capture and storage is an important option to reduce greenhouse gas emissions from fossil fuels.

The IEF-IFP Symposium on technology (Riyadh, December 2008) acknowledged the crucial role of CCS in delivering a sustainable energy future and concluded that "CCS in conjunction with CO_2 -EOR is a "double-win" option as it reduces greenhouse gas emissions while at the same time increasing recoverable reserves in mature fields and hence contributing to global energy security".

Other ministerial gatherings have also expressed support for CCS as a climate change mitigation option. The G8 Summit in Hokkaido, Japan (July 2008) acknowledged "the need to act now to commit by 2010, to at least 20 fully integrated industrial-scale demonstration projects for the broad deployment of CCS technology by 2020." The G8 meeting in L'Aquila, Italy (July 2009) subsequently concluded that "the development and deployment of innovative technologies such as CCS is expected to contribute substantially to reducing emissions". The ministerial group reaffirmed its commitment to:

- Accelerate the design of policies, regulatory frameworks and incentive schemes focused on the development and deployment of CCS technology;

- Identify sources of financing for CCS demonstration projects; and

- Identify investment needs and overcome obstacles through such initiatives as creation of innovative partnerships.

The expressed commitment of so many organizations, ministers and world leaders to CCS demonstrated the importance of this technology as a means to combat global climate change and the need for joint and coordinated efforts by organizations such as the IEF and the Global CCS Institute, among others, to promote CCS as a viable policy option.

Responding to a call-for-action from Ministers requesting the development of more commercial-scale demonstration projects, the IEF and the Global CCS Institute have jointly established a series of symposia on CCS. The primary objective was to share knowledge and to facilitate the development and commercial deployment of CCS technology.

The 1st IEF-Global CCS Institute symposium was hosted by the Energy Research Institute of the National Development and Reform Commission (ERI – NDRC) on 27-28 September 2009 in Beijing, China. The main objective of this first symposium was to assess the current state of CCS development, with particular focus on CO_2 - Enhanced Oil Recovery (EOR)/ Enhanced Gas Recovery (EGR) and its potential to enhance global energy security.

The symposium gathered representatives of governments from producing and consuming countries, from industry, research centres, financial and international institutions. The audience debated practical measures to address barriers to CCS deployment and developed messages regarding the importance of CCS in creating a lower carbon future. The findings of this first symposium were presented to Ministers, government officials and CEOs at the 12th IEF meeting, held in Cancun, 29-31 March 2010.

At the 12th IEF, Ministers and industry leaders welcomed the joint IEF-Global CCS Institute initiative to organize a series of symposia on CCS and affirmed that CCS is one of the key technologies that can contribute to mitigating climate change and delivering a sustainable energy future. Ministers took note of the key conclusions of this first symposium and observed that the progress of CCS has been encouraging, but cost, knowledge sharing and the necessary regulatory infrastructure remain significant obstacles.

They also reinforced the call for the inclusion of CCS in the Clean Development Mechanism (CDM) and other future financial mechanisms, as well as the need to better communicate the importance of CCS to the public in order to build greater awareness and broader support for its implementation. The general consensus was that more commercial-scale demonstration projects and international partnerships are needed to help CCS become commercially viable.

The 2nd IEF-Global CCS Institute symposium on CCS, supported by the Government of Algeria, was held in 31 May-1 June 2010 in Algiers with a visit to the In Salah CCS Project. It promoted the exchange of technical and policy elements of CCS projects and investigated ways to accelerate CCS deployment particularly through enhanced cooperation and partnership.

Building on messages developed in Beijing, the audience reviewed recent progress shared views on the challenges of development, and addressed technological, economic and regulatory issues facing CCS that could help build global support at all levels of government and industry.

The symposium examined impediments to large-scale CCS, discussed the role of all stakeholders, industry, governments and financial institutions in facilitating CCS deployment and proposed concrete recommendations for actions by governments and industry in consuming as well as producing countries and messages that may feed into CCS and climate change fora.

The IEF-Global CCS series of symposia was recognized as a significant contribution to enhance international dialogue, cooperation and industry-government collaboration for the reduction of barriers and acceleration of industrial scale CCS. The key issues and questions addressed by participants include the progress of CCS to date; actions needed to move from pilot project to commercial scale projects; reduction of barriers to CCS deployment; structural challenges; EOR as an accelerant for CCS deployment; the role of and action required by various stakeholders including industry, governments and financial institutions; policies to support and accelerate CCS deployment; and avenues for further cooperation and dialogue between producing and consuming countries.

3. Introduction

Levels of energy needs and economic development are strongly related. A growing world population with aspirations for higher standards of living implies a surge in energy demand, which will rely heavily on hydrocarbon fuels for many years to come. At the same time efforts have to be directed towards achieving a low-carbon and more sustainable energy future.

While the recent global economic crisis has somehow influenced short-term political and economic decisions and impacted energy demand, the long-term energy picture is unlikely to be altered. Established trends including the significant share of fossil fuels in the global energy mix will prevail over the long-term. Global primary demand is set to grow in the future under any scenario, although at a slower rate than in recent decades. According to recently released projections the growth of global energy demand over the next two decades is estimated at around 40%.

Under most mainstream scenarios, fossil fuels are expected to remain the main source of energy in the primary energy mix over the next two decades. Oil remains the dominant fuel in the primary energy mix during the outlook period; but its share is expected to fall. Natural gas is expected to grow at a higher rate than that of the other fossils fuels, increasing its share in the overall energy mix.

The geographical structure of global energy demand is changing with non-OECD countries capturing the future additional demand, while the OECD region will see its demand level off or decline. The faster pace of growth in primary energy demand that has occurred in non-OECD countries over the last few years is set to continue. Non-OECD countries are expected to account for over 90% of the total increase in primary energy demand.

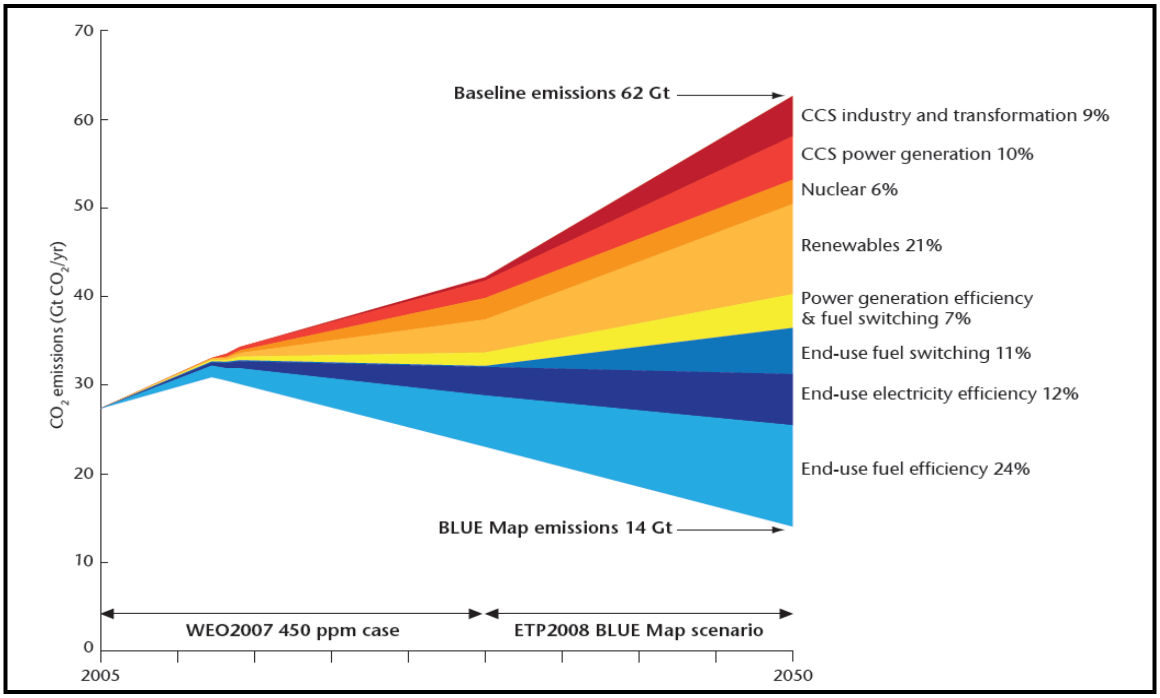
Total non-OECD energy consumption will increase by almost two-thirds over the next two decades. Within non-OECD area, global energy demand is shifting to developing countries with Asia and the Middle East (and to a lesser extent Africa and Latin America) playing an increasingly important role.

Given the projected increase in long-term demand and the prevalence of fossil fuels in the future energy mix, there is an urgent need to improve the environmental sustainability of fossil fuel production and consumption by moving toward low carbon emission technologies.

According to the IEA, worldwide, some 60% of greenhouse gas (GHG) emissions are linked to energy production, delivery and use. At current trends, global energy-related CO_2 emissions are expected to rise by 45% in 2030 and 97% of emissions growth is expected to come from non-OECD countries with China, India and the Middle East responsible for three-quarters of this increase. According to some estimates, the Middle East is on track to double its CO_2 emissions by 2030, which will make it the third largest growth area in CO_2 emissions globally.

Carbon capture and storage is expected to play a vital role in the reduction of greenhouse gas (GHG) emissions. Its development and deployment offer part of the solution that can contribute, along with other measures including energy efficiency programmes and renewable energy technologies to delivering a sustainable energy future. CCS is among the most promising GHG reduction technologies and has been singled out for its potential to achieve cuts in CO_2 emissions from fossil energy. The deployment of CCS in conjunction with enhanced oil recovery (EOR) in particular, is demonstrating significant potential to contribute towards global emissions reduction. CCS is expected to comprise 19% of the total mitigation options available, as demonstrated in the chart below.

Figure 1: Technology mix to combat global climate change



Source: IEA, WEO 2010

New, coordinated and cohesive policies must be implemented and concrete actions taken to change the path of this scenario and curb GHG emissions. However, any effective global climate-change strategy will require strong participation from the major oil and gas producing and consuming countries.

CCS technology is gaining momentum on a number of fronts and its role in delivering a sustainable energy future is acknowledged in international fora. The 11th and 12th IEF Ministerial meetings (Rome, April 2008 and Cancun, March 2010), the G8 Summits (Hokkaido, July 2008 and l'Aquila, July 2009) among other gatherings, recognized CCS technology as a solution that can contribute, to delivering a sustainable energy future and acknowledged "the need to act". There is also a rising interest and involvement noticeable in

CCS in producing countries in the Middle East. Saudi Arabia is an active member of the so-called "Four Kingdom's Initiative", Algeria has realized a full-scale demonstration CCS project in the In Salah gas field and the UAE is increasingly active in developing new initiatives (Masdar). CCS is also an important part of the EU-OPEC dialogue and OPEC has recently joined the IEA's implementing agreement on GHGs.

However, CCS technology has some way to go before it makes a significant impact on greenhouse gas emissions. The cost of implementation and the need to increase efficiencies in the capture, transportation and storage of CO_2, the need for a regulatory framework and public acceptance are among the main obstacles still to be overcome before CCS technology attains commercial viability.

4. Technology

The oil industry has been using CO_2 injection techniques in association with enhanced oil recovery (EOR) and enhanced gas recovery (EGR) for decades with a very good safety record. The industry possesses the technology and know-how to use gas to improve recovery rates of existing mature oil and gas fields. Its ability to deploy these techniques more widely has been constrained mainly by the availability of suitable and affordable supply of CO_2. Transportation of the captured CO_2 presents no real challenge to the oil industry. The oil and gas industry's knowledge and experience in EOR, EGR and gas transport and storage can be leveraged to accelerate CCS deployment.

The technologies required for CCS are generally well understood individually; however they have yet to be integrated and applied on a large scale in key sectors such as power generation and oil refining. Implementation of the three steps - CO_2 capture, transport and storage - requires capital investment and additional operating costs.

4.1 Capture

CO_2 capture can be applied to fossil fuel power plants, industrial processes and in the fuel production and transformation sectors. Capture technologies are based on those that have been applied in the chemical and refining industries for decades. Three main technology options currently exist for CO_2 capture: post-combustion, pre-combustion and oxyfueling. CO_2 capture requires energy, reduces overall energy efficiency and adds cost. The capture phase represents the largest cost as it requires capture-specific equipment and entails additional energy consumption. Approximately 60-80% of the cost of CCS is attributed to capture, 10-20% to transport and 10-20% to storage. Achieving reductions in CO_2 capture costs and their associated risks is critical for sustainable and large scale deployment of CCS.

4.1.1 Capture from oil and gas extraction

CO_2 capture from oil or gas fields uses the same technologies and methods. In both oil and gas fields, the liquids and gases that come from the well are separated on-site. This separation occurs in the Gas Oil Separation Plant (GOSP). In an oil treatment plant the crude oil is first sent to a gas-oil separation system where its pressure is reduced in stages to separate gas and liquids. In the gas plant the raw natural gas is dehydrated and processed through acid gas removal, molecular sieves, and chilling units to remove hydrogen sulfide, NGLs (Natural Gas Liquids) and LPG (Liquid Petroleum Gas). Once the CO_2 is separated out, it can then be flared, sent via pipeline, or re-injected for EOR/ EGR.

4.1.2 Capture from combustion

This combustion takes place in coal power plants, with capture occurring in the flue. Flue gas capture is currently the most widely used method for sequestering CO_2. The gas emitted from the combustion goes through an amine based solvent where the CO_2 is absorbed and separated from other gases. This CO_2 can go through a few other steps to be made into consumption grade CO_2 for the food industry, or for injection for storage in geological formations. Membranes may also be used to separate the CO_2 from other exhaust gases using pressure differentials, but due to the energy loss this currently is not as efficient as chemical absorption. Solid sorbents like sodium and potassium oxides, lithium, and carbonates are being used as well. Some new technologies like saltwater injection into flue gases to create calcium carbonate in a solid form are being developed by different companies involved in energy engineering. The reason flue gas capture is so widely used is that industrial flues are a choke point for concentrated CO_2 emission, and power plants, steel/cement factories, etc. produce vast amounts of CO_2, making flue gas capture the most efficient and cost effective way. This capture of CO_2 from combustion is accomplished in three ways:

1. Oxy-fuel combustion capture;
2. Pre-combustion capture; and
3. Post-combustion capture.

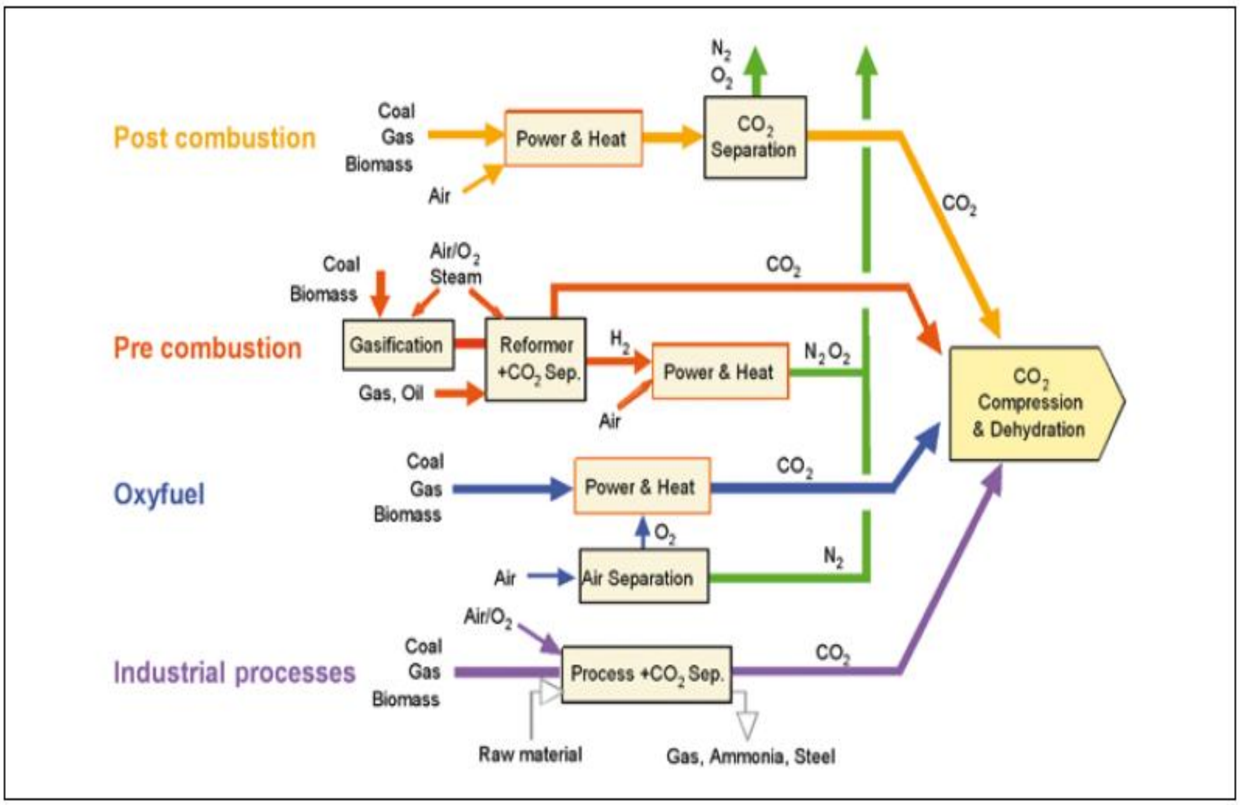
Box 1: IPCC's Report on combustion capture technology
Oxy-fuel combustion - In oxy-fuel combustion, nearly pure oxygen is used for combustion instead of air, resulting in a flue gas that is mainly CO_2 and H_2O. If fuel is burnt in pure oxygen, the flame temperature is excessively high, but CO_2 and/or H_2O-rich flue gas can be recycled to the combustor to moderate this. Oxygen is usually produced by low temperature (cryogenic) air separation and novel techniques to supply oxygen to the fuel, such as membranes and chemical looping cycles are being developed. The power plant systems of reference for oxy-fuel combustion capture systems are the same as those noted above for post-combustion capture systems. Pre-combustion - Pre-combustion capture involves reacting a fuel with oxygen or air and/or steam to give mainly a 'synthesis gas (syngas)' or 'fuel gas' composed of carbon monoxide and hydrogen. The carbon monoxide is reacted with steam in a catalytic reactor, called a shift converter, to give CO_2 and more hydrogen. CO_2 is then separated, usually by a physical or chemical absorption process, resulting in a hydrogen-rich fuel which can be used in many applications, such as boilers, furnaces, gas turbines, engines and fuel cells. These systems are considered to be strategically important but the power plant systems of reference today are of both oil and coal-based, integrated gasification combined cycles (IGCC).

Post-combustion - Capture of CO_2 from flue gases produced by combustion of fossil fuels and biomass in air is referred to as post-combustion capture. Instead of being discharged directly to the atmosphere, flue gas is passed through equipment which separates most of the CO_2. The CO_2 is fed to a storage reservoir and the remaining flue gas is discharged to the atmosphere. A chemical sorbent process would normally be used for CO_2 separation. Other techniques are also being considered but these are not at such an advanced stage of development.

4.1.3 Capture from industrial processes

Several industrial applications like steel and cement production, natural gas sweetening, and refining offer the opportunity to capture CO_2 in large quantities and at lower cost than the fossil fuel combustion methods described above. Capture from these industrial sources will not be the complete answer to the challenge of climate change since the volumes CO_2 are much higher in fossil fuel combustion, but it may well be the place where the first capture and storage occurs in large scale. Below is a chart showing the methods of CO_2 removal from combustion and industrial processes.

Figure 2: CO_2 capture methods



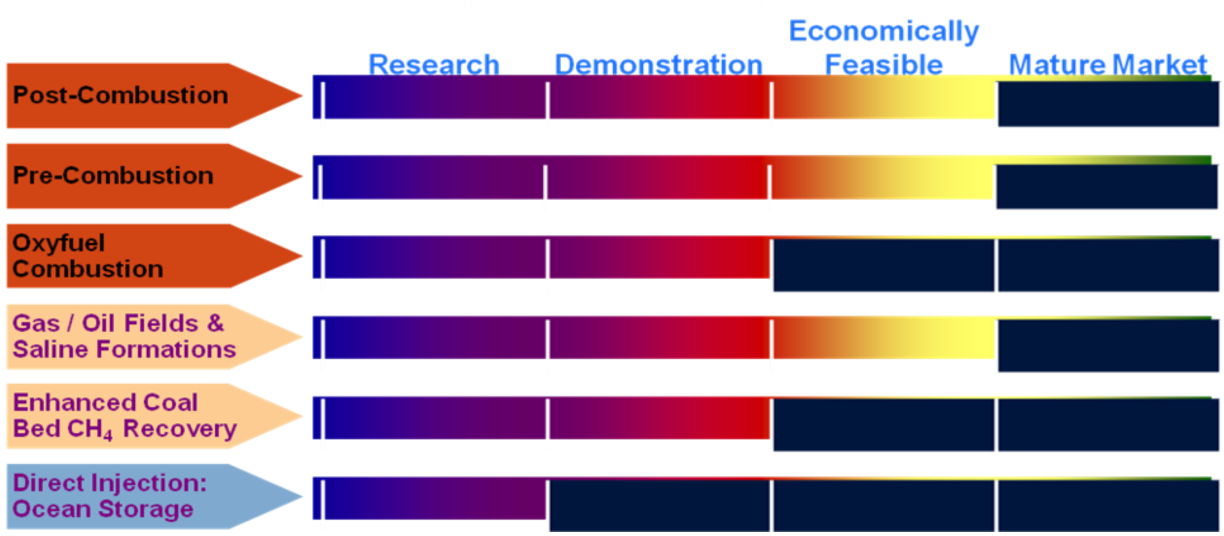
Source: IPCC special report on carbon dioxide capture and storage, 2005

One of the largest industrial processes producing CO_2 is the iron and steel industry which is the principal energy consuming industry, accounting for 10-15% of all industrial energy use according to the IEA. Steel mills produce large amounts of CO_2 as many plants use onsite coal power plants to heat the furnaces and provide electricity.

Cement production accounts for 6% of total global CO_2 emissions. Cement requires high amounts of energy in order to drive the extreme temperatures needed for the process, and its flue gases contain a higher percentage of CO_2 than gases from power production. While there is currently no CO_2 capture process for cement production, it offers a promising locus for CCS to take hold due to the high level of CO_2 concentrations.

Natural gas sweetening which involves removing CO_2 and other gases to prevent corrosion in the pipelines is another large contributor of CO_2 emissions. According to the IPCC, half of natural gas productions contain CO_2 concentrations averaging 4% by volume. Currently this CO_2 is either used in EOR/ EGR or vented into the atmosphere.
Another industrial CO_2 producer is ammonia production which takes place in oil refineries where there is steam reforming. Steam reforming takes place in most every refinery, so this is a major source of CO_2 emissions. Below the chart shows the different stages of CCS development from fossil fuel combustion and industrial processes.

Figure 3: Development stages of CCS



Source: Roosevelt IV, Theodore, presentation, Beijing, September 2009

4.2 Transport

There are few technical barriers to CO_2 transportation; pipelines have been in operation for around 30 years; the challenges lie with the high level of investment needed for new transportation infrastructure, the business model for commercial development and the management of a transport infrastructure. A transportation infrastructure that carries quantities of enough CO_2 to make a significant contribution to climate change mitigation will require a large network of pipelines and safety issues will undoubtedly become more complex. In the short term, a CO_2 pipeline operator faces high levels of financial risk due to the high cost of the asset and low returns. Transporting CO_2 by boat from one port to another or as far as an injection site is technically possible and could be an economically competitive solution under certain conditions.

Transport by pipeline is the most viable option due to the physical properties of CO_2 and the scale of CO_2 produced in order to make a CCS project economic. Since CO_2 is highly corrosive, the pipes used to transport it are different than that of natural gas which adds to the uncertainty of long term costs and reliability. Some of the concerns with transportation by pipeline are:

- Safety issues:
  - Slight toxicological effects at elevated concentrations
  - Risk analysis through consequence modelling is not validated with experiments

- Operational concerns:
  - Other gas compounds affect the CO_2 phase and water solubility
  - CO_2 solubility/material compatibility (polymers/elastomers in gaskets)
  - Corrosion rates (out of spec water contents - carbonic acid)

Other concerns with CO_2 transport by pipeline lay in the risk of leakage and how to detect this. Since many CCS projects will be undertaken in remote areas, pipelines will span large distances and run under water, which adds to the complexity of detecting leaks. One saving grace with CO_2 is that an undetected small leak would have low negative physical effects caused. A large leak would be immediately detected by a drop in pipeline pressure and this would be fixed quickly. As the technology of CO_2 pipelines evolve and the industry shares knowledge, the risks will be lowered and the safety and reliability increased.

Ships are considered a viable means of transport, but since many CCS projects are located inland, the CO_2 must still be shipped to the coast via pipeline. For long distance shipping, ocean transport is thought to be cost competitive where as short distance shipping would be uneconomic.

4.3 Storage

Storage in saline formation, in depleted oil and gas fields and in conjunction with the use of CO_2 for enhanced oil recovery is considered among the most viable storage options. Oil and gas reservoirs have been demonstrated as suitable for CO_2 storage to some extent and the experience of the oil and gas industry provides an important contribution to the CCS learning curve. CO_2 storage projects have already been operational for at least ten years in the Sleipner, Weyburn and In Salah projects. Identifying suitable storage sites and understanding the mechanisms at work in the subsurface, including how to verify the behaviour of injected CO_2, are some of the main areas of ongoing research in building and reinforcing the industry's capabilities in technologies associated with CCS. Storage of CO_2 presents a number of challenges. The main one is to identify suitable reservoirs, monitor the storage site to evaluate its integrity and to assess how the CO_2 is behaving. The issue of leakage is crucial in terms of public perception and acceptability of CCS. Of key importance is determining liability to cover potential leakage both during the active project and in the longer term. The Australian Government's recent agreement to accept long term liabilities arising from storage of the CO_2 and its approval of the Gorgon Project constitutes a milestone. Again, many of the technologies used by the oil and gas industry are playing a part. The petroleum industry has considerable experience in managing hydrocarbon extraction and there is now potential for a shift towards injection management.

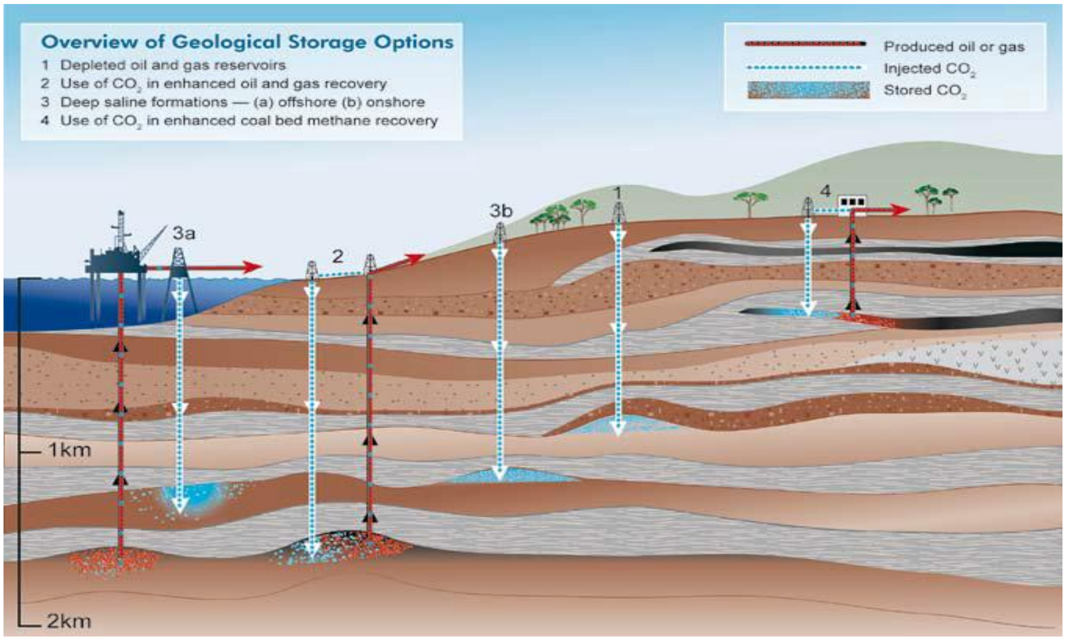
The most probable and economic storage option is that of geological storage in the earth, which can be accomplished in a number of different ways. Most promising are injection in saline water reservoirs such as in the Sleipner field (in Norway); use of hydrocarbon-bearing reservoirs such as the Krechba Carboniferous (in Algeria); or coal bed methane fields.

Saline water-bearing formations are non-potable aquifers that, for CO_2 storage, lie at least 800 meters underground. This strategy requires geological studies to confirm the quality of the seal to confine the gas, as well as the right porosity and permeability of the reservoir. The hydrocarbon-bearing reservoirs used for storage are either oil and gas fields that use enhanced oil recovery, or depleted oil and gas fields. In both cases, the presence of hydrocarbons indicates that the cap rock can contain gas and liquids for millions of years.

A newer and less-tested method of carbon storage is that of injecting CO_2 into coal beds where the coal absorbs and thus traps the gas, and can be used as a storage option or for Enhanced Coal Bed Methane recovery. In this approach, the CO_2 is injected into the coal seam, which displaces the methane gas that is locked in the coal and allows the capture of the methane as fuel. This process can unlock economic potential from un-minable coal seams or add value to a power plant located near coal beds using CCS.

Below is an illustration showing the various methods of geological storage.

Figure 4: CO_2 geological storage options



The monitoring of reservoir integrity after injection of CO_2 is an important issue facing CCS, and one that is gaining quite a bit of attention. The same technologies that are used to explore for new reservoirs such as seismic, wireline logging, etc. can be used to monitor storage reservoirs. The industry breaks monitoring down to three main areas: operational monitoring, verification monitoring, and assurance monitoring.

- Operational Monitoring includes:
  - Injection operation control: well pressure, temp, injection rate, etc.
  - Quantification of injected CO_2 : mass flow, gas stream composition

- Verification monitoring entails:
  - Well integrity: pressure, corrosion, cement, soil gas measurements
  - Cap rock/fault integrity: micro-seismicity, pressure interference
  - CO_2 displacement: well logs, PVT, geophysics, sampling

- Assurance monitoring:
  - Impact/HSE monitoring: water quality, soil acidity, atmosphere concentration, surface deformation
  - Detection of leaks/migration: chemical analysis, geophysics techniques, soil gas measurements, vegetation stress
  - Quantification of leaks: soil gas measurements, surface gas measurements.

CCS is not without its concerns and problems. Since it relies on geological sequestration, problems associated with CCS stem from fears that reservoirs will fail to contain CO_2 securely in the long run, and thus lead to disasters. Some of the main issues involved with geological storage are:

- Capacity of reservoirs
- Injectivity
- Impact to reservoir
- Cap rock integrity
- Leakage pathway and rate
- Monitoring
- Performance assessment
- Risk assessment

When looking at the sequestration of CO_2 and the ability of the reservoirs to hold the gas/liquid, some of the other issues are:

- Will the injected CO_2 react with the cap rock (shale), the fractures in the shale, and the cement grout for sealing off the existing wells?
- Does the reaction with CO_2 increase or decrease the permeability of shale? Does this reaction lead to opening or sealing of the fractures?
- How does the long-term presence of the CO_2 and brine mixture, and the reactions, modify the transport and mechanical properties of the cement grout?

These issues must be researched and tested in order to ensure the long term feasibility of CCS and to prove to the public that CCS is a safe technology.

4.4 Existing Projects

A vast number of initiatives and activities are underway to support widespread deployment of CCS technology including CCS research and development, construction of pilot and larger scale CCS demonstration and the development of directives and related regulations across a number of countries. Several large scale demonstration projects have been announced in Europe, North America and Australia along with cooperative programmes in non-OECD countries.

There is a triple challenge behind existing projects: a technical challenge, which consists of showing that CCS technology actually works and works well; an economic challenge which consists of carrying out these operations with acceptable costs; and finally the challenge of public acceptability.

The oil and gas industry with its knowledge in CO_2 - EOR/EGR has the ability to effectively demonstrate that, with the appropriate level of site assessment, monitoring and verification, the injected CO_2 could remain contained for long periods within the formation layers that have been targeted. The fundamental challenge in increasing the use of CO_2 - EOR is the need to ensure sufficient volumes of CO_2 at the right place and the right cost. Growing support for CCS is likely to boost the use of EOR and improve EOR techniques and rates of recovery.

At the time of the 2nd symposium there are four key large-scale CCS projects in operation each storing at least one million tons of CO_2 a year: Sleipner started in 1996, followed by Weyburn (2000), In Salah gas field (2004), and Snøhvit (2008). The Gorgon Project in Australia is now under development and aims to mitigate emissions of more than three million tons of CO_2 equivalent per year. These projects are operating or being executed under existing hydrocarbon production regulations.

4.4.1 Sleipner, Norway

Located in the North Sea in Norwegian waters, the Sleipner pilot is the benchmark in the field of the geological storage of CO_2 from a natural gas field into an upper saline aquifer, more than 800 meters below the sea floor. In 1996 in the North Sea, Statoil began producing from the gas/condensate field, Sleipner Vest. The natural gas at Sleipner contained around 9% CO_2 which was excessive for customer requirements. Statoil decided to remove the CO_2in the associated gas but the question was what to do with the CO_2. In 1991 the Norwegian authorities introduced a CO_2 offshore tax with the aim of reducing CO_2 emissions. The Norwegian CO_2 tax is currently around 50 USD/tonne. Motivated by this tax, Statoil proposed to sequester the CO_2 and inject it into a deep geological layer below the Sleipner platform. The Sleipner CCS plant was the first full-scale commercial CCS plant in the world and is still the largest single emission reduction measure in Norway. After 10 years of storage, seismic monitoring shows no signs of leakage from the subsea reservoir. The Sleipner project has contributed to the understanding of mapping, CO_2 migration and ascertaining whether it remains confined within the storage structure beneath the principal cap rock. It is providing a clearer picture of the reservoir's sealing efficiency - a major component in the development of models predicting CO_2 migration in a heterogeneous geological environment.

4.4.2 Weyburn-Midale, Saskatchewan, Canada

The Weyburn-Midale CO_2 Project is the first full-scale CO_2 measuring, monitoring and verification (MMV) initiative in association with EOR/EGR. Launched in 2000, this project studies CO_2 injection and storage underground in partially depleted oil fields. Around three million tonnes per year of CO_2 is produced at a North Dakota, USA gasification plant and transported by a 320 km pipeline north to the Weyburn and Midale oil fields in Saskatchewan, Canada. The project involves government, industry and academia nationally and internationally to collaboratively fund research and share results.

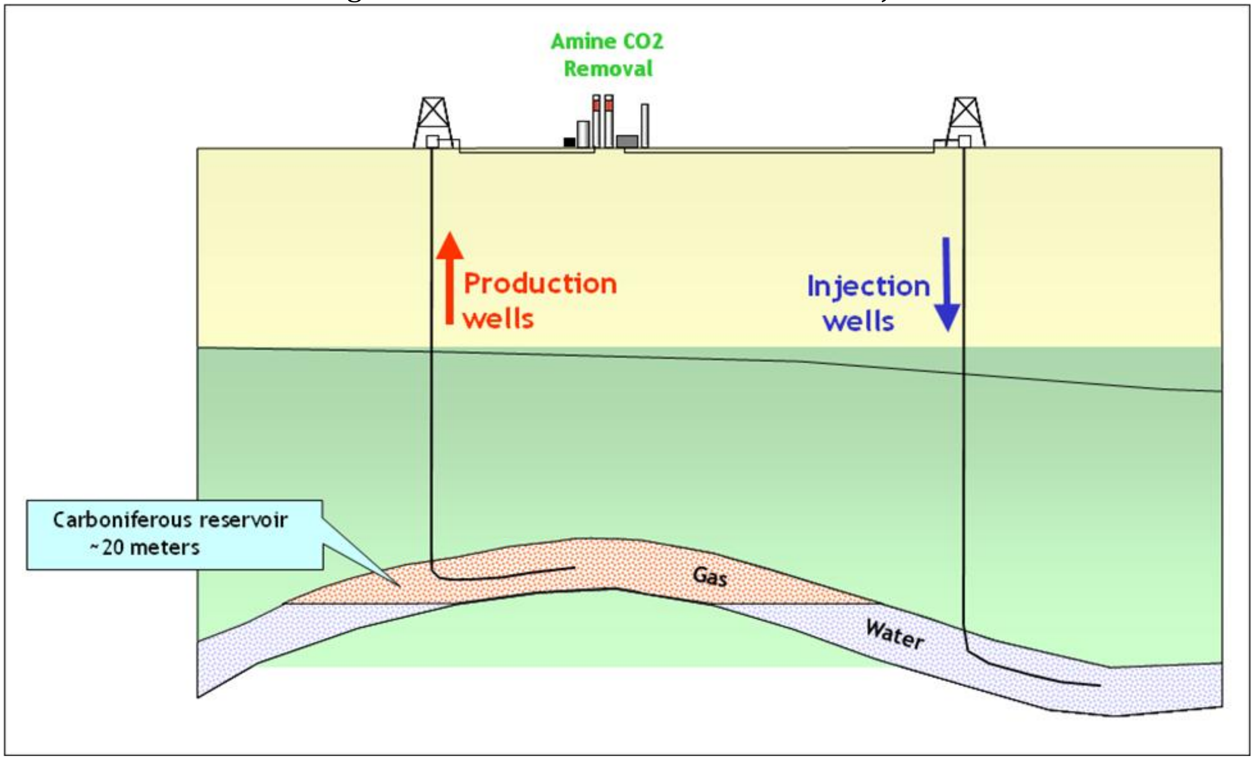
4.4.3 In Salah, Algeria

CO_2 capture and injection began at the In Salah gas field, Algeria, where one million tons of CO_2 is reinjected each year into a deep geological formation below the Sahara desert avoiding its release in the atmosphere. Since the In Salah gas fields have high CO_2 concentrations, the CO_2 produced is reinjected at the periphery of the gas field, into the saline aquifer at a depth of 1,800 meters, which helps maintain the gas field reservoir pressure while confining the CO_2 underground. This pilot represents a remarkable underground laboratory where numerous tools have been deployed to observe and at least anticipate reservoir behaviour during and after injection.

The In Salah project is one of the largest EGR projects in the oil industry in relation to CCS, and one of the first industrial-scale storage of CO_2 in a gas reservoir project. The project was started in 2001 and the first gas was produced in 2004. This project dubbed the Joint Industry Project (JIP) involves Sonatrach, BP, and Statoil as well as several research and development groups in Europe and the USA. The JIP has an active program in the field ranging from 4D seismic to potable water monitoring wells. Reservoir modelling and simulation is carried out to study the movement of the injected CO_2. The intention is to ensure that the carbon dioxide remains within the reservoir and to detect any possible breaches. The In Salah site was selected as it is a carboniferous reservoir with high storage capacity. The reservoir has high integrity and tightness, sufficient storage capacity, good porosity, and moderate pressure. The exploration and evaluation wells were already in place from an earlier project and seismic data was already available. This made the site and the data highly attractive for the CCS project.

At the Krechba Central Processing Facility, the CO_2 content of the gas from the In Salah field is reduced from between 5% and 10% to 0.3 %. The captured CO_2 is then compressed to 175 bars and injected into the waterleg of the Krechba Carboniferous reservoir through three horizontal injection wells as shown in the illustration below. At the same time, the reservoir is drained by five producers located above the gas-water contact.

Figure 5: Krechba reservoir, In Salah Project



Source: Sonatrach, In Salah Gas Project

4.4.4 Snøhvit, Norway

Snøhvit was the first LNG production plant in Europe and is the world's northern most offshore gas field. Due to the cold and ferocious nature of the North Sea, special considerations had to be taken into account when designing this project. The field is located in the Barents Sea, the gas is extracted then transported to land where CO_2 is separated from natural gas at the LNG plant onshore and transported through a 145 km pipeline back to the Snøhvit field where it is injected into the geological layer of porous sandstone containing salt water, 2,500 meters below the sea floor. At full capacity 0.7 million tons of CO_2 per year are stored. The gas production facilities are located underwater and the lines are heated to prevent freezing. A monitoring programme to investigate the behaviour of CO_2 underground is partly financed by the European Union.

4.4.5 Gorgon Project, Australia

The world's largest carbon injection project, Gorgon started construction in Western Australia in 1981 as part of the Gorgon LNG venture. Approximately 3.4 million tons a year of CO_2 will be eventually injected underground at Gorgon. In August 2010 the Australian Government took the decision to assume long term liability for CO_2 storage. The Gorgon Joint Venture is liable during the operation phase, expected to start in 2014 and last up to 60 years and for at least 15 years after the project closes down. Any liability for future damages to third parties will be shared 80 % by the Federal Government and 20% by the Government of Western Australia.

4.4.6 Other CCS Projects

A few of the other CCS projects (non-exhaustive) currently being undertaken world-wide are:

- Jilin Oil Field, Songyuan, China - In 2007, a major science and technology research project titled 'CO_2 EOR and Storage Underground' and a key pilot test named 'CO_2 EOR and Storage Pilot Test in Jilin Oil Field' were established by PetroChina. PetroChina will soon start a new CO_2 EOR and Storage Underground pilot test in the Daqing and Changqing Oil field.

- Rangely CO_2 Project, Colorado, USA - The Rangely CO_2 Project has been using CO_2 for enhanced oil recovery since 1986. Since then, approximately 23-25 million tonnes of CO_2 have been injected into the reservoir. Computer modelling suggests that nearly all has dissolved into the formation water as aqueous CO_2 and bicarbonate.

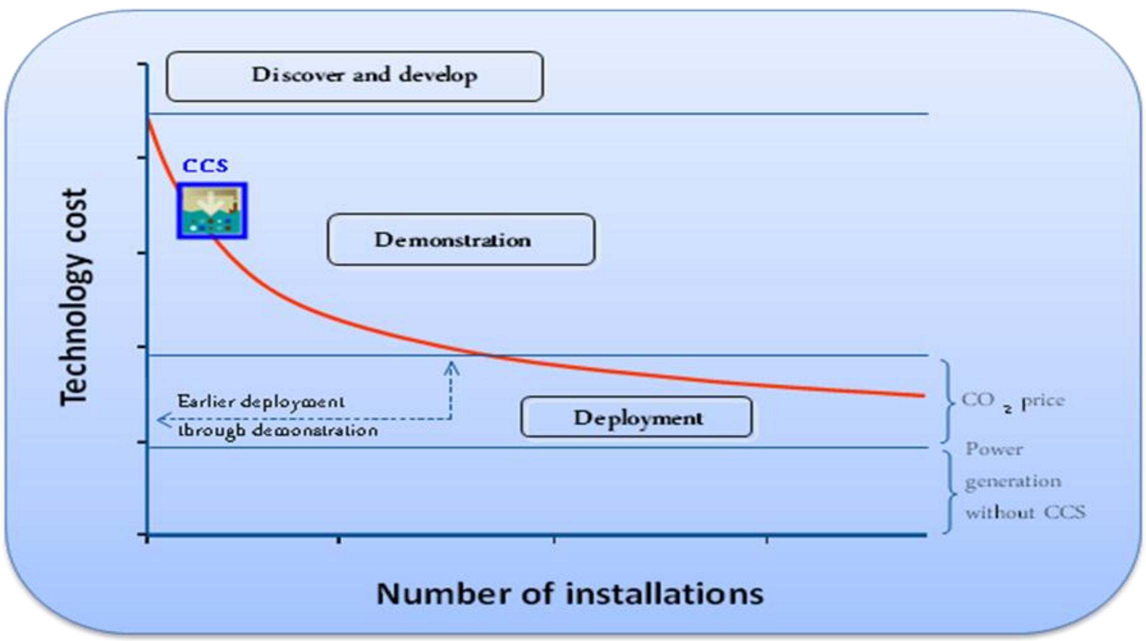
- Masdar CCS Project, Abu Dhabi - This CO_2-EOR project started in 2006 is led by Masdar, with Abu Dhabi National Oil Company. Plans for this project include the capture of CO_2 and its transportation to the Abu Dhabi oil fields through a new network of pipelines. The transported CO_2 will then be injected into the oil fields for EOR purposes. This planned use of CO_2 would also free up vast amounts of natural gas which is currently being used for EOR operations in the area. The Masdar CCS Project will be completed in phases. Phase I involves the capture of 5 million tons of CO_2 per year, from three different sources, with completion of this phase expected by 2013.

5. Investment and costs

Current cost levels are a key challenge facing CCS development and a serious barrier to its commercial deployment. There is a high degree of uncertainty in estimating the costs of CCS due to differences in methodologies applied to existing projects and also uncertainty regarding the evolution of costs over time.

First movers in CCS are at a severe disadvantage due to the high costs. According to existing estimates, CCS technologies could increase electricity production costs by 60-100 percent at existing power plants and 25-50 percent at new coal-fired power plants. Power companies will have to internalize the increased costs and match the energy prices of companies not using CCS. As more projects are built, and assuming there is knowledge sharing, the costs of new CCS projects will be decreased as shown on the illustration below. This illustration shows a fundamental economic theory that as time increases (to the right on the graph), the costs will come down along the curve.

Figure 6: Technology cost curve



When calculating the costs for the many components of CCS there is no clear cut formula due to multiple variables including location, taxes, regulatory requirements, fuel prices, etc. In addition, the data for figuring costs is highly speculative and complicated. Existing calculations estimate the current costs of CCS in the range of 78-117 USD/ton and this is forecasted to go down to 45-65 USD/ton by 2020. The most reliable information on costs to date has been produced by the IPCC, McKinsey, and IEA, among others.

5.1 Capture and compression

The most expensive component of CCS is the capture and compression of CO_2. This can amount to as much as 60-80% of the total CCS cost. The IPCC has developed one of the most comprehensive and accurate forecasts on capture and compression. The condensed version below reflects their forecasts for various power plants.

Figure 7: Capture and compression costs

Capture and Compression Cost			
	NGCC Plant	PC Plant	IGCC Plant
Capital cost without capture (US$/kW)	515-724	1161-1486	1169-1565
Capital cost with capture (US$/kW)	909-1261	1894-2578	1414-2270
Percent increase in COE with capture (%)	37-69	42-66	20-55
Cost of CO2 captured (US$/tCO2)	33-57	23-35	11-32
Cost of CO2 avoided (US$/tCO2)	37-74	29-51	13-37

Source: IPCC Special Report on carbon dioxide capture and storage, 2005

5.2 Transport

There is little information on the cost of CO_2 transport so it is hard to get a full picture of the pricing. According to the IPCC, to transport 6 Mt CO_2 per year a distance of 250 km by ship would cost an estimated 5 US$/t CO_2; and transport of the same 6 Mt CO_2 a distance of 1250 km would cost about 15 US$/t CO_2. Economies of scale are shown here in that marginal costs go down as distance increases. To transport by pipeline 6 Mt CO_2 per year a distance of 250 km it would cost 2-3.5 US$/ton CO_2 onshore and 3.4-4.2 US$/ton CO_2 for offshore. Transporting CO_2 1250 km by pipeline would cost about 15 US$/ton CO_2 which is about the same as transport by ship. So shipping CO_2 via tankers can be cost effective if the distance is long enough, and assuming the capture plant is on the coast. To contrast these numbers, McKinsey gives a slightly different estimate and shows it would cost 5.2 US$/ton CO_2 to ship CO_2 200km via pipeline onshore and 7.8 US$/ton CO_2 for 300km offshore.

5.3 Storage

Underground storage costs for saline aquifers or mature oil and gas fields is estimated at 0.5–8 US$/ton CO_2 according to the IPCC. The cost of monitoring is estimated at 0.1-0.3 US$/ton CO_2. The wide range in the cost shows the difficulty in estimating the expenditure due to the large number of variables. McKinsey estimates storage (including monitoring) costs at 5.2 US$/ton CO_2 for onshore depleted oil and gas fields and 6.5 US$/ton CO_2 for onshore saline aquifers. When looking at offshore storage costs, McKinsey calculates 14.3-15.6 US$/ton CO_2. This only reflects the cost for geological storage without EOR/EGR. Adding EOR/EGR to the equation, storage goes from costing to actually paying in the range of 10-16 US$ per ton of CO_2 for onshore operations. Ocean storage is quite the unknown in both economic terms and feasibly. The IPCC estimated a cost of 6-31 US$/ton CO_2 but this is only speculation on the cost of injecting CO_2 into the ocean since there are a multitude of factors regarding monitoring, leakage that could drastically effect the price.

The table below demonstrates the cost of CCS projects in Japan as estimated by both the IPCC and the Research Institute of Innovative Technology for the Earth (RITE). The analysis utilizes a Pulverized Coal power plant with CCS capture and injection into an aquifer. This chart reflects the difficulty in assigning a generalized price for CCS.

Figure 8: CCS costs in Japan vs. World

Case	Japan (US$/t-$CO_2$※)	IPCC SRCCS (US$/t-$CO_2$)		
	New PC plant -Aquifer storage	New PC plant -Aquifer storage	New NGCC plant -Aquifer storage	New PC plant -EOR
Capture & Compression	38	29-51	37-74	29-51
Transportation	7 1Mt-CO_2/y-20km	1-8 5-40Mt-CO_2t/y-250km		
Storage	21 0.1Mt/well/yr. ERD	0.5-8		△10-16
Total	66 1Mt-CO_2/y 20km-ERD	30-70	40-90	9-44

Source: Kusuda, Tsuneo, presentation, Beijing, September 2009

With continued investment in technology, costs will decline over time. McKinsey estimates the full abatement costs of CO_2 to be \$80-120 USD/ton CO_2. However, this is expected to lower to \$40-60 USD/ton CO_2 by 2030, which is in line with future CO_2 costs in the carbon markets. This lower cost would make CCS more self sustaining and profitable in the future. Additionally, the CO_2 recovered can add value if used in enhanced oil recovery or to obtain certified emission reductions from the Clean Development Mechanism. This would bring in additional revenue and make projects all the more profitable.

Some of the factors that influence the decline in cost over time include economies of scale, common transport, shared infrastructure, and reduced energy loss. In CCS this means that costs for specialized equipment, technology, and labour for a project will decrease in price as more units are built, more volumes of CO_2 are captured.

This applies to both transport and storage infrastructure, for if CCS is widely deployed to control CO_2 emissions, significant infrastructure investments will be required, particularly for geologic sequestration. Stationary source CO_2 emitters like coal-fired power plants may have to invest in a host of non-core assets, including carbon separation systems, CO_2 pipelines, drilling rigs, injection systems, and monitoring networks.

Reduced energy loss refers to the energy needed to power the CCS operation itself. This energy requirement adds hefty operational expenditure cost to the already large capital expenditure cost. For power plants this creates an additional problem as it will increase their cost per kilowatt hour.

Again, as more CCS projects are developed, the energy need will drop as the projects become more energy efficient. Thus, one of the common themes at the IEF-Global CCS Institute symposiums was the need for more test projects to be built. This economic constraint to widespread CCS development makes public funding essential if CCS is eventually to become a commercially viable venture.

5.4 Financial and fiscal incentives

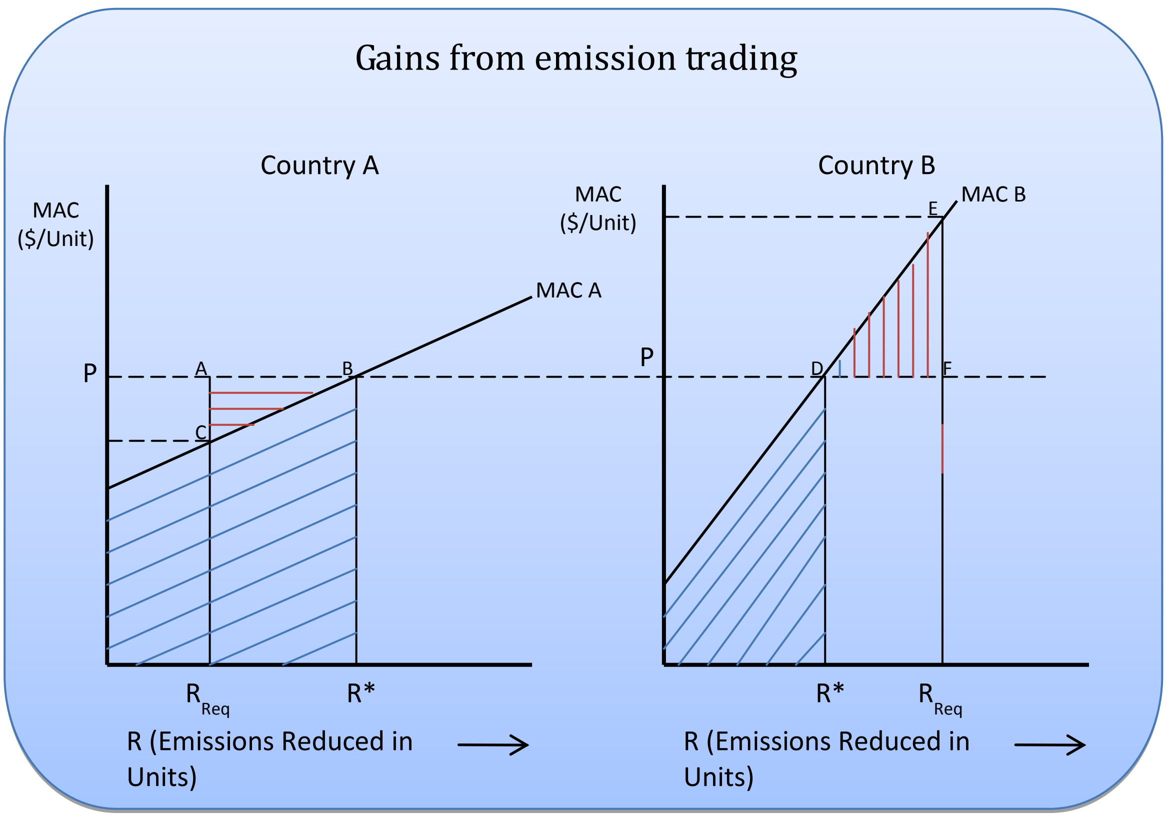
In order to jumpstart CCS and make it financially viable for companies, there need to be financial and fiscal incentives to motivate companies to invest the necessary capital. CCS technology will need significant government support and fiscal incentives if it is to be deployed at commercial scale. There are several means we can mention to do so:

- Develop cap-and-trade emissions programmes that recognise stored CO_2 as non-emitted (EU Emission Trading System). This can most effectively set a wholesale price of carbon;
- Taxing emissions so that it is cheaper to store the CO_2 than emit (this worked in the Sleipner project);
- Offer direct government subsidies or funds to cover the CCS installation costs.

5.5 Global carbon market

One important need to compliment the CDM is a global CO_2 market. While there are a few emission trading schemes in the world, the EU's Emission Trading Scheme (ETS) is the largest by a vast margin. This scheme allows each country in the EU to have a different allocation of carbon emissions allowance. Carbon allowances can be bought and sold on the ETS and provide an incentive for companies to reduce their CO_2 output. This system with financial incentives has proven to work in reducing carbon output, but is only in place for the European Union. A global carbon market is needed; such a market would provide an incentive for all nations to lower their CO_2 /GHG output. The figure below shows the economic gains that could be realized from an emission trading scheme between two countries.

Figure 9: Potential economic gains of a two-country emissions trading scheme



In the gains from emission trading example, the MAC (Marginal Abatement Cost) is the additional cost to not produce a unit of CO_2. Since country A has a flatter MAC curve we can assume it costs less for them to reduce their CO_2 output than country B. R_{Req} represents the required units of emissions a country needs to reduce. Since it is cheaper for country A to reduce its emission output, it would do so until it reaches R_{Req}. Since this point is under P or the market price of carbon, this creates an incentive for country A to further reduce its carbon output to R* and sell the balance of its emissions allowance for a profit. Since country B's R_{Req} is above the market price, it costs more for country B to abate and would be cheaper to buy carbon credits from country A at price P. This puts their R* to the left because they will not reduce emissions enough to meet R_{Req} but will buy the difference between R* and R_{Req}. This will allow country A to make a profit of ∆ABC, and country B to incur a savings of ∆DEF through purchase of these carbon credits from country A.

5.6 Taxing CO_2

Applying a monetary cost to CO_2 output would incentivize private industry to curb carbon emissions. Application of the correct level of carbon tax would make CCS a cost saving measure since it would be more expensive to vent CO_2 than capture and store it. This type of emissions tax was used in the United States starting in the 1990s to reduce acid rain caused by sulphur dioxide (SO_2) emissions. The tax made it more expensive for power plants to emit SO_2 than to install costly scrubbers to capture the gas. Since 1990, SO_2 emissions have been cut by 43% in the United States due to this tax. This shows that a tax on CO_2 could work but the cost per ton of carbon would have to be carefully calculated in order to make CCS a cheaper alternative but not be financially destructive for smaller industries. This could be accomplished by making the carbon tax applicable to only gross CO_2 emitters over a certain threshold of CO_2 produced per year.

5.7 Government subsidies

In order to create incentives for companies to invest the necessary capital to develop and improve existing CCS technology, government subsidies will be needed even with the existence of a carbon tax. The Dutch government recently announced a €150 million subsidy for a CCS project to store CO_2 in the North Sea. The United Kingdom, United States, China, Australia, etc. are all putting forth subsidies for CCS projects but more still needs to be done.

6. Funding

According to the Global CCS Institute, as of April 2010, 238 projects involving CO_2 capture, transport and/or storage are either active or planned worldwide. Of these, 80 are large-scale, integrated projects where the entire CO_2 capture-transport-storage chain is demonstrated, nine are operational, two are under construction, and 69 are in planning stages. Out of these 80 projects, 44 are in the power sector and 25 in Europe. Over $26 billion in funding has been proposed by governments globally for large-scale projects. While this amounts to a large investment of public money in CCS it is nowhere near the amount required to meet the plans put forth in the IEA CCS Roadmap or statements by the G-20 on CCS.

According to the IEA, total CCS related investment in power generation alone will amount to USD 556 billion over the period 2010-2030. Technological improvements should help reduce costs but investment in CCS will only occur if there are suitable incentives and regulatory mandates. Commercial CCS deployment, particularly in developing economies, is contingent upon cost reduction.

Funding for near-term demonstration projects is required in order to continue to prove CCS at the commercial scale and to reduce costs. Considering the scale of investment needed, Governments will be required to address the funding gap and to help facilitate private sector investments via public-private partnerships in CCS demonstration.

In the current regulatory and fiscal environment, the benefits of reducing emissions are not yet sufficient to outweigh the costs of deploying CCS. Therefore funding is a key issue for CCS.

6.1 Announced funding

Nearly all the major economies have announced initiatives to promote CCS and associated funding for large scale CCS demonstration projects.

The G8 has called for completion of 20 large-scale CCS demonstration projects by 2020 and stimulus money in both the EU and the US has been targeted for large scale CCS demonstration projects.

- In the US the Economic Recovery and Reinvestment Act includes USD 3.4 billion in funding for clean coal and CCS technology development. USD 1.0 billion has been allocated for developing and testing new ways to produce energy from coal, USD 0.8 billion will augment funds for the Clean Coal Power Initiative with a focus on carbon capture, and USD 1.52 billion will fund industrial CO_2 capture projects, including a small allocation for the beneficial re-use of CO_2. In December 2009 the federal government announced almost USD 1 billion of funding to fast-track the development of three new projects involving advanced coal technologies with commercial scale CCS. In addition to this amount, there will be USD 2.2 billion of private funds as part of the third round of the Energy

Department's Clean Coal Power Initiative. Adding to this momentum, the US announced an inter-agency taskforce that will develop a strategy to overcome the barriers to the deployment of CCS targeting a start up of 5-10 commercial demonstration projects by 2016.

- In addition to initiatives developed by member countries, the EU financial stimulus package includes Euros 1.05 billion for the support of seven CCS demonstration projects. The EU has also set aside the revenue from 300 million allowances within their Emissions Trading Scheme for the support of early CCS demonstration projects. Norway has announced the allocation of NOK 1.2 billion for CCS projects and UK has announced funding for up to four CCS projects. The first of these projects will be selected from projects via the CCS competition. The winner will have the additional costs of CCS covered by a government capital grant. The UK has recently announced that the remaining projects will be funded through a levy on electricity suppliers.

- The Australian government has announced AUD 2 billion funding for large scale demonstration projects in Australia; in addition to launching the Global CCS institute to foster international cooperation, with a funding of AUD 100 million a year for three years. Four projects have been selected to move to the next stage of assessment in the government's AUD 2 billion CCS Programme.

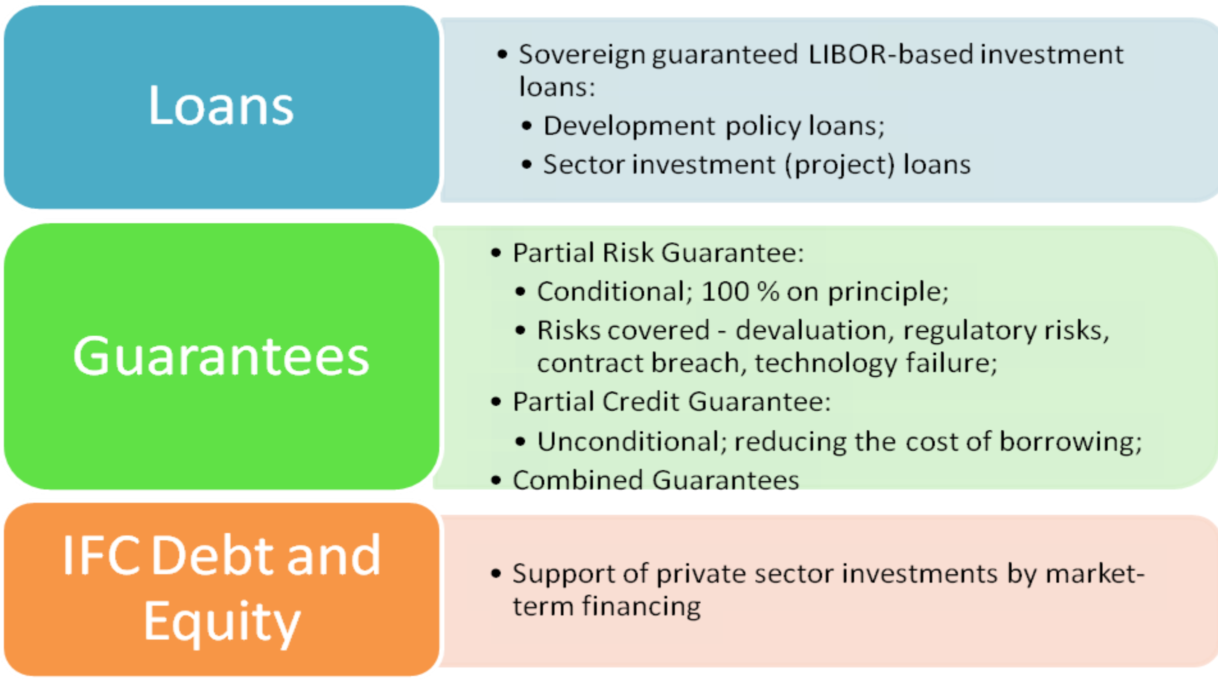
- Canada announced the allocation of CAD 2.5 billion for large scale CCS demonstration projects. The Canadian federal government has announced financial support of CAD 1.3 billion for R&D mapping and demonstration project support, while the Province of Alberta has committed CAD 2 billion in funding to support CCS deployment.

- The Japanese government has budgeted JPY 10.8 billion for study on large scale CCS demonstration since fiscal year 2008.

This non-exhaustive list of initiatives and funding announcements shows the increasing interest in CCS technology and will contribute to facilitate its development. However, substantial additional funding is required if we are to achieve commercial-scale CCS deployment.

In December, 2010 at the United Nations Climate Change Conference Cancun, it was announced the CCS would be included under the Clean Development Mechanism. The CDM will provide a conduit for which uneconomic CCS projects may now be economically viable in developing countries. Short-term mechanisms are currently needed to build a bridge to the future global CO_2 market that CCS will bring. The following illustration delineates the different funding options available for energy sector programs.

Figure 10: Conventional financial instruments for energy sector programs



Source: Kulichenko, Natalia, presentation, Algiers, June 2010

6.2 World Bank CCS Trust Fund

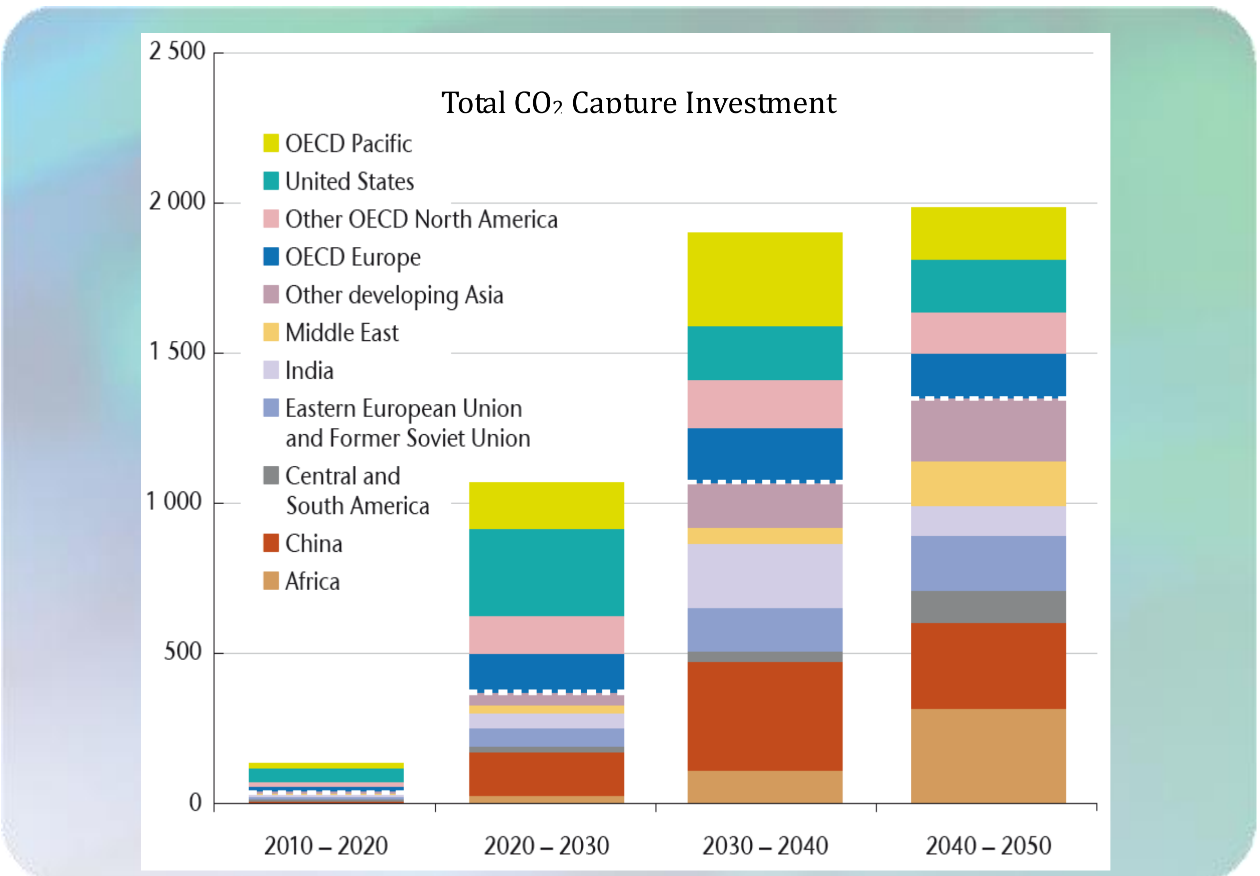
The World Bank Group is currently putting together a fund to help drive and promote CCS, with the monetary assistance of Norway ($6 Million USD) and the Global CCS Institute ($2 Million USD). This fund is still in development and other donors might be added. The fund is designed to provide capacity building and knowledge sharing assistance regarding CCS as well as carbon asset creation services. The work program consists of two components: a country level component with 10 projects, and an economic and sector work component. According to the Pew Centre on Global Climate Change, a CCS Trust Fund (in the United States) will:

- Raise funds at the scale needed to support a significant number—e.g., 10 to 30—of commercial-scale CCS projects;
- Ensure that the funds raised will be used to demonstrate CCS at commercial scale for a full range of systems applicable to U.S. power plants;
- Establish the true costs, reliability, and operability of power plants with CCS;
- Utilize private-sector business standards for project selection and management to ensure program cost effectiveness; and

- Significantly reduce CCS costs within 10 to 15 years by supporting approximately 30 demonstrations, yielding substantial national economic benefits as CCS becomes widely deployed.

The following graph illustrates where CCS investments will be most needed between 2010 and 2050. For example, China's potential for emission will increase dramatically between 2020 and 2040, with some reduction following 2040. Africa will increase its CO_2 emissions significantly over the next 10 years, and then expand dramatically.

Figure 11: CCS Anticipated investments based on expected CO_2 emissions



Source: IEA

6.3 CCS inclusion in the Clean Development Mechanism and Kyoto Protocol

The IEF, IEA, Global CCS Institute and other important organizations have advocated extensively for the inclusion of CCS into the CDM, and inclusion under the Kyoto Protocol has long been sought as a way to develop CCS. Likewise, CCS within the CDM has been pushed as a means to promote clean energy and development in developing countries. Many oil companies have advocated for inclusion of CCS into the CDM to improve the profitability of projects. The In Salah project and other CCS projects submitted CDM methodologies to the CDM Executive Board (CDMEB) for approval. In January 2010 the CDM Board refused to consider new methodology proposals for CCS citing, "no guidance or framework available to accept and evaluate CCS methodologies". The progress of including CCS within the CDM was blocked at the Conference of Parties (COP)/ Meeting of the Parties (MOP) level of the United Nations Framework Convention on Climate Change.

However, the situation changed in December, 2010 at the United Nations Climate Change Conference in Cancun, Mexico (COP 16) when it was announced that CCS projects will now be included under the Clean Development Mechanism according to the Kyoto Protocol. This will allow an entity in a developed country (Annex 1) to undertake a CCS project in a developing country (non-annex 1), and if that project creates additionality[1] then the entity would receive carbon credits which can be sold on the carbon market (e.g. European Union's Emission Trading Scheme) in the Annex 1 country. According to the statement released at the COP 16 in Cancun regarding CCS's inclusion into the CDM:

"[The COP] decides that carbon dioxide capture and storage in geological formations is eligible as project activities under the clean development mechanism, provided that the issues identified in decision 2/CMP.5, paragraph 29, are addressed and resolved in a satisfactory manner."

This decision at the COP 16 does not mean that CCS projects will see any benefit by the CDM anytime soon since there remains much bureaucratic red tape before the process can get underway. At the COP 16 it was announced that the UN's Subsidiary Body for Scientific and Technological Advice (SBSTTA) will design procedures and models to work out the methodologies and framework in regards to the CCS addition to the CDM. This will delay the timeframe until the first CCS projects get approval from the EB.

The issues with CCS inclusion into the CDM are mostly regulatory barriers on which the CDM Executive Board needs to reach consensus before allowing CCS proposals to be approved. The following matrix outlines some of the key issues confronting the CCS to be eligible to CDM.

[1] A CDM project activity is additional if anthropogenic emissions of greenhouse gases by sources are reduced below those that would have occurred in the absence of the registered CDM project activity (3/CMP.1, Annex, paragraph 43)

Box 2: Key issues and regulatory barriers for CCS inclusion in CDM		
Issue category	**Understanding of issue**	**Comment on the issue**
Non-permanence, including long-term permanence	The technology does not avoid emissions but rather stores them hence there is a risk that the stored GHG goes back into the atmosphere	The concept a a carbon sink is accepted under the CDM via, for example, forestry type projects
Measuring, reporting and verification	The CO_2 stored via CCS is modelled not measured. This is especially a concern when it comes to leakage over long periods of time	Most CDM projects depend on modelling to determine the volume of CERs generated
Environmental impacts	The lack of experience with CCS would pose challenges for conducting a CCS Environment Impact Assessment (EIA) especially relating to the risk of seepage	Most CDM projects depend on a host nation's assessment of the environmental impact of the project via a EIA process. As CDM projects are by definition not common practice in the host country the risk of a poor EIA is not very different for a CCS project then for any other CDM project
International law	International Maritime treaties were drafted without having CCS activities in mind	Many CDM projects that are currently in place operate under legislation that was not designed with CDM or the underlying project in mind. In most cases project specific solutions where designed and in some cases the regulations where adapted
Liability	Who will be liable for leakage and migration of CO_2 from a geological formations taking into account the long timeframe of the storage	This concern exists for all projects that apply the principle of a carbon sink (e.g. forestry projects that are hit by a forest fire). It is reasonable to assume that CO_2 storage in a empty gas field that held LNG for 2 million year carries a lower risk of leakage than a forest. Hence the question of liabilities is less of an issue for CCS projects than existing CDM projects
The potential for perverse outcomes	The carbon market could be flooded by CCS CERs making the CER price drop and thereby excluding some important CDM project types such as renewable energy	As indicated earlier the cost per t CO_2 stored via CCS are not substantially lower so the effect of flooding the market and dropping the price does not exists as CCS won't be feasible under the CDM at a low CER price. An increase in the volume of CERs generated should be addressed by tightening caps not defining a technology an issues because it contributes to mush to mitigating climate change.

Safety	The carbon market could be flooded by CCS CERs making the CER price drop and thereby excluding some important CDM project types such as renewable energy	As indicated earlier the cost per t CO_2 stored via CCS are not substantially lower so the effect of flooding the market and dropping the price does not exists as CCS won't be feasible under the CDM at a low CER price. An increase in the volume of CERs generated should be addressed by tightening caps not defining a technology an issues because it contributes to mush to mitigating climate change.
Insurance coverage and compensation for damages caused due to seepage or leakage	Idem as issue 1. The technology does not avoid emissions but rather stores them hence there is a risk that the stored GHG goes back into the atmosphere and who will be picking up the tab when there is leakage	The concept as a carbon sink is accepted under the CDM via, for example, forestry type projects
Project activity boundaries	The CCS reservoir could be cross boundary and migrate over time making it difficult to set the project boundary for a CCS project	There are several CDM methodologies in use today that apply cross boundary consideration when defining the project boundary (e.g. ACM0002 for renewable energy to the grid) so this would be nothing new. The migration of GHG beyond the project boundary is also possible in the case of the widely used CDM project type, Landfill gas to Energy and is not considered as a problem in these projects even though the GHG is stored mush closer to the service than would be that case with CCS

Source: Carbon Capture Journal

6.4 Funding gap

In 2008, the IEA and Carbon Sequestration Leadership Forum (CSLF) delivered 25 recommendations to the Group of Eight (G8) to accelerate commercial deployment of CCS technology. The core recommendation, strongly supported by G8 leaders, was that "20 large-scale projects need to be launched globally by 2010, with a view to supporting technology development and cost reduction for the beginning of broad deployment of CCS by 2020". The EU agreed to fund up to 12 large-scale CCS demonstration projects valued at €4-5 billion. The EU also launched an EU Energy Program for Recovery (EEPR) in which €1 billion was set aside for CCS demonstration projects. While current EU funding from the EEPR and NER 300 fund provide a good foundation for closing the funding gap for CCS demonstration projects, together they will only cover up to 50% of the incremental costs of CCS. In Canada the funding gap is estimated to be \$50/ton CO_2, even with EOR/EGR.

While industry will contribute significantly to closing the remaining gap, additional government support is essential and must be in place by the end of 2011 at the latest in order to reach the 2020 goal of the G8.

7. Regulatory Framework

One of the key issues raised during the IEF-GCCSI Symposiums was the need for a comprehensive legal and regulatory framework for CCS. Regulatory frameworks are being designed with the objective of managing risks associated with CCS. The task is to ensure that CO_2 is stored safely in sites where the environmental impacts have been assessed and where provisions for management and abandonment of the site ensure that stored CO_2 is retained in the long term. Regulatory issues, particularly those related to liability of storage will need to be resolved. Regulators need assurance that CCS activities will not result in any adverse effects (through good site selection, operation and closure). Regulations need to be developed to remove barriers in existing legislation and build on existing laws that apply to similar activities, such as the oil and gas industry. Regulatory frameworks at national and international levels are also needed to clarify long term rights, liabilities and institutional structures. Clear, co-ordinated and cohesive policy direction is needed to give investors a signal that this is an area offering sustainable commercial returns.

Regulatory framework would establish the laws and regulations for CCS to ensure that private industry controls the risks to the public welfare while it assures the industry where the government's position lies regarding this matter. Governments clearly outlining the laws and regulations on CCS will remove some of the risk that has kept private industry at bay. Existing legal and regulatory frameworks should be reviewed and adapted for CCS demonstration, and all countries with CCS potential should have a legal and regulatory framework suitable for large-scale CCS deployment by 2020. Developing countries will need to be assisted by OECD countries with experience in CCS technology.

Some of the major issues that regulation needs to address include the physical properties of site selection, storage methods, monitoring of reservoirs, measuring storage and verification of storage. By setting forth a solid framework regarding the physical properties of CCS it will create a more uniform approach to developing CCS projects and establish an industry standard for how sites will be monitored and verified. This will remove some of the risk from private industry by delineating a clear idea of how the sites will be regulated so that the industry can align CCS projects with these standards.

Leakage is one of the chief concerns of the industry from a liability aspect. While reservoirs can hold hydrocarbons for millions of years, the process of removing the hydrocarbons can damage the cap rock and make the reservoir unsuitable for long term storage. A slow leak would not be noticed for quite some time if the cap rock was not damaged significantly. Even if the cap rock is undamaged, other risks of leakage such as CO_2 migration, earthquakes that damage the cap rock, CO_2 turning aquifers acidic, can potentially create serious liability.

A regulatory framework setting forth standards for the closure of CCS projects in order to transfer the risk of liability to governments over the long run is a necessity. A standardized framework instructing how CCS projects will be closed and monitored will allow the industry to adhere to the standard. This framework will require a clear definition of liabilities and distribution among project stakeholders in order to make clear the risks as well as allow companies to adhere to the frameworks.

The IEA Greenhouse Research and Development Program list a few of the regional and international framework developments that are currently underway. These include the following:

- International framework:
  - 2006 IPCC Guidelines for GHG Inventories: methodology for CCS (site characterisation + modelling, + monitoring = zero leakage)
  - Marine Conventions: London Protocol (2006), OSPAR (2007)

- Regional/national regulation:
  - EU Storage Directive, ETS Directive (2008)
  - Australia: Offshore and Onshore GHG Storage Acts (2008-9)
  - US EPA Draft Rule (2008)
  - Japan, Canada

The IEA Greenhouse R and D Program lists the lessons learned so far in regulatory matters, including the following:

- Regulatory principles for CCS to ensure environmental integrity:
  - Site-by-site assessment
  - Risk assessment
  - Site characterisation and simulation, supported by monitoring
  - CO_2 stream impurities determined by impacts on integrity

- Development of regulations:
  - Use the technical and scientific evidence base
  - Learn from existing regulatory developments
  - Benefit of having real projects to drive and test regulations

There have been strong efforts recently at national levels to implement regulations on CCS within several countries where CCS is gaining traction. Some of these regulations are:

- The United States Environmental Protection Agency is using the Clean Air Act to set regulation that will affect CCS by regulating GHG from stationary power sources.

- The EU has demanded member nations to include a CCS Directive in their national systems by June 2011. Recently the European Commission issued guidance documents to detail plans on the CCS Directive so that the implementation is consistent across all EU countries.
- In Canada the government set forth the Capture and Storage Amendment Act in December 2010. This established a national regulatory framework on CCS which will help with the development of CCS in a systematic manner.

- Australia has recently put in place CCS regulations for some of its offshore territory and set up the permitting process for onshore gas storage.

There are quite a few barriers preventing the establishment of widespread implementation of CCS.

Box 3: Barriers and the possible resolution that regulatory frameworks can provide

BARRIER ISSUE	POSSIBLE FRAMEWORK RESOLUTION
Pore Space Access. CCS projects must have access to geologic pore space for CO_2 storage. In some jurisdictions pore space is privately owned or ownership is unclear. In other jurisdictions, pore space is owned by national, provincial, or state government.	• Clarify private ownership rights. • Provide mechanisms to secure access to privately-owned pore space subject to equitable compensation to the owners. • Establish procedures for licensing pore space owned by national, provincial, or state government. • Harmonize the right to store CO_2 with other rights to exploit the subsurface such as oil and gas extraction.
Storage Site Access. CCS Projects must have access to storage sites, which in many cases are not co-located with the emission source. Sites may be privately owned or owned by the national, provincial, or state governments. Storage sites may also be located beneath the sea-floor in national, state, or provincial waters.	• Provide mechanisms to secure access to privately-owned storage sites subject to equitable compensation to owners. • Make government-owned storage sites (onshore and offshore) available to CCS projects.
Pipeline Access. CCS projects must have access to pipelines and pipeline routes to transport CO_2 from source to storage facility. Some jurisdictions have existing rules for CO_2 pipelines or other pipeline rules that may be used or modified.	• Provide mechanisms to obtain pipeline right-of-ways or third party access to pipelines as applicable. • Develop common CCS pipeline networks. • Establish, adopt, or modify CO_2 pipeline transport rules as necessary.

Geologic Storage. Some jurisdictions have no rules for geological storage facilities. Others have analogs in CO_2EOR and natural gas storage.
 	
Potential remediation and third party liability costs during the injection and post-injection monitoring phases are not well understood.
	• Issue permits for demonstration projects under existing or interim rules where possible, using appropriate measures to ensure operator financial and technical capability, site suitability, safety, and permanence.
	• Establish rules for permanent storage that address:
	    ○ Site selection
	    ○ Suitability of storage formations.
	    ○ Environmental requirements.
	    ○ Purity of stream requirements.
	    ○ Ownership of injected CO_2.
	    ○ MVA requirements.
	    ○ Storage operator financial responsibility/financial security.
	    ○ Site closure, certification, and abandonment.
	    ○ Harmonization with hazardous waste rules.
	• Use knowledge from demonstration projects to inform and adjust final rules.

Long-term Liability/Stewardship. CO_2 must be stored indefinitely. However, indefinite responsibility and liability for storage facility operators is neither practical (because companies do not last indefinitely) nor conducive to CCS deployment.	• Assumption of liability and long-term stewardship by government bodies, trusts, or other entity with perpetual existence after completion of post-injection monitoring period.

Financial Support - Demonstration Projects. The lack of clear rules, first-of-a-kind technology risk and cost penalty, and insufficient carbon price are disincentives for investment in demonstration projects. Many demonstration projects under development may fail for lack of adequate financing and access to capital.	• Incentivize demonstration projects through:
	    ○ Grants.
	    ○ Tax incentives.
	    ○ Credit support.
	    ○ Liability relief.

Financial Support Deployment Phase. CCS deployment may require financial incentives, particularly in the early stages.	• Incentivize deployment through:
	    ○ Tax incentives.
	    ○ Bonus allowances in trading schemes.
	    ○ Feed-in tariffs.
	    ○ CCS inclusion in portfolio standards.

Public Acceptance. Public acceptance is essential to CCS deployment because of concerns about CCS effectiveness and risk associated with transport and underground storage of large quantities of material.	• Transparent processes for approving CCS storage facilities that include public involvement. • Knowledge dissemination. • Public outreach.

The bottom line for establishing a legal and regulatory framework for CCS is that the sooner frameworks are in place, the sooner large-scale CCS projects can be planned and developed. Without regulatory framework, there will be no standardized way of developing or monitoring CCS. In particular, the perceived risks of liability will inhibit CCS development. Many companies will be hesitant to invest heavily in a technology without governments cementing their legal parameters within regulatory frameworks.

8. Public Perception

One of the largest issues confronting CCS is the negative public perception of this technology. During the two IEF-Global CCS Institute Symposiums the need to increase public awareness was one of the key issues debated by participants. Gaining general acceptance of CCS technologies will be necessary to demonstrating that CCS is a safe and environmentally acceptable option. Currently there are public concerns about the environmental integrity of CCS, about whether the CO_2 stored will remain isolated in the long-term and whether the capture, transport and storage elements present health and ecosystem risks. Public awareness of CCS is low which has lead to low acceptance rates and levels of public support for CCS technology to date. Existing plants, particularly those using EOR, provide good starting points for communicating the feasibility and value of CCS. CCS stakeholders must address public concerns and perceptions and educate and communicate on large scale CCS deployment.

A major factor limiting better understanding is the lack of information presented to the public by firms working and developing CCS. With proper education on the benefits, methodology and safeguards, the public will recognize CCS as an essential technology to confronting global climate change. The public's perception of CCS is founded mainly on information provided in the news or from environmental organizations. Many such organizations have taken a stance against CCS and negatively influenced public perceptions with claims that it is untested and unsafe.

Reports of the Tyndall Centre in the United Kingdom on public perception indicate that with adequate information about the climate change context the public may look favourably on CCS. A study conducted in the United States suggests that the U.S. public may be more sceptical and less accepting than the U.K. public. The conclusions of this U.S. study urge careful consideration in considering the ways in which the public becomes informed about the technology and suggests that the way in which the public debate gets framed will be critical in determining the public's perception. Environmental advocacy groups play a critical role in shaping public debate about how best to address environmental problems, so how these groups portray CCS will influence public perception.

The view on CCS is changing over the past year or two. There has been some increase in public awareness of CCS, as shown by a survey of the general US public conducted every three years by the MIT Carbon Sequestration Initiative. To the question "have you heard or read about CCS in the last year", only 4 % said yes in 2003, 5 % in 2006 and it was up to 17 % in 2009, which reflects a growing interest in CCS by governments and industry as well as its increased coverage by the press. The challenge will be to build on this and convert awareness to acceptance.

As climate change concerns continue to increase, more and more environmental organizations are seeing the benefit of CCS. These groups have realized there is no silver bullet to solve global climate change and that CCS is needed in addition to other carbon reduction mechanisms. A more positive stance on CCS by these organizations will help sway the public opinion.

A report from Australia showing changes over time in public perceptions of the benefits of CCS was recently released. One of the most striking parts of this report was a study showing how public perception of CCS changed with sufficient information. The following illustration reflects numerically how people changed their minds after being better educated on CCS. The question poised in this study was how strongly do you agree or disagree with CCS? What is shown is that in the majority of cases the perception shifted towards the positive.

Figure 12: Public perception of CCS

	Feb, 2008		**Mar, 2008**		**Jun, 2008**		**Nov, 2008**		**Feb, 2009**	
	Youth 29		**Brisbane 60**		**Melbourne 47**		**Perth 62**		**Adelaide 131**	
	Before %	After %	Before %	After %	Before %	After %	Before %	After %	Before %	After %
Strongly disagree	6.9	3.6	8.6	10.2	2.1	2.1	1.6	4.8	1.5	0
Moderately disagree	13.8	10.7	5.2	1.7	2.1	4.3	4.8	4.8	3.1	2.3
Disagree	0	14.3	6.9	5.1	14.9	4.3	1.6	6.5	5.3	3.8
Unsure	48.3	25	48.3	32.2	59.6	14.9	54.8	21	47.3	9.9
Agree	13.8	35.7	8.6	27.1	6.4	40.4	22.6	37.1	10.7	22.1
Moderately agree	13.8	7.1	17.2	13.6	8.5	19.1	9.7	17.7	13	38.2
Strongly agree	3.4	3.6	5.2	10.2	6.4	12.8	4.8	6.5	17.6	23.7
Missing responses	0	0	0	0	0	2.1	0	1.6	1.5	0
Total	100	100	100	100.1	100	100	99.9	100	100	100

Source: Ashworth, Peta, presentation, Beijing, September 2009

In order to achieve a major shift of perception among the public, the target audience needs to be defined. The Commonwealth Scientific and Industrial Research Organization (CSIRO) defines four groups on which to focus the dissemination of CCS information:

- Influential stakeholders (politicians, media, finance, NGO's, insurance, CEO's)
- Community
- Education (schools, museums, libraries)
- Project specific (local regions)

Reaching out effectively to various groups can be difficult. The IEF-Global CCS Institute symposiums suggest a few key points to help develop public support for CCS:

- For storage, success in public support is key. Learn to design a monitoring system onshore and to gain public acceptance on CO_2 storage;
- Hold early discussions with elected representatives to organize the public consultation process;
- Have local specific issues raised early during the public consultation process.

Another strategy for public outreach is for CCS-involved companies to develop a public relations campaign using a variety of media resources to educate a given population on CCS. Oil and gas companies have long been aware of the power of media and how to effectively use this to garner public support. They have learned that well-done dissemination of information can effectively shift public perception. Press packets for media outlets, being open with news organizations on new CCS projects, and tours of CCS sites for local leaders and news is a way to increase public support. Meetings in local communities allow for question and answer sessions and more personal interaction and relationship-building for support and understanding of CCS benefits. Sound and well-supported public education efforts will net increasingly positive results for CCS.

A critical public support tool that the industry must utilize is the involvement of local communities in the decision-making process. Local communities need information, and must be engaged in dialogue, feel ownership of positive outcomes of CCS, be polled and their agreement acquired before the start of a CCS project. Without this public acceptance, CCS will not have the necessary approval from the local populations most immediately affected.

The local level and larger public perception of CCS will be crucial in the coming years since without the support of those who vote and/or speak out, political and governmental support will be hard to achieve. Government support is vital to help subsidize these early and very expensive CCS projects in order to develop the technology and bring down costs to the point where more private industry steps in with investment. Without the support of the public, CCS will be made that much harder to bring to scale at an industrial level.

The industry has to prove that CCS is a safe technology over the long run. What is needed is further research on developing and demonstrating, monitoring of sequestered CO_2 identifying potential hazards, protecting groundwater quality, and developing safety and management expertise. With these measures taken, the public will be more aware of the risk and rewards of CCS.

9. Knowledge Sharing

Lowering the cost of CCS mandates the energy industry to share knowledge of the technologies and methods used. This issue was one of the key points raised during the two IEF-Global CCS Institute Symposiums and is a topic broached in many reports and research documents.

Knowledge sharing is one of the major ways to lower the cost and increase the reliability of CCS as it will enable collaboration among many firms, each with comparative advantage. Public funding will oblige companies involved in CCS technology to share information in the public spectrum. This allows the cost and performance data to be shared while the intellectual property can be preserved, protecting the technology involved from reverse engineering. Some of the lessons learned that could be shared include those in technology, regulation, business models, financing, plant operations, best practice, and plant management.

Developing countries will need the most help with knowledge sharing in relation to CCS due to the structural issues of smaller local companies and less influence and contact with international companies. One way to assist will be the establishment of an organization with the mission to create networks that connect different industries in developing economies with one another and with international companies.

When looking at how to facilitate this knowledge sharing there are some well-defined methods:

- Joint Industry Projects: JIPs are carried out in collaboration with industry, national authorities, international institutions, and public enterprises assigned with responsibility for managing CCS.
- Publication in Scientific Journals: To increase knowledge sharing for CCS it is important that technology updates and breakthroughs as well as data obtained be published in various scientific journals. The Carbon Capture Journal is an example of a medium for the dissemination of CCS technology and ideas.
- Workshops: In order to bring together energy industry professionals who specialize in CCS, there is a growing need for conferences, symposiums, and workshops. These meetings of the minds allow for the presentation and debate of new ideas as well as extensive networking to create partnerships.

10. Other Issues in CCS technology

10.1 Enhanced Oil Recovery/ Enhanced Gas Recovery

EOR/EGR has the greatest potential for CO_2 sequestration in the oil industry due to the proximity of the injection sites, large volume of CO_2 produced, and the economic benefits EOR/EGR brings by increasing the recoverable crude and gas reserves. More than 70 EOR projects around the world are now underway. Most of the CO_2 used in these operations is recycled, but some projects are adapted to permanently store the CO_2. EOR/EGR is a tried and tested technology and there is vast information about the lessons learned on injection, storage, and monitoring. EOR/EGR historically was used when the pressure from a mature oil/gas field began to decline, thus lowering the amount of crude oil/gas recovered.

EOR/EGR has been an ongoing process in the oil and gas industry for many years. One of the largest EGR projects in the world is In Salah which is currently a bellwether project for CCS taking place in Algeria. In Norway, Statoil has been re-injecting CO_2 co-produced from natural gas successfully for many years. Many oil producing countries are following and Saudi Arabia plans to have an EOR demonstration plant by 2013.

This represents one of the biggest opportunities for CCS as the knowledge from EOR/EGR is applicable to CCS as well. The experience with EOR/EGR shortens the learning curve for CCS and allows for faster approval of the regulatory issues around geological storage. EOR/EGR is not without its issues, however.

Box 4: Major positive and negative effects of EOR/EGR	
CO_2 injection in oil fields	
Pros of injection	Cons of injection
Incremental oil recovery	Large volumes of water and CO_2 produced
Known seal/enclosure/trap to oil	Significant additional CO_2 generated to power recycling
Existing injection facilities	Facilities and well upgrades required
Well characterized (knowledge of reservoir architecture and dynamic performance)	Limited window of opportunity prior to cessation of production
Modest pressure change during lifetime	Abandoned wells may compromise trap
CO_2 injection in gas fields	
Pros of injection	Cons of injection
Known physical trap and seal to hydrocarbon gas (at least originally)	Significant pressure drop may compromise trap
Well characterised (knowledge of reservoir architecture and dynamic performance)	Abandoned wells may compromise trap
Known capacity (volume previously occupied by produced gas)	CO_2 expansion required at base of well (CO_2 delivered in dense phase but initially stored in gas phase)
Known injectivity (inferred from productivity)	Aquifer influx may limit capacity/injection rate
Existing infrastructure	Facilities and well upgrades required

Source: Munier, Gilles, presentation, Algiers, June 2010

10.2 Cooperation

Since cooperation between entities is paramount to improving knowledge transfer, lowering costs, and obtaining financing, it is important to look at the major groups involved and how they interact.

10.2.1 Multilateral cooperation

Many inter-government partnerships are being established in order to facilitate greater knowledge and financial burden sharing. Most government to government cooperation is through groups or associations rather than individual governments working together. Some of the groups through which governments collaborate on CCS:

- G8
- IEA
- Asia Pacific Economic Cooperation (APEC)
- Carbon Sequestration Leadership Forum (CSLF)
- Four Kingdoms Initiative: teamwork of the Netherlands, Norway, Saudi Arabia, and the UK as a collaborative between governments and industry to create an arena for cooperation between stakeholders from all four countries.

10.2.2 Academia

Many inter-universities partnerships have been created to foster a sharing of knowledge and communications. An example is Columbia University-China Young Scientist and Engineering Leadership Program. Another example is the Institute of Clean Energy (ICE) of Peking University and its collaboration with the University of California, Berkeley.

10.2.3 Public-Private Partnership (PPP)

The most common form of cooperation is that between government, companies, and academia in a public-private partnership. The following are some of the most prominent examples of PPPs:

- The Public Institute for Research and Expertise in Earth Sciences (EPIC) is a French public-private partnership. Its mission is to:
  - Understand geological phenomena, develop methodologies and new techniques, and produce and distribute relevant and quality data; and
  - Distribute necessary advice and tools to local and central governmental administrations in order to enable better management of natural resources, natural hazards, pollution of soil and water, and regional development.
- The EU-China COACH program is a public-private partnership funded by the EU government, and comprised of academia, (IFP in Paris and KTH in Stockholm) and private companies (Shell, Statoil, BP, Schlumberger and Alstom). Its objectives are to enhance knowledge sharing and capacity building and address cost cutting issues.
- The Climate Group is an independent, not-for-profit organization working internationally with government and business leaders. Its objective is to accelerate the construction of five CCS demonstration plants at scale in China,

India, US, Europe, and Australia by 2014. Members include BP, HSBC, AIG, JPMorgan, News Corp, State of California, and City of London, to name a few.

- The U.S.-China Clean Energy Research Centre (CERC) is funded by a bilateral $150 million USD in public-private funding. The focus of the centre is energy efficiency, clean coal including CCS and clean vehicles.

- The Global CCS Institute was set up by the Australian government as a not-for-profit entity and now operates privately with support from 287 governmental and private donors. The objectives of the Institute are:

- Sharing Knowledge
  - Collecting information to create a central repository for CCS knowledge.
  - Analyzing and disseminating information to fill knowledge gaps and build capacity.

- Fact-Based Advocacy
  - Using empirical data to inform and influence domestic and international low carbon policies.
  - Supporting the commercialization of CCS by advancing the understanding of appropriate funding and financing solutions and risk regimes.
  - Increasing the awareness of the benefits of CCS and the role it plays within a portfolio of low carbon technologies.

- Assisting Projects
  - Bridging knowledge gaps between demonstration efforts.
  - Developing project specific solutions particularly amongst early movers.

Since the founding of the Institute, it has become the largest partnership and greatest authority on CCS. One of the major achievements of the Global CCS Institute is the Status of CCS Report – the only comprehensive annual overview of global CCS projects. The Global CCS Institute is also the lead agency carrying out work for the Action Group on CCS through the Major Economies Forum (MEF) Clean Energy Ministerial. The Institute drafted a CCS Roadmap in consultation with the UK and Australian governments, and produced an Industrial Roadmap for CCS.

- EU/UK/China nZEC Project

- ENhanced CAPture of CO_2 Project (ENCAP)

- CO_2 Capture and STORage Project (CASTOR)

- Carbon Dioxide Capture and Hydrogen Production from Gaseous Fuels Project (CACHET)

- CO_2 SINK/ CO_2 STORE/ CO_2 NET Projects

- European Technology Platform on Zero Emission Fossil Fuel Power Plants (ETP ZEP)

11. Findings and Recommendations

For CCS to become an economically viable and safe sequestration option, key actions and many steps must be taken. All CCS issues are interrelated and affect one another as they develop; they must all come together to facilitate CCS development and accelerate its commercial deployment. The following provides a summary of those key lessons to date and recommendations presented during the IEF-GCCSI symposiums.

11.1 Cost Reduction

11.1.1 Key findings

- At the present moment, the cost of CCS is the largest obstacle facing the industry. Gaining experience to enable greater efficiency requires enhanced cooperation and knowledge sharing among firms, academia and government. A cyclical snowball effect of learning and cost reduction occurs with better knowledge, which leads to more efficient CCS projects, which in turn generate greater knowledge, understanding and lowering of costs. This increase in projects creates economies of scale to further reduce capital and operating costs of CCS projects. Public funding of projects is essential to develop pilot projects since the perceived risks are too high for private investment to bear the full burden. Without broad government support, CCS is not a global carbon mitigation option.

- The decision to include CCS in the Clean Development Mechanism under the Kyoto Protocol now facilitates further reduction in costs by allowing sequestered carbon to be sold as credits on carbon trading markets. Global cap and trade mechanisms make the difference in whether a project and the industry can be economically viable. Yet the EU Trading Scheme is too regional and not large enough to handle the level of carbon credits that will be available in 30 years. In order to increase revenues from carbon sequestration sufficiently to bring CCS to scale, a global carbon trading scheme must be enacted.

- The Copenhagen Accord provided for a new "Copenhagen Green Climate Fund" to support immediate action on climate change (including mitigation and adaptation). Considering the role that CCS plays in reducing CO_2 emissions in a least-cost scenario, the recognized positive and appropriate contributions of CCS projects in the suite of technologies position CCS to qualify for these funds. Government support helps ensure that CCS projects are able to access funds under this scheme.

- Technological improvements should help reduce costs but investment in CCS occurs only when there are suitable incentives and regulatory mandates. Commercial CCS deployment, particularly in developing economies, is contingent upon significant cost reduction. Considering the scale of investment needed, government support is essential to address the funding gap and facilitate private sector investments through strong financial incentives, including an effective and stable price on CO_2. A key factor to reduce costs is to establish an effective price for carbon, which requires strong leadership by governments. CCS technology used in conjunction with EOR/EGR is a win-win option as it reduces GHG emissions while increasing recoverable reserves in mature oil fields, thus contributing to global energy security.

11.1.2 Key recommendations:

The key recommendations for cost reduction can be summarized as follows:

- Knowledge sharing to increase efficiency and reduce costs.
- Governments enacting an effective and stable price on CO_2.
- Public funding to support pilot projects and lower private borrowing costs.
- Enactment of a global carbon trading market.
- Economies of scale based on initial public funding, extensive knowledge-sharing and resulting reductions in costs for new methods and facilities.

11.2 Knowledge sharing

11.2.1 Key findings:

- Collaboration globally in sharing information and generating knowledge is crucial to facilitate reduction in the learning curve and creation of synergies for innovation and cost reduction.
- Increased knowledge sharing on CCS project experiences, including measurement, monitoring and verification (MMV), is vital to reducing costs and accelerating CCS deployment but to date little information has been shared between firms.
- The Global CCS Institute, IEF, and other key organizations play a pivotal role in knowledge sharing and generation. Through these global thought leaders, industry leaders are encouraged to take a collaborative approach for the benefit of accelerating CCS deployment more broadly. Project proponents are encouraged to develop in-depth case studies that could be of benefit to other projects.
- For example, In Salah, and CO_2 Project partners Sonatrach, Statoil, and BP are commended for their efforts in this area to date. Some of the major oil companies have more than 10 years experience with carbon sequestration for enhanced oil recovery, have learned much and developed technologies that increase efficiency.

- Knowledge sharing and Joint Industry Projects are crucial to avoid duplication of efforts, and to enable the entry of new firms that can contribute to the field of knowledge without the high costs of being a first mover in CCS. Collaborative JIPs will bring firms with new and different expertise in CCS together to lower cost and share knowledge.

- Communication tools facilitate information dissemination and greater knowledge generation. Specialized CCS publications are an effective means for information sharing throughout the industry.

- Face to face discussions among CCS stakeholders are unparalleled for building synergies in the industry. Workshops, conferences, and symposiums facilitate presentation of developments in technology and other CCS related topics. They allow for instant feedback and discussion on the information presented. Of great importance, they facilitate professional networking and relationship-building that creates a global communication network of interrelated thought leaders and doers. CCS is not a zero sum game but the opposite: the more players that are involved, the more everyone benefits. Knowledge sharing is a win-win scenario for all participants involved as well as for the global environment.

- International cooperation, government-industry collaboration, and cohesive policy direction are prerequisites to the acceleration of CCS deployment on a commercial scale. In addition to demonstrating technology performance, it contributes to better use of funding, knowledge-sharing, local capacity-building, and shortening the CCS learning curve. Governments can provide the long-term policy and regulatory framework that enables commercial-scale deployment while industry can provide know-how, technological innovation, and a share of the capital needed to develop large scale projects. Public-private partnerships that involve cost and risk-sharing for CCS demonstration are a must.

11.2.2 Recommendations:

- Promotion of Public-Private Partnerships that bring together the thought leaders from government, academia and the private sector.

- Development of Joint Industry Projects that not only share costs/risks but also facilitate the dissemination of information among all firms involved.

- Scientific publications with a specific focus on CCS will disseminate knowledge on technological advancements as well as the data to support these developments.

- Publishing of case studies on previous CCS projects.

- Workshops, conferences, and symposiums son CCS are needed to disseminate information; to create a healthy dialogue among all players involved, including debate and discussion on the direction CCS is heading; to generate new ideas; and to build a synergistic global network of communications and relationships among thought leaders in government, academia and the industry.

11.3 Regulatory framework

11.3.1 Findings:

- For private industry to invest in new operations, technologies and processes in any country, a regulatory framework for CSS must be in place that provides adequate assurances of acceptable risk to companies and their investors. An enabling environment requires well-written and favourable regulations that limit risks and send more transparent price signals to private investors.

- Likewise, governments and their citizens need assurances through regulations and controls on CCS operations, particularly geological storage, to prevent future accidents that could pose a risk if there were no regulatory requirements on storage.

- Regulatory frameworks at national and international levels are needed to clarify long term rights, liabilities and institutional structures. In particular, regulations defining the limits of liability for storage need to be established.

- Frameworks for OECD countries are needed soon so that developing countries may take cues as to which frameworks will work best for their needs.

11.3.2 Recommendations:

- Prioritize establishment of international and country-specific regulatory and legal frameworks in current CCS countries, and assist developing countries to develop their own frameworks.

- Send clear signals to private industry by making the framework clear and concise on the legal and financial risks they will be assuming.

- Learn from existing regulatory developments and build from there using current and scientific and technical information as available.

- Develop reliable measuring, monitoring, and verification (MMV) schemes that can verify the amount of CO_2 injected and confidently demonstrate, and assure governments, that CO_2 will remain permanently sequestered.

11.4 Public perception

11.4.1 Findings:

- Since public funding is crucial to CCS, the public's perception of CCS is pivotal to government funding that is adequate to bring CCS to scale globally.

- CCS has been disadvantageously presented from many news and environmental organizations mainly due to misguided and incomplete information, which has negatively influenced public perceptions. The biggest shortfall in the industry's relationship with the public has been the lack of information from the industry, which has created a knowledge gap and often allowed pundits to influence public opinion against CCS.

- There is an urgent need for the industry to develop strategies that educate the broader public. Full and accurate information is essential in order to increase awareness and support for CCS as necessary in greenhouse gas mitigation efforts to stem global climate change. Major media campaigns are effective with the public as demonstrated by major oil and gas companies on other issues. With adequate information on climate change and pressure by constituent advocates, local and national leaders have become leading proponents of CCS and its safe track record.

- The public lacks adequate information on the successful track record of CCS projects that have been taking place for many years now. Safety of CO_2 storage is of particular concern to local communities. There is also a need for a local value proposition of each CCS project to show the benefits of this technology to the local community.

- CCS stakeholders must better address public concerns and perceptions and educate and communicate more effectively on large scale CCS deployment. Existing pilot plants, particularly those associated with EOR/EGR; provide good starting points for communicating the feasibility and value of CCS.

11.4.2 Recommendations:

The following are key symposium recommendations to increase the public's awareness and improve perceptions of CCS benefits and safety:

- Employ well-developed and well-funded media campaigns in select markets to inform and garner public support.

- Raise public awareness of CCS as a necessary technology to battle global climate change.

- Educate the public on the long history of CCS and its successful operations in places

- Enter into dialogue with local leaders and politicians where CCS projects are undertaken and with national leaders where government funding is essential to support innovation and development of CCS technology.

12. Conclusion

Although CCS technology holds significant potential for climate change mitigation, there is still a long way to go to move demonstration projects to a commercial scale capable of significant impacts on GHG emissions. Barriers must be overcome before commercial deployment of CCS technology becomes a reality. These include technology efficiency developments, the creation of legal and regulatory frameworks and improvements in public awareness and acceptance. Uncertainties surrounding costs should be tackled and funding solutions need to be found to support the demonstration project phase.

Accelerating CCS deployment requires measures that "push" technology advances through investment and cost reductions as well as policies that "pull" CCS technology through regulatory frameworks, incentives, private-public partnership, international cooperation and an enhanced producer-consumer dialogue.

Accelerating CCS deployment requires the joint and coordinated efforts of all stakeholders, working together to address existing barriers to the adoption of these technologies and to develop effective policies and measures to overcome them. Industry and governments both have a key role to play in achieving the full potential of CCS. Industry can provide know-how, technology innovation and the capital needed to develop large scale projects, while governments can provide the long-term policy and regulatory framework that enables the move to commercial scale deployment. Government-industry cooperation is also needed to communicate on CCS technology and to gain public acceptance.

Cooperation between producing and consuming countries, developed and developing countries, industry and government is needed to accelerate CCS deployment, harvest its potential and meet climate change goals. Information-sharing in CCS technology, structural and regulatory capacity building as well as additional R&D will play an important role in shortening the CCS learning curve. An international mechanism for funding deployment of CCS in developing countries is a key element that needs to be discussed in future international forums.

The future of CCS can build upon the successes of the past few years. The experience of the oil industry in enhanced oil recovery can be shared in order to speed up investment and development. The inclusion of CCS in the CDM under the Kyoto Protocol, although there are still issues to be addressed, may pave the way for future CCS projects in developing countries to be developed and operated economically. It will also contribute to improve the economics of CO_2-EOR projects.