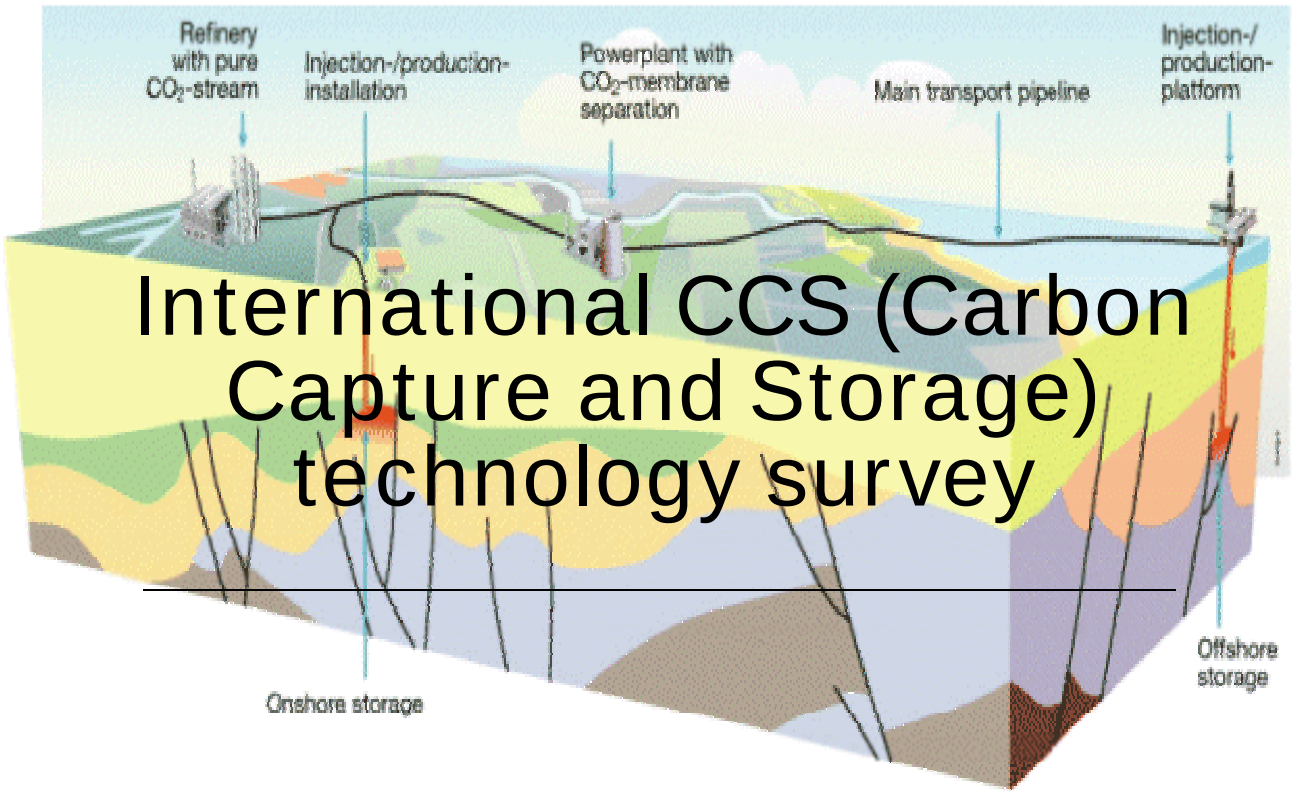
GASSNOVA

INNOVATION NORWAY



International CCS (Carbon Capture and Storage) technology survey

Report prepared for Gassnova by Innovation Norway.
Issue 5 - July 2009.

Contact: Per Christer Lund, IN Tokyo. per.christer.lund@innovationnorway.no, +81-3-3440-2611

Table of Contents

Introduction

This report is compiled by Innovation Norway as part of a joint project with Gassnova SF.

The purpose is to maintain an updated overview of CCS projects and strategies around the world, and the report will be updated twice per year. This is the 5th version.

The report is written by Innovation Norway "CCS task team" which consists of:

Dr. Per Christer Lund (project manager)[1], Tokyo

Ms. Alana Prashad[2], Toronto

Ms. Teresa Völker[3], Hamburg

Dr. Pernille Holtedahl[4], London

Contributions have been given from other Innovation Norway international offices, and from various Norwegian embassy counsellors.

The global survey is not complete, as it is covering only the following countries: USA, Canada, UK, Germany, Japan, Australia and China. There are significant CCS activities in other EU countries such as Netherlands, France and Eastern Europe, but they are not comprehensively covered in this version of the report and may not be fully up to date.

The project scope is to collect information and compile a report from these regions addressing:

- Governmental programs and political ambitions related to CO2 management, especially CCS
- Public funding an programs dedicated for CCS research and demonstration projects
- Listing of current, completed and planned CCS projects
- Listing of main CCS technology companies and institutions
- Brief overview of CCS research organizations

The methods used to collect and qualify information has been meetings and conversation with key persons with the CCS community in each region; combined with extensive data search in media and on Internet.

The report is published at Gassnova's web site: www.gassnova.no

[1] Per.christer.lund@innovationnorway.no . +81-3-3440-9929
[2] alana.prashad@ innovationnorway.no +1 416-920-0434
[3] Teresa.Volker@ innovationnorway.no +49 40 22 94 15 99
[4] Pernille.Holtedahl@innovationnorway.no +44 207 389 8805

Executive Summary

CANADA AND USA

Governmental Programs and Strategies

Canada

Oil sands operations were once seen as a blight in the middle of Canada's heartland, and seen as completely infeasible and totally dirty. The government as well as many private stakeholders have come up with plans to address cleaner upgrading (much bigger issue than just CO_2), making permitting a simpler process and to strongly encourage new upgrader proposals to include CCS lest they be turned down.

Environment Minister Jim Prentice says that CCS is not the answer to reducing greenhouse gas emissions from oil sands projects in northeastern Alberta. While Ottawa and Alberta are spending billions of dollars on CCS demonstration projects, the minister has acknowledged what critics have said all along: The technology has limited application at the energy-intensive mines and insitu projects that extract the bitumen from the ground.

However, CCS could play a major role in virtually eliminating carbon dioxide emissions from upgraders that process the bitumen into synthetic crude oil, thereby reducing the carbon footprint of oil sands projects over all. The industry will have to rely mainly on other technologies to reduce emissions at the production sites.

US

The American election which saw Barak Obama elected was a strong vote for clean coal development. The regional sequestration partnerships continue to be an internationally impressive initiative and many of the partnerships have been granted funds to complete their phased projects. Once the new government takes shape and someone is appointed to run the Department of Energy, the agenda for CCS will become clear.

The DOE is continuing with its breakthrough CO_2 projects listed in previous installments of this report, and the IEA has just announced that it views the US/ Canada partnership program as the most aggressive in the world. This is excellent re-branding and public relations for the US after the Futuregen project was seen as a failure by many.

Interstate Oil and Gas Compact Commission – Regulation update for US and Canada

On September 26th, the IOGCC released a clear and comprehensive model for legal and regulatory framework for storage that should meet the unique requirements for each Canadian province and American state. The report recommends the provinces and states actively solicit public involvement as early as possible in the site selection process, and that the process remains as transparent as possible. It also stresses that CO2 is viewed in a manner that allows beneficial uses of CO_2 following removal from regulated emission streams. Hydrogen sulphide, nitrogen oxide and sulphur oxide should remain highly regulated for public health, safety and environmental concerns.

Public CCS funding and programs

US DOE Regional Carbon Sequestration Partnership has the following timeline:

- Characterization- 2003-2005
- Validation 2005-2009
- Deployment 2009-2017

During the validation phase, each partnership will focus on conducting small-scale field tests in different geographic regions and geologies. Deployment, planned to begin in 2009 will focus on implementing several large volume sequestration tests. Proposals include 25 geologic sequestration tests to be conducted, and between 1,000 and 525,000 ton of CO2 will be injected at each site.

Plains CO_2 Reduction Partnership (PCOR)

The PCOR are developing CO_2 sequestration opportunities for the central interior of North America. PCOR includes 50 partners from industry, government and NGOs (Non-Governmental Organization). PCOR is involved in

sequestration issues and is one of 7 regional partnerships that the US DOE and the NETL established to assess carbon sequestration opportunities that exist in the United States and Canada. PCOR efforts support the president's global climate change initiative, which seeks to reduce CO2 intensity in the US by 18% by 2012.

US DOE's Clean Coal Power Initiative (CCPI) - Round 3

The United States Department of Energy's CCPI has invited private industry to partner with government to demonstrate new clean coal tech at a commercial scale at the beginning of October. This has been released for public comment. Public comment begins immediately in November.

The CCPI is a ten-year $2 billion project initiated in 2002 in response to the Bush administration's support for clean-coal technology to demonstrate advanced coal-based power generation technology at the commercial scale. The DOE is seeking new and innovative technologies rather than new applications or minor improvements to existing technology. Potential projects must ensure a minimum of 75% fuel energy input from coal, and a minimum 50% of energy-equivalent output is from electricity.

Current CCS Projects

The Canadian CO2 Capture and Storage Technology Network (CCCSTN) lists 48 Canadian projects related to CCS; including pre- and post-combustion capture; oxy-fuel combustion and storage (injection, reliability and assessment). Most of these are studies and analysis, and only a few are large-scale demonstration projects relevant for this report.

The following are the significant demonstration projects for CCS in North America.

The International Test Centre for CO2 Capture (ITC) at the University of Regina has two main components: a pre-commercial scale chemical absorption technology demonstration pilot plant at the Boundary Dam power plant near Estevan, and a technology development pilot plant at the Petroleum Technology Research Centre (PTRC), University of Regina. Small scale (4 ton/day) from coal/gas plants, with focus on research post-combustion capture by absorption using MEA or mixed-amine (MEA-MDEA).

Weyburn-Midale CO2 Project. The $1.1 billion Encana Weyburn CO_2 enhanced oil recovery project in which CO_2, pipelined from the Dakota (coal) Gasification Company in Beulah, North Dakota, will be pumped into the Weyburn field to reduce the viscosity of the oil and thereby increase its recoverability. An incremental 120 million barrels of oil will be recovered over the next 15 to 20 years, at the same time storing about 14 million ton net of CO2 underground. This IEA activity, chaired by Canada and with offices in the U.K., brings together the interests of 16 countries and the Commission of European Communities. As well, BP Amoco, DMT-FP, EPRI (Electric Power Research Institute, California), Mobil Oil, RWE AG and Shell International are sponsors.

Pembina Enhanced Oil Recovery Project. Currently, Penn West is working toward the construction of a pipeline spine from the CO_2 source to the Pembina field, a distance of about 150 kilometers. Spine will be used not only to supply Pembina, but also other fields in Central Alberta including fields where Penn West has interests. The first phase of the Pembina Enhanced Recovery Project will include construction of a CO_2 supply pipeline, infill drilling, well recompletions, and field facility upgrades. Estimated cost of this work to Penn West will be $200 to $250 million. We anticipate that production from the first phase will commence in 2009 and will average 5,000 to 8,000 barrels per day. Multiple additional phases are planned. The additional phases will not require the per-unit expenditure of the first phase since the supply pipeline and the proportion of the facility upgrades are part of phase one.

Sask Power's clean coal project. The $1.5 billion, 300 MW lignite power plant will capture 90% of the CO_2 emission at a rate of 8,000 tons per day. The project will create enough liquefied CO2 to extract millions of new barrels of oil from Sask's oilfields. A decision on whether to proceed with the project will be made in mid-2007, with an in service date of 2011. SaskPower, Babcock & Wilcox Canada (B&W) and Air Liquide will jointly develop an oxyfuel separation technology as the core process for this project. Saskpower, the utility company wholly owned by the Saskatchewan government, announced in early September their plans to put the Clean Coal project on hold for now. They are opting for cheaper natural gas fired generation, wind power and renewables to meet needs until 2014.

DOE financed projects. The US Department of Energy's (DOE) Office of Fossil Energy typically manages more than 500 active research and development projects spanning a wide range of coal, petroleum and natural gas topics, including 90 projects (March 2007) related to CCS. DOE Secretary Samuel W. Bodman announced October 23 2006 the selection of nine projects totaling nearly $24 million aimed at developing novel and cost-effective technologies to capture the CO_2 produced in coal-fired power plants so that it can be safely and permanently sequestered. Grant recipients will contribute nearly $8 million in cost-sharing for the program.

BP Carson project. BP, in partnership with Edison Mission Group is planning to develop a first-of-its-kind plant which would convert petroleum coke produced at California refineries into hydrogen and CO_2 with around 90% of the CO2 being captured. The captured CO2 - about 4 million ton of CO_2 per year - would be transported by pipeline to an oilfield where the injected CO2 would stimulate additional oil production and permanently trap CO2. The project would require total capital investment of about $1 billion. Front-end engineering will start in early 2007 and it is anticipated that the plant will be operational by 2011.

The Future Gen Alliance project. FutureGen is an initiative to build the world's first integrated sequestration and hydrogen production research power plant. The $1 billion dollar project is intended to create the world's first zero-emissions fossil fuel plant by coal gasification of a 275 MW plant and EOR. It is a public-private partnership with alliance members including American Electric Power Service Corporation (Columbus, Ohio); Anglo American Services (UK) Limited (London, UK); BHP Billiton Energy Coal Inc (Melbourne, Australia; China Huaneng Group (Beijing, China); CONSOL Energy Inc (Pittsburgh, Pennsylvania; E.ON U.S. LLC (Louisville, Kentucky); Foundation Coal Corporation (Linthicum Heights, Maryland); Peabody Energy Corporation (St. Louis, Missouri); PPL Energy Services Group, LLC (Allentown, Pennsylvania; Rio Tinto Energy America (RTEA) Services (Gillette, Wyoming); Southern Company Services, Inc (Atlanta, Georgia) and Xstrata Coal (Sydney, Australia).

The site for plant and CO_2 deposition has not been determined yet. The FutureGen Alliance and the U.S. Department of Energy plan an aggressive development schedule that includes selecting a site in 2007, beginning construction in 2009, and initiating full-scale plant operations in 2012. Currently, the major activities include hiring senior management, evaluating candidate site proposals, completing an environmental impact assessment, and conducting engineering design work. The US DOE will issue its "record of decision" Oct. 29 and the alliance, a consortium of 12 global industrial giants, will announce the winner of the site selection in late November. The first decision will identify which bidders are acceptable to the DOE's National Energy Technology Laboratory and could name just one or all four, an official explained. Construction will start on one of the four sites in 2009 and finish three years later in time for extensive testing and electrical production to begin in 2012.

Alstom and AEP. Alstom and American Electric Power signed a Memorandum of Understanding to bring Alstom's chilled ammonia process for CO2 post-combustion capture to full commercial scale of up to 200 MW by 2011. In phase one, Alstom and AEP will jointly develop a 30 MWth product validation that will capture CO2 from flue gas emitted from AEP's 1300 MW Mountaineer Plant located in New Haven, West Virginia. It is targeted to capture up to 100,000 ton of CO_2 per year. This pilot is scheduled for start-up at the end of 2008 and will operate for approximately 12-18 months. In phase two, Alstom will design, construct and commission a commercial scale of up to 200 MW CO2 capture system on one of the 450 MW coal-fired units at its Northeastern Station in Oologah, Oklahoma. The coal-fired system is scheduled for start-up in late 2011. It is expected to capture about 1.5 million ton of CO2 a year. This will be used for EOR.

BP and Powerspan Collaborate. On August 3, 2007, BP Alternative Energy and Powerspan Corporation announced their collaboration on Powerspan's CO2 capture technology for power plants called ECO2. This will include sequestration of the CO2 captured into an 8,000 foot test well. This will be associated with the Midwest Regional Sequestration Partnership. BP and Powerspan will conduct pilot testing of the ammonia based CO2 capture technology. This technology would be used as a retrofit solution on coal-fired plants.

GERMANY

Governmental Programs and Strategies

Germany, being Europe's largest emitter of greenhouse gas (GHGs) emissions[5] is meeting its Kyoto target within the overall European target of 8% and committed itself under the Burden Sharing Agreement to cut CO_2 emissions by 21% in the period 2008-2012 on the basis of 1990 levels. Germany's self imposed mid term goal is however even more ambitious, to cut CO_2 emissions by up to 40% of their 1990 level by 2020 whilst simultaneously phase out nuclear energy by 2022. Just as for Europe, there is a tremendous need for re-investments in generation capacity over the next two decades. Determined by the lifecycle structure of the existing power generation system in Germany and including the projection of nuclear phase –out over the next 15 – 16 years, power stations with a capacity of around 40 GW will have to be replaced in the next 15 to 20 years in order to meet the conservatively estimated future demand of about 550 TWh per year in 2020[6]. In Germany this poses a further challenge, since the overall capacity is characterised by the special dominance of coal and lignite. Hard coal and lignite together represented almost 50% of the fuel basis for the gross electricity production in 2007. The extensive use of coal stands in contrast to Germany's ambitious climate targets and if lignite and coal burning power stations are to have a future over the medium to long term, given the tightening of reduction targets, it will be necessary to develop power stations with high efficiency and CCS technologies.

German climate policy and hence the political framework for the development of CCS is embedded in the European energy and climate package which was passed in December 2008. The package entails quantitative targets for renewable energy (20% by 2020), energy efficiency (improvements of 20% by 2020) and the reduction of GHGs (20% by 2020). The European Directive on CCS provides the legal framework to manage risks and liabilities issues as well as funding mechanism for CCS.

The German government is implementing these fundamental European policy decisions at a national level by means of the German energy and climate protection package, which was decided in Meseberg in August 2007, called the *Integrated Energy and Climate Programme*. Proving the feasibility of CCS is one important pillar of the climate package. To prove the feasibility of CCS, increased R&D efforts have been funded and initiated in 2007 and the construction of at least two or three of the 12 demonstration CCS power station that are to be built across

[5] with 994 million tones of CO_2 equivalent in 2005

[6] These estimates represent a conservative compromise between more extensive growth rates and energy savings potential through widespread use of efficiency gains (EWI/Prognos).

Europe are envisaged, as well as further storage projects. Taking into consideration the results of relevant R&D projects, the German Government has in this context stated that it would consider proposals for a "capture ready" standard for future fossil fuel power plants. The German Government will furthermore develop a suitable legal framework for underground storage on an industrial scale (including the planned demonstration power stations), transport and capture in parallel to and on the basis of the European legal framework. Challenges for CCS in Germany remain storage related. Onshore storage capacities, regionalism and public acceptance remain complex issues associated wit CCS.

Private sector engagement

There is generally agreement between the political and business communities that climate protection is a central element of environmental policy and an integral part of economic and energy policy. German businesses have a self imposed objective of making a special effort, on a voluntary basis to reduce specific CO_2-emissions by 30% by 2012. Additionally, major players in the energy sector are signing up to the 3C – Combat Climate Change – initiative of business leaders with the commitment to draw a road map to a low emitting society.

German electricity producers are examining the potential of low emission power stations in the view of these commitments and due to their obligation to reduce emissions under the EU-ETS and the associated changes in the energy sector. Especially for companies like RWE, which are heavily invested in lignite and coal fired power plants; CCS could prove a viable technology under stricter climate regulation in the long-term.

Current techno – economic prerequisites, including the rise in cost of power plant construction due to high demand and rising commodity prices, render the operation of CCS power plants not profitable. Nevertheless three of the large power companies are embracing CCS with several pilot and demonstration projects and are getting involved in the development of a national legal framework for CCS in Germany.

Germany is the second largest exporter in the power generation plant sector. CCS technologies might become an interesting export commodity especially when considering emerging markets such as China as a possible, coal dependent trading partner. In September 2005, a Chinese-European collaboration was initiated for the development of clean cola technologies. Until 2020 low emission power plants are planned in China, whereby technologies will be provided by European power plant builders.

Public CCS funding and programs

In Germany, the majority of public funding to CCS activities originates from two Ministries, the Federal Ministry of Economics and Technology (BMWi) and the Federal Ministry for Education and Research (BMBF).

Since 2005, the BMBF supports as part of its geo-scientific research and development program *GEOTECHNOLOGIEN* research projects on CO_2 storage. CO_2 storage in geological formations is investigated within the research theme "Investigation, Use and Protection of the Underground". The projects are undertaken in the form of collaborations from Universities and industry and in the first phase (2005-2008) nine interdisciplinary projects with the focus on technological, ecological and economic perspectives concerning CO_2 storage and monitoring in geological formations were funded with a financial volume of € 6.9 million. 12 Universities as well as 13 companies of the German energy sector were involved.

To quantify the CO_2 storage potential for Germany further, a second funding phase (2008-2011) for the national R&D programme "*Geological Storage of CO_2 in Germany*" was in 2007. The financial volume is € 19.6 million per year and 17 research institutions and 11 companies are involved. The main objectives are the extension of basic research on storage and surveillance technologies, complementary to the pilot projects. Basic R&D activities without site specification will be supported from 2008 with a budget of €8 million per year. Research fields include, monitoring and modelling tools, trapping mechanisms, CO_2 mobility, stability and integrity of reservoir and injection wells. Site specific pilot projects as public private partnerships will be funded with € 9 million per year, starting from 2008.

The BMWi is supporting the development of capture technologies with the research and development concept **COORETEC**, which aims at reducing the emissions of fossil fired power plants to near zero. The COORETEC concept rests on the two pillars of efficiency increase and avoidance of CO2 emissions and intends to create the basis for satisfying at the highest possible technical level a standard for new and replacement plants in the power generation sector foreseeable after the year 2010. In 2007, COORETEC launched the "Lighthouse Concept" with the aim to bring down the costs of CCS. Five technology related working groups have been created in the covering natural gas combined cycle, steam cycle power plants, IGCC with carbon capture, Oxyfuel and storage. In 2008, CCS research projects on capture technologies were funded with approximately € 30 million. Additional funding of € 35 million annually is envisaged.

Germany has a great interest in international exchange regarding CCS. Germany is supporting R&D activities with the framework programs, the ZEP (Zero Emission Fossil Fuel Power Plants Technology Platform), and the ERA-Nets. Internationally, Germany plays an active role in the CSLF (Carbon Sequestration Leadership forum) task forces and is participating actively in the programs of the IEA.

Current CCS projects in Germany

Although Germany has been approaching CCS cautiously in the past, both R&D and pilot projects are increasingly catching up and several CCS projects have been officially announced. Projects ongoing or in the concrete planning process are:

CO2 SINK: The CO_2SINK integrated project, is supported under the FP/6 framework by the EU commission with a budget of € 14 million, and is the first European Showcase for Onshore CO2 storage. The main objective is to monitor behaviour of CO2 injected into a saline aquifer at 600 meter depth near Berlin. About 60,000 tons of commercial CO2 will be injected over a 2 year period. Whilst the first phase of the project, starting 2004, was mainly occupied with attaining the approval for injections, injections of CO2 started in the second phase, June 2008 with commercial CO2. By the end of July 2009, 18.417 tons have been successfully injected.

Vattenfall Oxyfuel Pilot Plant "Schwarze Pumpe": Vattenfall has since 2001 had an R&D project on Oxyfuel technology and in 2006 commissioned a € 70 million 30 MW (thermal) Oxyfuel pilot plant. Operation of the pilot plant commenced operation in September 2008 and the plant is expected to be in operation for 3 years. The CCS pilot plant will produce about 60,000 tonnes of CO2 per year at full load. The separated and liquefied CO2 produced by the pilot plant might be transferred to the CO2 carbon storage facility in the Altmark gas field. Further expansion plans include a 250 to 300 MW plant around 2012-2015 and a 1000 MW plant around 2015-2020.

Vattenfall Oxyfuel and Post combustion Demonstration Plant Jänschwalde: In Mai 2008, Vattenfall announced its plans to build a demonstration plant for CCS technologies at one of the 500 MW blocks of the conventional lignite power plant Jänschwalde in the State of Brandenburg, Germany. The investment for the demonstration is estimated to be € 1 billion. The Jänschwalde lignite power plant consists of six 500 MW blocks. For the demonstration plant one of the blocks, consisting of two boilers, will be equipped with CCS. One boiler will be newly built with an oxy-fuel technology; the other will be retrofitted with a post combustion technology. To compensate the loss of efficiency of approximately ten percent in the generation process, incurred by the installation of additional components, Vattenfall is developing methods for increasing efficiency by using higher temperatures and pre drying of lignite as well as operational excellence. The demonstration plant will produce 300 MW.

Enhanced Gas Recovery in the Altmark gas field: In 2007 Gaz de France announced its plans to engage in a CO2 storage and EGR project in the Altmark gas field. With a storage potential of 508 MMt, the reservoir currently has the largest storage volume available in depleted gas fields in Europe and is the only nearly exhausted gas field capable of storing the CO_2 from a power plant over its entire lifespan. Being already investigated, explored and developed, this gas field therefore provides very favourable conditions to explore the possibilities of the entire CO_2 value chain. Vattenfall and Gaz de France are cooperating in the project and the CO2 from Vattenfall's test facilities could be transported by truck to the Altmark field and injected into one compartment of the Altmark field. However, due to the lack of a federal legal framework for the storage of CO2 the project is on hold and Vattenfall is exploring alternative storage sites.

E.ON: POST COMBUSTION CAPTURE: E.ON plans to pursue the development of post combustion technologies with a budget of € 100 million until 2014. Four of its seven projects are planned in Germany in cooperation with Siemens, Flur, Consolv and Mitsubishi. One of the projects is located at E.ON's coal fired power plant in Wilhelmshaven and is scheduled to start operation in 2010. Flor and E.ON Energy have formed a strategic partnership for the development of a retrofitted pilot plant using Flour's Econamine FG+ technology. The technology uses monoethanolamine as the solvent for efficient capture of CO_2. The pilot plant will be small in scale with only 5.5 MW.In North Rhine Westphalia E.ON Energy will work together with Canadian Cansolv Technologies at its location in Heyden. The objective of this project is again to improve efficiency of post combustion by testing different solvents. The pilot plant which is expected to commence its operation in 2009 is planed to produce 7 MW. In cooperation with Siemens E.ON is planning another 1 MW pilot facility at the Staudinger power station near Hanau east of Frankfurt.

RWE IGCC Plant with CO_2 Storage. In April 2006 RWE announced the development of an IGCC coal or lignite fuelled power plant. The power plant is expected to have a gross output of 450 MW and integrate CO_2 capture and storage. RWE is planning to operate the plant by 2014. Investment costs have risen to € 2 billion in this project. RWE plans to store some 2.6 millions tonnes of CO_2 annually and is currently assessing 3 different locations in the North of Germany for appropriate storage capacity. In 2008 RWE started the exploration phase and if permissions are granted seismic investigations will start 2009. RWE is also planning to build a pipeline from the plant location in Hürth, in North Rheine Westphalia to Schleswig Holstein. Currently this project is in the regional planning procedure.

RWE's Scrubbing Pilot Plant: RWE is also active in post combustion technologies and has started operation of its pilot plant at the power plant Niederaussem in July 2009, in cooperation with BASF and Linde Group. An extensive investigation programme conducted under real operating conditions to test the new CO2 solvents developed by BASF will be completed in early 2010. The height of the pilot CO2 scrubbing plant (40 m) corresponds to that of the future commercial plant. The plant also comprises all individual components of large plants, but on a smaller scale. The diameter of the absorber column was limited to the size required to obtain representative results. Depending on the set test parameters, up to 300 kg CO2 per hour can be separated from a flue gas bypass (corresponds to a capture rate of 90 %).

A listing of current CCS projects in Germany is given in Annex 1.

CCS Technology companies in Germany

The large electricity utilities E.ON, RWE, EnBW and Vattenfall Europe are locomotives for CCS technologies in Germany from a technology user perspective. Energy technology manufacturing industry (boilers, plants, turbines etc.) in Germany is traditionally very strong, including companies such as Alstom, Siemens, Linde AG, BASF AG, Krupp Uhde GmbH, Babcock and Mannesmann Anlagebau AG . These companies have substantial focus on CO_2 capture technologies, including pre-combustion technologies and oxyfuel, and post-combustion capture using e.g. chilled ammonia (Alstrom) and Amin (BASF). They are involved in several CCS programs and projects. Consultancy companies include Fichtner, G.E.O.S Freiberg and VDI Technology Centre.

CCS Research and Development in Germany

The two governmental programs COORTEC and GEOTECHNOLOGIEN are described above. Each of them enraptures a number of projects covering various aspects of CCS technology, involving a number of universities, research organizations and private industry.

German universities, research and companies are furthermore engaged in most of the significant EU projects related to CCS, including GESTCO, RECOPOL, CO2STORE, CASTOR, ISCC, ENCAP and GEO NET.

The leading German research institutes in this context are Federal Institute for Geoscience and Natural Resources (BGR); Wuppertal Institut für Klima, Umwelt, Energie; Potsdam Institute for Climate Impact Research (PIK) and GeoForschungsZentrum Potsdam.

UK

Governmental Programmes, Strategies, and Initiatives

In May 2002, the United Kingdom ratified the Kyoto Protocol with a goal of reducing Green House Gas (GHG) emissions to 12.5% below the 1990 levels by 2008-12. In 2007, it is estimated that emissions were 16.4% below 1990 levels, so effectively the country has already fulfilled its commitment.

The current UK government is strongly focused on climate change and has implemented a number of policies, such as the Climate Change Levy, Renewable Obligation Certificates and Energy Efficiency Commitment. Climate change is a subject which all three major political parties in the UK agree is important. The UK is an active international player: it actively supports CCS both within the EU and bilaterally with countries such as Norway, India and China.

The 2007 Energy White Paper underpins current UK energy policy. It discusses CCS and points out that demonstration of commercial-scale CCS on power generation in the UK could enable the technology to be proven and facilitate a better understanding of the costs. Other important policy developments include the passing of the Energy Bill on Nov. 28th 2008, which, amongst other things, proposed primary legislation that for the first time will lay the foundations for a UK regulatory framework for CCS projects. Finally, in the spring and summer of 2009, the Government proposed a series of measures, through

- The consultation document *"A framework for the development of clean coal"* that proposes that new coal-fired power plants will not be given consent unless they demonstrate CCS on at least 25% of capacity from the beginning and 100% after 2025 and asks for views on the introduction of an emissions performance standard (EPS)

The proposed new Energy Bill launched in June 2009, that would introduce a financial mechanism to fund up to four commercial-scale CCS demonstration plants.

Currently, the most important UK activity within CCS is the Government's funding competition, where one project will be chosen to demonstrate 300MW of post-combustion capture. There are now three consortia left, led by Scottish Power, E:ON, and RWE. Negotiations are currently ongoing regarding the submission of detailed proposal bids, although the process is currently running behind schedule. There is also a continued resentment among some in the industry about the Government's decision to limit the Competition to post-combustion technologies.

The government has recently announced its intention to fund an additional 3 demonstration projects. Furthermore, various options for transport and storage of CCS are being studies, with the possibility of creating "hubs" around high-emission areas in Yorkshire and Thames Valley.

Current CCS projects in UK

There are some currently some 12 CCS projects in the UK on the drawing board, a majority of which are using post-combustion capture:

They are:

Post-combustion:

- RWE, Blyth

- RWE, Tilbury
- RWE, Aberthaw
- RWE, Hunterston
- Scottish Power, Cockenzie/Longannet
- Scottish & Southern Energy, Ferrybridge
- E.ON, Kingsnorth

Pre-combustion:

- Progressive, Teesside
- E.ON, Killingolme
- (BP, Peterhead)
- Powerfuel, Hatfield
- Valleys Energy, Onllwyn

CCS Technology companies in UK

There are currently no CCS capture technology companies in the UK, but, there exist a number of suppliers, engineering companies and consulting firms with expertise and interest in the field of CCS , including M.W. Kellog, Doosan Babcock and RPS.

CCS Research and Development in UK

A number of universities in England and Scotland are actively researching various aspects of CCS. Two prominent ones are:

The **Scottish Centre for Carbon Storage** (SCCS) was established in 2005. It is a partnership between the British Geological Survey, Herriot Watt University and The University of Edinburgh, and is the UK's largest grouping of CO2 Storage researchers. It offers a Master's programme focusing solely on CCS.

The latest addition to the UK's list of research consortia is the IC4S at Imperial College, launched in June 2009.

FRANCE AND ITALY

Governmental Programs and Strategies

The French Agency for the Environment and Energy Management (ADEME), has earmarked CO2 capture and storage as one of its research priorities. In this context, it takes part in federating and structuring national efforts in the field, with the creation in 2002 of Club CO2. ADEME supports large numbers of projects and initiatives concerning all aspects of the capture/transport/storage technological stream, and devotes special attention to socio-economic and environmental impacts in a sustainable development perspective. Within the Club CO2 there are two thematic foci; CO2 capture and transport, and on geological storage.

The Italian government recognizes the huge challenge of meeting Italy's Kyoto Protocol commitments (existing gap 97 Mt CO2/yr) while satisfying an ever-increasing energy demand. To address this, the Italian energy policy foresees a number of measures, including CCS. A number of National projects and programs is supported by National Government, Ministry of Economic Development, Ministry of Research and Regional Governments. The 3-year Energy R&D National Programs with a funding of 150 Million euro includes funding for 2 CO2 Separation & Capture program; "quantifying existing potential capacity to storage CO2 over time" and "ECBM Site-Tests in Sardina (Sulcis Area)".

Current CCS projects in France and Italy

There are three main CCS projects in France:

- **Total's project in Lacq** – a pilot CO2 capture and sequestration project in the Lacq basin in southwestern France. The project calls for up to 150,000 metric tons of CO2 to be injected into a depleted natural gas field in Rousse (Pyrenees) over a period of two years as from end-2008. The source of the CO2 is from oxy-fuel combustion at Lacq's steam production unit at the gas processing plant. The purified CO2 will be compressed and conveyed via pipeline to the depleted Rousse field, 30 kilometres from Lacq, where it will be injected through an existing well into a rock formation 4,500 metres under ground. CO2 injection is scheduled to begin in November 2008. The project, which will cost nearly 60 million euros, will be carried out in partnership with Air Liquide and in cooperation with the French Petroleum Institute (IFP),

the French Bureau of Geological and Mining Research (BRGM) and others. Over the past ten years, Total has participated in several CO2 sequestration projects, notably in saline aquifers at North Sea oil production sites.

- **Project PICOREF** - is a R&D programme dedicated to the storage of CO2 in permeable reservoirs. It is supported by the French Ministry of Industry and by a consortium of French companies, research institutions and academic laboratories. The two-year project started 2005, with a budget of 3,75MEURO for 2005. PICOREF follows a four-year study of the geological storage of CO_2, supported by the RTPG (Réseau des Technologies Pétrolières et Gazières - network of oil and gas technologies), industry and French research organizations. These studies were aimed in particular at taking stock of available knowledge and tools in a field that is new to the oil extraction and underground storage industries. The year 2005 is a year of transition between this fundamental research and its application to industrial projects. This project PICOREF continued in 2006-2007 within the French National Research Agency (ANR). The preliminary inventory done within the European GETSCO project will be completed by a new French project funded by ADEME (French Agency for Environment). METSTOR (Methodology for CO2 Storage) began in 2006 for site selection in France.
- **The CRUST project:** K12-B CO2 re-injection. Gaz de France operates the ORC project (Offshore Reinjection of CO2) forms part of a Dutch study known as the CRUST program (CO2 Re-use through Underground STorage). Launched by the Dutch government in 2002, CRUST aims to make an inventory of possible sequestration sites, to study legal and environmental aspects and the possibilities for CO2 re-use. Gaz de France Production Netherland B.V. (ProNed) is currently producing natural gas from the Dutch sector of the North Sea. The gas produced at one of ProNed's platform, the K12-B platform, located 150 km NW of Amsterdam, contains a relatively high concentration of CO_2 (about 13%). The produced gas is treated on the platform and the CO2 removed from the natural gas used to be vented. The treated natural gas is subsequently transported to shore by a pipeline to Groningen. Preliminary assessment done in 2001 have shown that it might be relatively easy to re-inject this CO2 into the Rotliegende sandstone reservoir located at a depth of about 3800 meters.

In Italy, research is conducted on storage and sequestration, with much focus on reliability of long-term storage of CO2 in e.g. earth-quake prone areas.

The most significant CCS demonstration projects are carried out by **ENEL**:

- Enel – the largest power company in Italy, is engaged in several projects related to CCS; including the Zero Emission Power project that entails CO2 post-combustion capture demo in Brindisi (2 m3/hr – MEA absorption technology), and oxy-coal combustion demo. Phase two of the "Brindisi CO2 capture project" entails capture of up to 2 ton CO2/hr from a 660 MW coal power station unit. The plant will be ready by the end of 2008 and allow the testing of different CO2 sorbents and process conditions. Based on experience gained with the pilot, Enel will then build a demo plant of this technology at the USC pulverized coal power station, currently under construction. About 600,000 Nm3/h of flue gases from one unit will be processed and the concentrated CO2 flow transported and stored in an underground reservoir. The demo plant is expected to be ready by 2012.

A 2 year storage feasibility studies are conducted in collaboration with the National Institute of Geology and Vulcanology (INGV).

Enel has also signed a cooperation agreement on oxy-combustion technology with ENEA and ITEA. ITEA has patented an innovative process called ISOTHERM that has already been tested on a pilot scale (pictured) for over 4000 hours. The partners will finish a feasibility study for a coal-fired power plant in 2007, with a 50 MWth plant planned for 2009. A small demo plant (35-70 MWe) should be ready by 2012.

ENEA - Italian National Agency for New Technologies, Energy and the Environment - has a wide range of research programmes related to energy and environment; including CCS activites such as "Clean coal/Zero emission Coal Technologies" and the proposed ZECOMIX test platform.

ZECOMIX consist of three main components: H2 production by advanced coal gasification process; power production through high efficiency H2-O2 cycle with gas turbine and CO2 capture and storage.

CCS Technology companies in France and Italy

France

Research organization in France include (BRGM) – the national geologic survey agency in France - addressing CO2 storage in geological formations; Centre national de la recherche scientifique (CNRS); Frech Gas Institute (IFP) and L'Institut National de l'environnement industriel (Ineris).

Private and public companies engaged in CCS projects are the energy companies Electricite de France (EDF) ; Gaz de France (GDF) and Total. Technology and manufacturing industry is represented by Air Liquide; Alstom; Arcelor Mittal; SARP Industrie and Schlumberger.

Italy

Research agencies in Italyengaged in CCS research (mainly storage oriented) include ENEA (National Agency for New Technologies, Energy and the Environment); CNR - The National Research Council; and National Institute for Geophysic and Vulcanology. L'Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) and CESI RICERCA are also engaged in projects.

The utilities are represented by ENEL – engaged in several projects related to CCS; including the Zero Emission Power and oxy-coal combustion demo and ENI – the leading gas company engaged in the CO2 Capture Project.

Technology companies include Ansaldo and Sotacarbo are. Ansaldo is specializing in power plants, while Sotacarbo specializes on clean coal technologies. Carbosulcis is a public mining company in Sardinia, doing study of underground storage.

Universita di Roma "La Sapienza" and OGS partcipates in the European Networks of Excellence CO_2GeoNet together with 11 other institutes to study underground CO_2 storage.

JAPAN

Governmental Programs and Strategies

Japan ratified in June 2002 the "Kyoto Protocol" with a goal of reducing their Green House Gas (GHG) emissions to 6% below the 1990 levels. As per 2005, the emission level is about 6-7% above the 1990 level, implying a total reduction of 12-13% GHG emission from today's level. This amounts to about 150 million ton CO2 equivalents. The Kyoto Target Achievement Plan of April 2005 stipulates that this reduction target should be met through reduction in domestic emission (50%), CO2 sinks – including CCS (30%), and the rest by procuring emission credits, e.g. the Kyoto Mechanisms.

Japan has been, and is, very active in the CCS arena, in both international policy and on technology development. Japan has been leading in the ocean deposition research and continues to spend public funding in the order of $2.5 million over another 5 years. This work will probably be shifted from RITE to Tokyo University. The Nagaoka and JCOP projects are completed, but the Japan government - though NEDO and METI/RITE continue to support research, demonstration and development on aquifer and coal seam deposition through the JAPEX project.

It seems, however, that the main focus for Japanese CCS research will focus on capture, oxification and "clean coal" technologies – where also the leading technology providers Mitsubishi Heavy Industry and IHI – is heavily involved. There are two "treads" in oxification – oxygen-blown and air-blown technology. Japan has up until now been focusing on air-blown technology, but with the heavier engagement in USA and Australia seems to lean towards oxygen-blown methodology.

In the close future, the main issues is introduction of domestic CO2 emission cap or trading regime, and what effect that will have on innovation and increased R, D & D in Japan. The government's plan of large-scale and economically feasible deposition (200 million ton/year) seems very ambitious. Japan will continue to be a significant contributor to international CCS activities. The industry aims to be world leader on capture and oxyfuel technologies – both for coal and gas generation.

Public CCS funding and programs

A majority of public funding to CCS activities originates from Ministry of Economy, Trade and Industry (METI), Ministry of Science and Education (MEXT), Ministry of Environment (MoE) and the Prime Minster Cabinet Office.

METI's Office of Environmental Affairs R&D budget for FY 2006 was 5.66 billion Yen (~$50 million) and request for FY 2007 is 4.3 billion Yen (~$37 million), with main focus on two areas; ocean/aquifer sequestration and on clean coal technologies.

MoE has a large project for "Global warming countermeasures" with an FY 2007 budget of 3,3 billion Yen (~$30 million) but that includes bio fuel and development of new energy. It is not clear how much is earmarked for CCS.

NEDO (New Energy and Industrial Technology Development Organization) is focusing on clean coal technologies projects, and supported in FY 2006 6 projects with a total budget of about 25 M$. In addition, a budget of ~$10 million was allotted for International Coal Utilization Projects with e.g. China, Indonesia, Vietnam etc.

Finally, NEDO has a Kyoto Mechanisms Credit Acquisition Programme for 2007-2013 with annual budget for procuring CDM credits of at least $50 million/year. 3 Kyoto Mechanisms Promotion Programs have a total budget for 2006 on ~$162 million.

Prime minister Fukuda announced at the World Economic Forum in Davos January 2008 a follow-up of Koizumi's "Cool Earth 50" programme named "Cool Earth Promotion Program"[7], with the following key elements:

- Japan will utilize it's G8 presidency in 2008 to drive the Bali-process further
- From 2008, Japan will provide approximately $10 billion in aggregate over the subsequent five years as assistance for adaptation and access to clean energy ($2 billion) and mitigation ($8 billion).
- Japan will invest $30 billion over the next 5 years to develop new, innovative technology on a range of areas, including CCS on coal fired power plants. However, much of these funds are already in existing R&D plans.

Japan CCS Company Ltd.

The Japanese CCS Company, Ltd. was launched in May 2008 by 29 major Japanese power and energy-related companies to jointly develop carbon capture and storage technologies.

Japan CCS aims to *conduct feasibility studies* for the government in FY 2008 in an attempt toward realizing Japan's goal to capture and store 100 million ton of CO_2 per year from 2020. Japan CCS aims to combine the CCS technologies of the participating companies to overcome technological difficulties for commercialization. It also said it aims to launch large-scale experiments as early as possible.

Current CCS projects in Japan

Currently, demonstration projects within CCS inside Japan are mainly done for small-scale aquifer sequestration and on CO2 post-combustion capture demonstrations.

The national storage projects; such as the Nagaoka, JAPEX and JCOP underground sequestration; and the ocean sequestration projects are either phased out; or are receiving decreasing funding and attention from both government, industry and leading researchers. The proposed JAPEX project – which is an extension of the Nagaoka project - may have some merits, but it's too early to estimate its importance.

A number of demonstration projects for amine absorption technology has been conducted on chemical and power plants within Japan over the last two decades – mainly driven by Mitsubishi Heavy Industry in collaboration with it's industrial customer – and supported by governmental funds.

Japan companies, supported by the government, are however engaged in larger scale demonstration projects internationally; such as sequestration projects in Canada, Algeria, Europe and Australia; and on capture and clean coal projects in Australia; such as the Callide project.

The list on Japanese engagements in Asia includes the planned White Tiger CCS project and the Bintulu CCS project – both large scale and ambitions projects projected for start-up around 2010/2011. These projects are however, uncertain and depends on e.g. if CCS will be accredited as CDM projects.

CCS Technology companies in Japan

A number of Japanese companies within the power/fuel industry and manufacturing industry are engaged in international CCS projects (currently 35 projects - ~10% of all projects in UNFCCC's registry), with the dual aim at demonstrating technologies; and in the long run to earn CDM credits – provided that CCS is eligible as CDM/JI measures. That includes capture projects in various Asian countries, oxyfuel projects in e.g. Australia, and storage projects in Algeria and Vietnam. The leading companies on the technology side are MHI, IHI and JGC, while energy utilities and associations such as KEPCO, (to some extent TEPCO), JPower, and JCOAL are financing and hosts. Trading companies such as Sumitomo, Mitsui and Marubeni are looking as CDM opportunities for trading purposes.

Mitsubishi Heavy Industries; in collaboration with e.g. Sumitomo, KEPCO, Nippon Steel and industrial players; have delivered a number of demonstration and full-scale CO2 capture facilities for chemical and power plants both domestically and internationally. This technology is mainly based on MHI's patented amine absorption technology.

On October 1 2008, Toshiba established a new CCS development and promotion organization, and will seek to further accelerate commercialization through the Mikawa pilot plant.

CCS Research and Development in Japan

Research is conducted at governmental institutions such as RITE, and at universities such as Tokyo, Tohoku, Hokkaido, and Kyoto. CRIEPI has reduced research on CCS technology, and are now mainly focusing on policy issues. There is, off course, substantial research at the private companies such at MHI and IHI, and this is to some extent in collaboration with the public research (although not a close link between private and public research as e.g. in Norway). Funding is mainly from METI and NEDO, although also MoE is contributing.

[7] www.mx.emb-japan.go.jp/sp/Davos.ppt

AUSTRALIA

Governmental Programs and Strategies

In a major shift of policy, the Labour Government led by PM Kevin Rudd government ratified the Kyoto protocol on March 11th 2008[8], and issued their Initial Report under the Kyoto Protocol[9] one year ahead of the deadline set by UN. The government thus demonstrated its strong will and ability to address domestic and international climate change challenges.

Australia is entering international agreements to meet its reduction targets through emission allowance trading, such as the recent agreement (March 2008) with Papua New-Guinea on a Forest Carbon Partnership[10]. The Rudd government is pushing for a national Emission Trading Scheme[11] within 2010, and is considering how to integrate this system in an international context.

On May 20th 2008, the the Australian Government has released draft legislation for consultation which will establish the world's first framework for CO2 capture and geological storage (CCS). The CCS legislation establishes access and property rights for the injection and storage of greenhouse gases into sub sea reservoirs in Commonwealth waters (more than three nautical miles offshore).

In May 2009, the government announced that The Carbon Pollution Reduction Scheme (CPRS), a cap and trade system, will be phased in from 1 July 2011, delayed by one year 'to manage the impacts of the global recession.' A one year fixed price period will be introduced, with permits costing $10 per tonne of carbon in 2011-12, with the transition to full market trading from 1 July 2012.

The Global CCS Initiative (GCCSI)[12]

The Australian initiative the *Global CCS Institute (GCCSI)* was formally launched[13] April 16, 2009 to speed up the development of carbon capture and storage technology. The Institute is headquartered in Australia, and provides international policy and management oversight to the goal of delivering at least 20 commercial scale CCS plants around the world by 2020. The Australian Government will contribute up to $100 million per annum towards its operation.

The Institute will aim to accelerate carbon projects through facilitating demonstration projects and identifying and supporting necessary research - including regulatory settings and regulatory frameworks.

Public CCS funding and programs

Australia has several large funds for promoting R, D & D within CCS technology. This includes the A$500 million Low Emission Technology Demonstration Fund, of which more than half has been allotted in 4 projects (thus matched with about A$1 billion from private sector). Further funds are the A$ 200 million that Australia puts up in the Asia-Pacific Partnership on Clean Development and Climate (AP6), and about A$ 500 million from various state programs.

The government has established a number of research partnerships, creating so-called Cooperative Research Centers (CRCs), which ties the government, researchers and private industry into the various projects. The industry commitment seems solid, especially in development of "clean coal technologies" – which will give the various coal, oil and gas companies a perceived leading edge in emission-lean future power generation technologies. There are strong international links, mainly within the Asia-Pacific circle (Japan, USA) and to some extent also to Europe. Many of the leading companies engaged in CCS projects are subsidiaries of foreign companies.

Current CCS projects in Australia

There is currently 14 proposed and ongoing CCS projects in Australia:

Capture only projects:

The Mulgrave IDGCC project. This Integrated Drying Gasification Combined-Cycle (IDGCC) project at Loy Yang in Victoria is pressurized drying and gasification of a 400MW brown coal-fired power plant, with the objective to reduce CO2 emissions by 40%. Precombustion CO2 capture will be employed at a 10 MW pilot scale initially. The project partners are HRL Developments, Harbin Power Engineering Ltd (HPE) and CO2CRC. The project, estimated

[8] www.theage.com.au/news/national/rudd-ratifies-kyoto/2007/12/03/1196530553722.html
[9] www.climatechange.gov.au/projections/pubs/tracking2007.pdf
[10] carbonfinance.org/Router.cfm?Page=FCPF&ft=About
[11] www.greenhouse.gov.au/emissionstrading/about.html
[12] www.globalccsinstitute.com
[13] www.pm.gov.au/media/Release/2009/media_release_0913.cfm

at A$750 million, is supported with A$100 million from LETDF and A$50 million from ETIS (Energy Technology Innovation Strategy).

The CO2CRC/HRL Mulgrave Capture Project will look at three technologies – solvent, membrane and absorbent – for capturing CO2 from the next generation of high-efficiency power stations. To test the new technologies, three CO2 capture rigs have been commissioned at HRL's gasifier research facility at Mulgrave in Melbourne

The Hazelwood Post-Combustion Capture project is a brown coal drying and a post-combustion CO2 capture and storage project at the International Power's Hazelwood facility. The project aims to initially cut CO2 emissions by 30 per cent at a retrofitted 200MW brown coal unit at Hazelwood. The CO2 capture in the order of 25-50 tons per day will be based on ammonia absorption technology. The coal drying demonstration phase of the project will be completed by the end of 2009. The CO2 capture scheme is expected to be operational by 2008.

Project partners are Hazelwood Power/International Power, Alstom, RWE, Process Group and CO2CRC. The total project cost is A$369 million. The Australian Government is contributing A$50 million through the LETDF and the Victorian Government an additional A$30 million.

The Loy Yang Post-Combustion Capture project. A mobile pilot PPC facility provided by CSIRO will be tested at Loy Yang Power's coal power plant. The capture capacity is up to 5,000 ton per year. Project partners are Loy Yang Power, CO2CRC, CSIRO and the Process Group. The project cost is A$5 million.

The Munmorah Post-Combustion Capture project aims to investigate the potential to adapt post carbon capture (PCC) ammonia absorption processes to Australian conditions. Delta and CSIRO are jointly developing a $5 million research scale pilot facility at Munmorah Power Station on the NSW Central Coast to capture (and release) up to 3,000 ton per year of CO2. The first phase will capture up to 11 ton/day. It will use ammonia absorption technology, and is expected to be operational by mid 2008.

Transport ad storage is currently not included in the project, but the State government is looking into four possible carbon storage sites in the state.

The Tarong Energy Post Combustion Capture project is a A$5 million joint pilot project to capture greenhouse gases. The project will see the installation of a post-combustion capture (PCC) pilot plant at coal fired Tarong Power Station, 45km south of Kingaroy. The pilot plant is designed to capture 1,500 ton per annum of CO_2 from the power station and is part of a broader research program to identify ways to reduce greenhouse gas emissions from the energy sector. The two-year project will start September 2009, with the pilot plant expected to be operational in the first half of 2009 and the research activities associated with the technology completed in 2011.

The CO2CRC H3 Capture Project project, led by CO2CRC, is based at International Power's Hazelwood plant and overlaps with the Hazelwood Capture Project. CO2CRC is testing a range of solvents and different process configurations using the solvent post-combustion capture plant. In addition, post-combustion techniques using adsorbent and membrane technologies are being developed using two purpose-built rigs.

The Latrobe Valley Post Combustion Capture project is collaboration by Loy Yang Power, International Power, CSIRO and CO2CRC to create a multisite, multi-technology post combustion capture (PCC) hub to identify CCS options for the Victorian brown coal generators.

Capture and Storage projects:

The Callide Oxy-Fuel Project ("Callide Project") is a demonstration of oxy-fuel pulverized coal technology includes retrofitting of a 30 megawatt unit at CS Energy Ltd.'s Callide A in Biloela in Central Queensland. At a later stage the project will include CO2 capture; and transport, injection and storage of the captured and liquefied CO2 in deep geological formations. The project team is assessing potential geosequestration sites to the west of Biloela and plans to select the final location in 2009. The gas volumes are up to 17,000 ton CO2 per year.The project is headed by CS Energy Ltd (CSE) in partnership with IHI Corporation (Japan), J-Power (Japan), Mitsui & Co. (Japan), Schlumberger Oilfields Australia, and Xstrata Coal. Supporting parties are the Australian Coal Association and Queensland Government. JCoal (Japan) is providing man management support to the project.

The total estimated total project expenditure: approx A$206 million, including A$50 million from LETDF.

The ZeroGen project is Queensland Government's demonstration project of Integrated Coal Gasification Open Cycle project combined with CCS.

Stage One of the project will involve an 80 megawatt net coal gasification plant located near Rockhampton in Central Queensland. CO2 emissions will be captured at site and transported approximately 220 kilometres by truck for injection and safe storage in deep underground reservoirs in the Northern Denison Trough.

Stage Two of the project will be developed concurrently with Stage One and will involve the deployment of a large-scale 300 megawatt net coal gasification plant with carbon capture and storage facilities. Stage Two of the project will also be located in Queensland, with a specific site to be determined during the pre-feasibility study.

The capture capacity can be up to 400,000 ton/year.

The project partners the Queensland Government, Australian Coal Association's COAL21 Fund, Shell Development (Australia) and ZeroGen Pty Ltd. A decision on Stage One construction will be taken in 2009 following completion of the Stage One feasibility study.

The project cost is A$445 million.

The Coolimba Oxy-Fuel Project. Aviva Corp. announced the development of a 2x200MV baseload "oxy-fuel ready" power station in the Mid West region of Western Australia. The Coolimba Project will be built from the outset as a coal fired boiler that will be capable of rapid conversion to capture the CO2 produced during the combustion of coal. A 30 MW demonstration project is currently being built in Queensland, and will enter service in 2009.

Converting the boiler to oxy firing is only one step in the process of capturing and sequestering C02. Suitable locations will need to be found for the long term storage of C02. Hence, Aviva will work with the CRC for C02 capture and storage, based in WA at Curtin University, to support the necessary research and development work to allow the C02 to be sequestered immediately after the oxy firing conversion is completed at Coolimba.

Coolimba Power commissioned the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) in February 2008 to undertake a study to assess the potential for the underground storage of CO2 in WA's Mid West region. The $250,000 study is a major step toward low-emission power generation in WA and will position Coolimba among the first commercial projects to adopt this technology in the world.

The project cost is in the order of A$1 billion.

Storage only projects:

The Gorgon CO2 Injection Project is a part of Chevron Pty's sub sea natural gas exploitation project at the Gorgon gas field; one of the world's premier hydrocarbon resources. The gas field is situated 130 km off the northwest coast of Western Australia. The project is world's largest CO2 capture and storage project with a potential to capture 3-4 million ton CO_2 annually from separation of CO_2 from the natural gas.

The project is a commercial-scale demonstration project involving three components:

Capture of CO2 from reservoir natural ga; compressing, drying and liquefying the CO2 and transportation by pipeline to the injection site.

injecting the CO2 2.5 km underground into the Dupuy Formation saline aquifer under the Barrow Island.

long-term monitoring of the stored CO2 to ensure its safety. The project aims to store a total of 125 million ton of CO2 over its 40 years lifetime.

Chevron is operator of the Project with a 50% interest, with ExxonMobil and Shell each holding 25%.

The overall project cost is A$841,3 million. The Australian Government announced in Nov. 2006 that it provides A$60 million from the Low Emissions Technology Demonstration Fund to support the Gorgon project.

The overall project is expected to commence 2009, and CO2 reinjection is expected to start in 2012-13. Data wells have been drilled and a major study of the subsurface is underway.

The CO2CRC Otway storage Project is the most advanced storage project in Australia and the world's largest research and geosequestration demonstration project. The project includes:

Injection of bout 100,000 ton of CO2 will be injected and stored deep underground. The injected gas is a mixture of 80% CO2 and 20% methane) from the Buttress production, and is stored in the depleted natural gas field Waarre C Formation at approximately 2100m below the surface.

a monitoring program, which international and national scientists believe to be the most comprehensive of its type in the world. A wide range of monitoring and verification technologies are being installed including down-hole geochemical and geophysical techniques for monitoring the CO2 migrating plume via the existing observation Naylor-1 well. Drilling of the injection well (CRC-1) was completed in March 2007 and the injection of a mixture of CO2 and methane into a deep geological formation is scheduled before the end of this year.

The budget is A$40 million and funded through the Australian Federal Government through the Australian Greenhouse Office and AusIndustry; The Victorian Government; the CRC program; CO2CRC Pilot Project Ltd (CPPL) industry partners; CO2CRC members; and US Department of Energy.

The project was launched April 2008, and injection will continue into 2009.

CCS Research and Development in Australia

The Federal Government's Cooperative Research Programme has initiated a number of research partnerships, creating so-called Cooperative Research Centers (CRCs):

Cooperative Centre for Greenhouse Gas Technologies (CO2CRC) was established in October 2003 to take over the work done under the APCRC with the GEODISC project on geological storage/geo-sequestration. The research area was extended to also include CO2 capture, where research on pre-, post- and oxy-fuel combustion is done in collaboration with e.g. NTNU and US/Canadian universities. CO2CRC also contributes on the Sleipner project. CO2CRC are involved in a number of projects within CO2 storage and CO2 capture technologies. In addition, the centre is central in the Otway Basin Pilot demonstration project. The budget over 7 Year (2003-2010) is in the order of $A140 million until 2010.

Cooperative Centre for Coal in Sustainable Development (CCSD) is mainly engaged in assessment and technology development of zero-emission coal power plants, such as oxy-fuel and Integrated coal Gasification Combined Cycle (IGCC). CCSD is part of the Callide-A oxy-fuel working group. CCSD will be terminated mid 2008.

Centre for Low Emission Technologies (cLET) is a partnership between the Queensland Government, CSIRO, Stanwell, Tarong, ACARP and the University of Queensland. The primary focus of the Centre is on research and development of next-generation low emission technologies with an emphasis on improved gas cleaning, gas separation and gas conditioning technologies for the development of Pulverised Coal (PC) and IGCC based, advanced power and/or hydrogen and syn-fuels production technologies. Five main program areas of work associated with the development of the core technologies identified above will be pursued in the work undertaken by the centre. These include gasification and core facility development, gas cleaning, gas processing (or conditioning), gas separation and social and economic integration. The cLET will end in 2009.

Commonwealth Scientific and Industrial Research Organization (CSIRO) conducts research and technology transfer in pre- and post-combustion capture as well as technical developments in CO2 storage in relevant Australian situations. CSRIO is involved in a number of projects in collaboration with various institutions on

Scenario development and modeling program with Government, industry and community groups to develop possible scenarios for future Australian energy demand/supply and to model the scenarios for their economic and environmental (GHG) impacts.

Pre-combustion: develop expertise and knowledge through gasification research of Australian coals. Programs are conducted with the CRC for Coal in Sustainable Development.

Gas Separation: key technology for clean coal gasification and CO_2 separation with the principal research vehicle the Centre for Low Emissions Technology.

Post-Combustion: proposal for demonstration of post-combustion capture for existing black coal and brown coal fired generators.

CO_2 Sequestration: CSIRO is a partner in the CO2CRC.

International demonstration projects

Australia is member country of the Carbon Sequestration Leadership Forum, and they hosted the 3rd meeting in 2004 and play an active role in various task teams and committees.

Most of Australia's international activity related to CCS RD&D is under the Asia-Pacific Partnership on Clean Development and Climate and a majority of these initiatives are actually in Australia, with other countries such as Japan, US participating in Australia. Some exemption is CSIRO's participation in the recently completed RECOPOL project ('Reduction of CO2 emission by means of CO_2 storage in coal seams in the Silesian Coal Basin of Poland') in Poland, and CO2CRC's participation in the Frio Brine Project in Texas.

AP6 partners Australia, Canada, China, India, Japan, Republic of Korea, and the United States have agreed to work together and with private sector partners to meet goals for energy security, national air pollution reduction, and climate change in ways that promote sustainable economic growth and poverty reduction. The Partnership will focus on expanding investment and trade in cleaner energy technologies, goods and services in key market sectors.

In November 2007, Australia and China signed a partnership agreement that will pave the way for the installation of a post combustion capture (PCC) plant in Beijing 2008. Signed by CSIRO (Commonwealth Scientific and Industrial Research Organization) Energy Technology Chief Executive, Dr Geoff Garrett, and Mr Li Xiaopeng, the President of China's state-owned energy enterprise, the China Huaneng Group, the agreement will see the plant installed at the Huaneng Beijing Co-generation Power Plant.

Australia-China Joint Coordination Group on Clean Coal Technologies was announced in April 2008. The Australian government will invest A$20 million in this partnership as part of it's A$500 million Clean Coal Fund.

CHINA

Although the first phase of the Kyoto Protocol exempts China from reducing its own CO2 output, China, as the first or second largest CO2 emission country, is facing growing international political pressure. As a responsible big country, China will almost certainly have to respond to climate change in the future. China is entering unexpected fast development period of the industrialization, urbanization and motorization, in which large-scale new infrastructures will be built.

This provides great opportunity to plan for longer-term CO2 mitigation—the infrastructures built today have a long life time and are not easy to upgrade the technologies involved, and decisions made now will have a major impact on energy utilization mode and CO2 mitigation technology option in coming years. Carbon Capture and Storage (CCS), as an option in the portfolio of mitigation actions to combat climate change, is expected to have far-reaching implications for China.

CCS projects in China

There are only two ongoing CCS projects in China:

- **GreenGen**: GreenGen is a joint venture representing China's largest electric utilities and coal companies. China Huaneng Group is managing partner. It is China's centerpiece initiative to advance near-zero emissions coal-fueled generation with CCS. The project includes multiple phases between 2006 and 2020 for additional generation and capture. The total investment is about RMB 7 billion. The first phase of GreenGen will build a 250 MW IGCC plant. The later phase will have a 2 400 MW IGCC with CCS.
- P**CC Demo Project**: The project is China's first Post Combustion Capture (PCC) demonstration project. As one part of APP, the project is based on the agreement between the Australian government research organization CSIRO and China's Thermal Power Research Institute (TPRI). TPRI is responsible for the installing, commissioning and operating of the PCC pilot plant at the Huaneng Beijing Thermal Power Plant, with all of its equipments domestically made. The project was put into operation on July 17, 2008, with a capability of recovering more than 85 percent of CO2 from flue gases and can thus trap 3,000 ton of the gas annually.

In addition, China is engaged in a number of international CCS projects and programs.

- **The CSLF** (Carbon Sequestration Leadership Forum) is an international climate change initiative that is focused on development of improved cost-effective technologies for the separation and capture of CO2 for its transport and long-term safe storage. China was one of the initial members of CSLF, and the Chinese Ministry of Science and Technology (MOST) is engaging in the forum on behalf of China.
- **FutureGen** is a public-private partnership to build a first-of-its-kind coal-fueled, near-zero emissions power plant. In 2005, the China Huaneng Group—China's largest coal-fueled power generator—joined FutureGen Alliance. The investment from Huaneng in FutureGen accounts for two percent of the total investment. However, Huaneng is in a position to share the technology and achievements of FutureGen as a shareholder.
- **COACH** (Cooperation Action with CCS China-EU) is a Sino-EU research project aimed at creating a strong and durable cooperation between China and Europe. Responding to the fast growing energy demand of China, COACH will prepare the ground for new energy technology options that employ CCS—including the use of CO2-EOR (Enhanced Oil Recovery) or CO2-ECBM (Enhanced Coal Bed Methane Recovery).
- **NZEC** (Near Zero Emissions Coal) is a joint venture initiative between the UK and China. It is designed to help build capacity for CCS in China. It is hoped NZEC will lead to a demonstration project starting up between 2010 and 2015. COACH and NZEC are part of the EU-China Partnership on Climate Change. Chinese partners in both include Administrative Centre for China's Agenda 21 (ACCA21), Tsinghua University, Zhejiang University and GreenGen.
- **APP** The Asia-Pacific Partnership on Clean Development and Climate (APP) is a voluntary partnership among seven major Asia-Pacific countries—Australia, Canada, China, India, Japan, Korea, and the United States—that have joined together to address increased energy needs and the associated issues of air pollution, energy security, and climate change. The partners intend to accelerate the development and deployment of cleaner, more efficient technologies to meet national pollution reduction, energy security and climate change concerns in ways that promote economic development and reduce poverty.
- **GeoCapacity**, co-funded by the EU within FP6, will provide the storage capacity data required for the Europe wide adoption of CCS. It will also build a framework for international cooperation, especially with other CSLF countries (notably China, India and Russia), focusing on technology transfer facilitating the countries to undertake similar studies, as these countries perhaps face an even greater challenge to reduce CO2 emissions due to their rapidly growing energy demands. MOST has joined the GeoCapacity initiative as a full project partner. Under the supervision of MOST, Tsinghua University and Chinese Academy of Sciences participated into the GeoCapacity research project.

Canada and USA

GOVERNMENTAL PROGRAMS AND STRATEGIES

General policy Canada

As noted in the CCS roadmap issued in 2006 by National Resources Canada, CCS is strategically important for Canada for several reasons. First and foremost, Canada is endowed with an abundance of fossil fuels, including an unparalleled oil sands resource, around which a very strong set of industry sectors already exist. Second, CCS will increase reserves through enhanced oil, gas and coal bed methane recovery. Third, reducing CO2 emissions is a critical federal government policy priority as noted in Canada's climate change plan, which concluded that CCS technology could play a prominent role in domestic GHG reductions. Finally, Canadian researchers and energy industries are already recognized internationally in certain areas of CCS and if Canada maintains its competitiveness it could reap large economic advantages.

An election in the province of Alberta has delayed a guide to limits, scheduled for release in the first half of 2007. According to some industry officials, there is still concern with the cost and benefit of enhancing EOR- all life cycles have not been evaluated, and liability from leakage, to a missing regulatory framework.

The Harper government has said they'll lay out emissions targets in 2007 for various sectors. Environmentalists work that Ottawa and Alberta will set targets that merely reflect the energy efficiently improvements that the oil sands producers are already expected to achieve in their expansions.

The conservative Government will not allow Canada to purchase credits from other countries to exceed their potential limits, Harper's Conservatives have promised to focus n technological innovation. **Governments have been careful to not be seen subsidizing the highly profitable oil industry.** Added government industry partnership is critical to kick start the development of an expensive new technologies.

Canada's Prime Minister Stephen Harper, Addresses The United Nations Secretary-General's High-Level Event on Climate Change in New York:

> "In the near-term, the world will continue to rely heavily on fossil fuels. As a major, reliable producer, Canada will play an increasingly important role in global energy security. We therefore have a responsibility to find cleaner and more efficient ways to convert hydrocarbons into energy. "Canada is working on a variety of strategies, but one of the most exciting is carbon capture and storage.. "It holds great potential for major emission reductions at home and abroad…Trapping it there creates a virtuous energy cycle: We take hydrocarbons out, tap their energy, and put the emissions back. The Government of Canada and the Province of Alberta have established a Carbon Capture and Storage Task Force that will develop practical options for government and industry to work together to implement this technology on a large scale in Canada".

The topic of climate change and the oil sands have been in the headlines for the past six months, and recently the price of oil has been taking the spotlight. The government is feeling pressure to meet public demands and concerns about these issues.

Oil sands operations were once seen as blight in the middle of Canada's heartland, and seen as completely infeasible and totally dirty. The government as well as many private stakeholders have come up with plans to address cleaner upgrading (much bigger issue than just CO2), making permitting a simpler process and to strongly encourage new upgrader proposals to include CCS lest they be turned down.

The re-elected Conservative Government (federal election in November 2008) led by Stephen Harper will implement the "Turning the Corner" action plan to reduce Canada's greenhouse gas emissions in absolute terms by 20 per cent over 2006 levels by 2020. The goal is a North American cap and trade system for greenhouse gases and air pollution, with implementation to occur between 2012 and 2015. Current unrest in the Canadian parliament would mean that the Conservative government may lose all of its power because of a possible coalition between the centrist (Liberal), leftist (New Democrats) and Bloc (Quebec) parties. January 2009 will see the resulting government.

Canadian Government

On March 10, 2008 the Canadian Environment Ministry announced new controls requiring carbon sequestration from 2010, including criminal sanctions for violators.

Environment Canada released new actions and steps in for Canada's Carbon Capture and Storage Roadmap:

- **Immediate Action #1** – Federal and Provincial governments should allocate $2 billion in new public funding to leverage the billions of dollars of industry investment in the first CCS projects. This funding should be distributed expeditiously through a competitive request for proposals process so phase-one projects are operational by 2015.
- **Immediate Action #2** – Authorities responsible for oil and gas regulation should provide regulatory clarity to move the first CCS projects forward by: quickly confirming legislation and regulation related to pore-space ownership and disposition rights; clearly articulating the terms for the transfer of long-term liability from industry to government; and increasing the transparency of regulatory processes.
- **Immediate Action #3** – Federal and Provincial governments should ensure as much opportunity for CCS projects under the GHG regulatory frameworks as for any other qualifying emission reduction option. This will require the creation of CCS-specific measurement and crediting protocols.
- **Next Step #1** – Industry and both government levels should form a collaborative framework including an advisory group over the next two years to coordinate discussion, to institutionalize learning, and to potentially carry out specific aspects of immediate actions 1, 2, and 3.
- **Next Step #2** – Federal and Provincial governments should provide stable financial incentives to help drive CCS activities beyond the phase-one projects. These may include the continuation of RFPs for phase-two projects, CO2 storage incentives, and/or the use of tax and royalty incentives.
- **Next Step #3** – Canadian-based research organizations and technology developers should focus research and demonstration efforts on CCS to achieve two goals: to drive down the cost of existing CCS technologies; and to enable the deployment of next generation CCS technology and processes.

The Federal and Provincial governments should provide financial support for these activities.

The potential for underground storage of CO2 in Western Canada is already well known. The new funding from the Government of Canada will be used to assess whether similar CCS opportunities can be developed in Nova Scotia, where coal-fired generating stations supply some three-quarters of the province's electricity.

Budget 2008 committed $250 million in funding for CCS research. In addition to the $5 million in funding for the Nova Scotia project, Prime Minister Harper announced $240 million for the Boundary Dam Project in Saskatchewan on March 25, and Minister Lunn announced $5 million in funding for the Institute for Sustainable Energy, Environment and Economy at the University of Calgary on April 4.

There will also be a $155.9-million federal grant and a joint task force to study creation of a large-scale pipeline and storage network in Alberta,. This money will be spent to figure out the roadmap to the $1.5-billion CO2 pipeline for EOR. Government sources have suggested that $1.5 billion is an outdated figure, and just a starting point.

The task force will be chaired by the CEO of TransAlta, and has been asked to offer recommendations later this year. The $155.9-million s also designed to go towards an Edmonton project that converts garbage into electricity and technology for cleaner coal-based power generation.

Alberta takes the lead

As one of the largest energy producers in the world, Alberta's challenges are perhaps bigger than those of other jurisdictions, but so are the opportunities to make a real and positive impact. Alberta's climate change strategy takes the province's unique position as a starting point. Given the world's continuing reliance on Alberta's supply of oil and gas, all projections point to continued strong growth in Alberta's economy over the next few years.

In January 2008, the Alberta government released Alberta's 2008 Climate Change Strategy14. Alberta's emissions are projected to grow to 400 megaton (Mt) by 2050, largely due to forecast growth in the oil sands sector. The new plan will cut the projected 400 Mt in half by 2050, with a 139 Mt reduction coming from carbon capture and storage—the bulk of those reductions (100 Mt) will come from activities related to oil sands production.

Alberta's approach is focused on three broad initiatives:

- Implementing carbon capture and storage;
- Conserving and using energy efficiently; and
- Greening energy production.

Together these initiatives will deliver a 50 per cent reduction in emissions by 2050 compared to business as usual or a 14 per cent reduction below 2005 levels.

Implementing carbon capture and storage –139 megaton

Alberta is the first jurisdiction in North America to direct dedicated funding to implement carbon capture and storage technology across industrial sectors. The technology will be responsible for 70 per cent of our emissions reductions by 2050 – the bulk of those reductions will come from activities related to oil sands production.

[14] http://www.environment.alberta.ca/1319.html

In the coming months, the provincial government will outline specific implementation plans to move ahead with the actions in this strategy. The government will report regularly on progress made and adapt the strategy as more is learned.

Test Wells in Alberta

The Government of Alberta announced that three test wells will soon be drilled for a large-volume CCS project in Alberta, Canada, to support Alberta's Climate Change Strategy by examining the CO2 injection capability and storage capacity.

Through the Alberta Energy Research Institute (AERI), the Government of Alberta is providing $6.6 million in funding for the three-year, $20-million project near Shell Canada's Scotford facility. According to Shell, the first well will be drilled at the Scotford upgrader site and two more wells would be located 10 and 60 kilometers away. Two more wells may have to be drilled to understand the geology of the area, as there are few cores available to study. Shell has already initiated the engineering and design work necessary for the bitumen upgraders to add carbon capture technology and officials project small amounts of CO2, likely between 50 and 100 ton of CO2 per year, could be captured and injected, eventually increasing to 1.2 million ton per year.

The field test phase is expected to conclude by June 2010. The funding is independent of Alberta's $2 billion CCS fund, which seeks to reduce CO2 emissions by up to 5 million ton per year by 2015 through the development of three to five commercial-scale CCS projects.

The Alberta Saline Aquifer Project announced that five companies were awarded contracts for the engineering, design, and environmental-related work needed for Phase I of the initiative. Specifically, Norwest Engineering will identify three potential aquifers in Alberta, Canada, with the assistance of an Athabasca Basin data log donated by ConocoPhillips.

Schlumberger Carbon Services will develop a set of MMV protocols. A company called Colt WorleyParsons will produce a pre-FEED study and cost estimate on the compression and pipeline system to carry the CO2 in liquid form to the sequestration sites and conduct a preliminary study of any health and safety concerns that could affect the public, wildlife, or the environment.

Hatch Energy will design and prepare a cost estimate for the facilities needed at the sequestration sites. Finally, Oxand Canada will develop risk and mitigation strategies associated with compressing, transporting, and sequestering CO2.

The contracts indicate that Phase I, which includes the identification of viable formation locations and applications for permitting, is on schedule for completion by the end of 2008. Several companies have agreed to donate a reservoir injection simulation and a report containing recommendations on several MMV approaches to achieve the project's Phase I goals. ASAP believes that Phase II, consisting of constructing the pilot project and initiating CO2 injection, will begin in 2009 depending on approval. The initiative's Phase III activities entail expanding the pilot-scale project to a large-scale, commercial operation.

Climate Change and the Oil Sands

Oil sands projects in Canada could face tougher regulatory scrutiny after a federal court ruling on March 6, 2008, which found the approval of Imperial Oil Ltd.'s $8-billion oil sands mine insufficient on climate change and greenhouse gas emissions. Numerous large proposals are in the regulatory system right now, including major mines by Total SA of France, by Anglo-Dutch Royal Dutch Shell and by Petro-Canada, as well as steam-injection projects by EnCana of Calgary. StatoilHydro's project has been delayed 2 years. All projects beginning after 2012 will have to have CCS in their plans, or not be permitted at all.

The production of bitumen and synthetic crude oil emits higher greenhouse gas (GHG) emissions than the production of conventional crude oil and has been identified as the largest contributor to GHG emissions growth in Canada, as it accounts for 40 million ton of CO2 emissions per year.

While the emissions intensity of producing oil sands has decreased substantially, i.e., 26% over the past decade, total emissions are expected to increase due to higher production levels. Currently, to produce one barrel of oil from the oil sands releases almost 75 kg of GHG with total emissions estimated to be 67 megatonne (Mt) per year by 2015.

The general sentiment at this moment in the oil sands is "Pause". Regulators are under pressure to deal with public outcry about the perceived environmental disaster the oil sands are, and infrastructure in some areas of the province are collapsing under the weight of labor and social problems. Areas like Alberta's Heartland, northeast of the capital city of Edmonton, are coming up with comprehensive development plans, which will include everything from schools, roads and other transit systems all the way to CO2 pipelines.

CCS technology will not be a viable solution in the oil sands. The emissions aren't pure enough, and the opportunities are limited to upgrader facilities. There is currently more controversy recently about the oil sands, because the major Canadian broadcaster CBC did (another) negative story on CCS in the sands. The story quoted David Keith, lead scientist on the carbon capture task force and renowned scientist saying "frustrated that politicians and the industry keep focusing on the oil sands when there are sources of greenhouse gases to capture more easily and at less cost, including coal-fired power plants." He went on to say that "rational people shouldn't focus on reducing emissions in the oil sands through CCS".

Environment Minister Jim Prentice says that CCS is not the answer to reducing greenhouse gas emissions from oil sands projects in northeastern Alberta. While Ottawa and Alberta are spending billions of dollars on CCS demonstration projects, the minister has acknowledged what critics have said all along: The technology has limited application at the energy-intensive mines and insitu projects that extract the bitumen from the ground.

However, CCS could play a major role in virtually eliminating carbon dioxide emissions from upgraders that process the bitumen into synthetic crude oil, thereby reducing the carbon footprint of oil sands projects over all. The industry will have to rely mainly on other technologies to reduce emissions at the production sites, he said.

The oil sands represent the fastest-growing source of emissions in Canada. Without dramatic mitigation efforts, Canada will find it nearly impossible to meet its target of reducing greenhouse gas emissions by 20 per cent from 2006 levels by 2020, according to the National Round Table on the Environment and the Economy, a government-appointed advisory group. Mr. Prentice said he intends to spell out the government's policy on greenhouse gas emissions for each industry, including the oil sands, before the Copenhagen climate change conference in December. He then expects to unveil next year the actual regulations, which will take effect on Jan. 1, 2011.

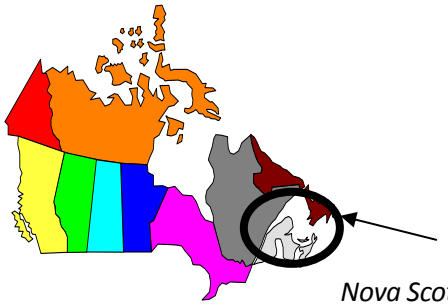
The minister said Canada will pursue policies that are comparable but not identical to those in the United States. Climate change rules here "will be driven by Canada's national interest," he said. Mr. Prentice said CCS is particularly critical for the coal industry because coal-fired power is a far greater source of greenhouse gas emissions globally than is the oil industry. Ottawa is funding coal power CCS projects in Saskatchewan and Alberta, while the Alberta government will soon announce funding for carbon capture projects involving a coal-fired plant and, likely, an oil sands upgrader. Older oil sands projects, including the mines at Syncrude Canada Ltd., and Suncor Energy Inc., have upgraders on site that process the bitumen into lighter synthetic crude oil.

With the proposed expansion in the oil sands, several companies are planning to build upgraders in central Alberta. A stand-alone upgrader would account for 40 per cent of emissions that result from producing a barrel of synthetic crude oil from an in situ project, and 60 per cent of emissions from a barrel that comes from a mining operation.

Eliminating emissions from upgraders would go a long way to making the overall emissions from an oil sands project comparable to that of conventional light oil. While Imperial Oil Ltd. has begun construction of its Kearl oil sands mine with no special technology for reducing emissions, several companies are pioneering new approaches - especially for in situ projects, which could substantially lower CO2 emissions.

Both Suncor and EnCana are experimenting with the use of solvents to reduce the need for natural-gas-generated steam to free up the bitumen. While those approaches could prove commercially attractive by reducing costs, Mr. McColl said their adoption could be speeded through government support and the introduction of effective carbon caps.

Nova Scotia public funding



Nova Scotia

The Ministry of Natural Resources, announced in April 2008 that the Government of Canada will provide $5 million to support CCS research in the province of Nova Scotia.

British Columbia carbon tax

Starting in July of 2008 carbon emissions for fossil fuel consumed in the province will be taxed at $10 a ton, rising by $5 a ton over the next four years to $30. Those costs will be built into the price of fuel, with a liter of gasoline hit with a 2.41-cent tax this year, rising to 7.24 cents by 2012.

The starting point is low; far below what anyone believes is needed to curb energy consumption. But the cost of carbon will rise, and by the end of the four years, it will approach a traction point where higher energy prices start changing patterns of consumption.

The carbon tax applies only to fuels and doesn't deal with the remaining quarter of greenhouse gas emissions from heavy industry. B.C. has yet to decide what precise policies it will take to reduce industrial emissions, although the province has said it will adopt some version of a system that caps emissions and allows companies to trade carbon credits. The greenhouse gases emitted from the production of the cement are, as yet, unregulated. That will change some time before 2010, by which time B.C. and other provinces and states that are part of the Western Climate Initiative (WCI) are expected to have the rules set for a regional cap-and-trade system. Issues to consider

include industrial allotment of carbon credits, emission reduction targets, and jurisdictional issues between the US and Canadian border.

US and Canada Partnering

According to a White House official, the United States and Canada announced plans to work together on clean energy technology, including CCS, as a way to meet their goal of cutting emissions from within their countries. As part of the agreement, both countries will advance technologies and collaborate on a Smart Grid. The focus of the plan is to mitigate emissions from existing energy sources, specifically from Alberta's oil sands and America's vast coal deposits. Funding will come from both governments' respective stimulus packages, which have a portion set up for clean energy. The agreement is viewed as the first step towards bringing together Canadian and American environmental regulations to limit GHGs.

General policy US

According the Department of Energy's roadmap issued in 2006, the Carbon Sequestration Program highlights include a number of main focus; Regional Carbon Sequestration partnerships; Amine based CO_2 capture; Novel CO_2 capture technologies including novel metal organic frameworks as CO_2 sorbents and organic salt, an ionic liquid, better than selexol and finally Stacked geological formations.

Barak Obama

With the election of President-elect Barack Obama and the shift toward a Democratic Congress, there going to be changes in the national energy policy. During his campaign, Obama published a proposed energy plan that has a two-pronged approach of climate change and energy independence. His climate-change program includes mandatory reductions of greenhouse-gas emissions to 80 percent below 1990 levels by 2050. He has also proposed a 10-year, $150-billion fund for renewable energy including biofuels, wind, solar, plug-in hybrids, and clean-coal technology. The plan would require utilities to produce 25 percent of their power from renewable energy by 2025. Obama's priority is to develop clean-coal technologies. He wants to create five coal-fired demonstration plants that would capture carbon emissions and store them underground. His commitment to coal is not surprising, given his background. His home state of Illinois is ranked ninth among coal-producing states. Obama supported the state's bid for the FutureGen experimental coal-fired power plant with underground storage. Obama has not yet indicated who he will choose to run the Department of Energy, a decision that will have a great impact, and he has also not provided enough details to determine the additional costs to the energy industry to achieve its goals.

He told the San Francisco Chronicle in January that if regulatory limits are placed on carbon emissions, then it would discourage the building of traditional coal-fired plants. That is because utilities will then have to buy credits or add new technologies to comply with the limitations. In making his case, he used the term "bankrupt," which set off anger among coal advocates. Coal provides more than half of the the US's electric generation mix. According to Obama's campaign web site, his administration will "use whatever policy tools are necessary, including standards that ban new traditional coal facilities ... a stringent cap on carbon will also make it uneconomic to site traditional coal facilities and discourage the use of existing inefficient coal facilities." He has also voted to finance innovative uses for coal, such as coal liquefaction that can be used as a motor fuel which is opposed by the green movement.

This sort of tension has meant that Wisconsin Power and Light's proposal to build a 300 megawatt coal plant that could also burn up to 20 percent biomass was turned down. Regulators rejected the $1.26 billion facility, saying that the utility had less expensive options and that potential new carbon rules made the proposition too risky.

The DOE is continuing with its breakthrough CO2 projects listed in previous installments of this report, and the IEA has just announced that it views the US/ Canada partnership program as the most aggressive in the world. This is excellent rebranding and public relations for the US after the Futuregen project was seen as a failure by many.

US Environmental Protection Agency- New Rule[15],[16]

On March 10, 2009, the U.S. Environmental Protection Agency, proposed a new rule that requires industries to report their GHG emissions. Covering any upstream suppliers of fuels or direct emitters that emit at least 25,000 metric tons of GHGs per year, the rule would affect a range of industrial plants and operations, such as power plants, refineries, coal mines, and auto and engine makers – approximately 13,000 facilities, or 85 to 90 percent of all U.S. emissions. The rule is expected to cost industries $160 million for the first year, and $127 million annually in the following years. EPA plans for the new reporting requirements to go into effect by 2010, with the first annual report submitted in 2011 for the 2010 calendar year, with the exception of the vehicle and engine makers, who would begin reporting with model year 2011. According to a draft EPA presentation, the agency also plans to issue an "endangerment finding" in mid-April that will address the relation between GHG emissions and human health. After public hearings, EPA could be allowed to regulate GHG emissions under the Clean Air Act, which mandates the collecting of data on emissions from power plants.

[15] www.epa.gov/climatechange/emissions/ghg_infosheets.html

[16] www.epa.gov/climatechange/emissions/downloads/MRR-Rule.pdf

Regulation standards

CAPTURE

Neither the US or Canada enforce regulatory standards for power plant efficiency. Installation of a new CO2 capture plant is unlikely to trigger new permitting issues in this context. Safety is covered under existing health, environment and safety regulations. In Canada, changes in exhaust parameters will be handled through existing codes of practice and pollution prevention plans, which could include CO2 if changes in designation are made at the federal level.

TRANSPORT

State/provincial level regulations in the US and Canada are long established for permitting pipeline transport of hazardous gases including CO2 for the purpose of EOR in the Permian Basin and acid gas from oil production in Alberta and BC.

CO2 STORAGE

There are established regulations for any above ground installation for injection of CO2. For below ground, Class 1 UIC covers injection of hazardous materials, Class II regulates wells injecting CO2 for EOR purposes. Class V covers research wells. Most consider that class I or II should be applied to CO2 injection. Depending on state level implementation, class I or II generally lays down requirements on well construction, monitoring and testing by regulators. US Environmental Protection Agency (EPA)[17] is considering introducing Class VI for CO2 injection. CO2 storage operation on Federal lands is likely subject to review under the National Environmental Policy Act. In Canada, acid gas injection regulations in Alberta and BC generally lay down controls on citing of wells, monitoring requirements for wells and various other technical controls on well operations. Province level Environmental assessment regulations are also wide ranging in coverage, and could likely imposes strict environmental quality standards for CO2 storage site monitoring requirements for environmental protection policy.

Although the Interstate Oil & Gas Compact Commission (IOGCC)[18] concluded that CCS regulatory issues could be covered under existing regulations in both the US and Canada, the US EPA is currently reviewing the regulatory scheme that could be applicable to CCS operations in the US, with a view to drawing conclusions over the next year or so. Some say the Canadian regulators are more in line with the view of the IOGCC and consider that no new regulations are needed for CCS in the future.

Interstate Oil and Gas Compact Commission – Regulation update for US and Canada[19]

On September 26th, the IOGCC released a clear and comprehensive model for legal and regulatory framework for storage that should meet the unique requirements for each Canadian province and American state.

The report recommends the provinces and states actively solicit public involvement as early as possible in the site selection process, and that the process remains as transparent as possible. It also stresses that CO2 is viewed in a manner that allows beneficial uses of CO2 following removal from regulated emission streams. Hydrogen sulfide, nitrogen oxide and sulfur oxide should remain highly regulated for public health, safety and environmental concerns.

The carbon storage standards are rigorous and have been jointly developed by the affiliates of the IOGCC, who all have extensive CO2 experience and expertise through the oil and gas regulation industry, as well as EOR. There is a proposal for long-term monitoring and liability closure periods, where the operator of the storage site would be liable for ten years after the injection site is plugged, unless otherwise designated longer by state/province regulations. A trust fund will also be industry-funded and would provide oversight after the 10-year period. The trust fund would be funded by a fee assessed to the storage operator and calculated per ton.

The IOGCC assists member states efficiently maximize oil and natural gas resources through sound regulatory practices while protecting public health, safety and the environment. The Commission serves as the collective voice of member governors on oil and gas issues and advocates states' rights to govern petroleum resources within their borders.

[17] www.epa.gov
[18] www.iogcc.state.ok.us
[19] www.iogcc.state.ok.us

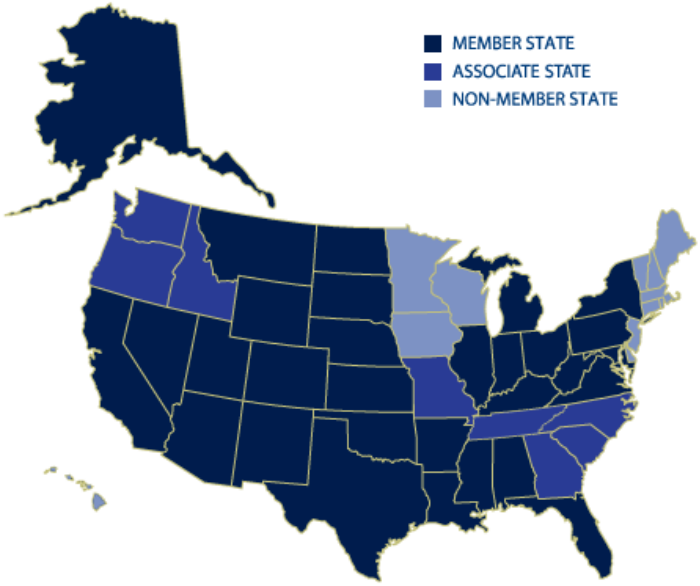


Figure 1: IOGCC member status.

International Affiliates:

- Alberta
- British Columbia
- Egypt

Republic of Georgia

Newfoundland and Labrador

Nova Scotia

Venezuela

Other:

U.S. Department of Energy

U.S. Department of the Interior

U.S. Environmental Protection Agency

Federal Energy Regulatory Commission

National Association of Regulatory Utility Commissioners

Public CCS funding initiatives and partnerships - Canada

ecoENERGY Technology Initiative

The $230-million ecoENERGY Technology initiative was launched in 2007 to support the development of technologies to increase Canada's supply of clean energy, reduce energy waste and reduce the environmental impact of the production and use of conventional energy. It is one of a series of ecoENERGY initiatives through which the Government of Canada is investing a total of $3.6 billion to work with Canadians to increase production of cleaner energy and cleaner fuels and increase energy efficiency. The eight successful projects were selected in response to a call for proposals issued by the Government of Canada in April of 2008. Under the ecoENERGY Technology initiative, up to $140 million will be invested in these projects to support industry-led research, development and demonstration of CCS technologies. The Government of Canada will now invite the project proponents to begin negotiations toward formal contribution agreements to set the conditions under which funding will be delivered. The funding amounts are expected to range from $3 million to $30 million for each project.

Montana and Saskatchewan: Development Partners

On May 7, 2009, officials in Montana and Saskatchewan signed a Memorandum of Understanding to develop North America's first large-scale initiative to capture and store GHGs from a coal-fired power plant. The $230 million project would retrofit an existing Canadian coal-fired power plant, owned by SaskPower, for CO2 capture, piping the GHG into northern Montana where it would be injected into deep geological formations for storage. Construction is scheduled for early Fall 2009 and the project is set to go online in 2011. Saskatchewan is investing $42 million and seeking an additional $85 million from the Canadian government; Montana is pursuing a $100-million grant in addition to its contributions of a CO2 pipeline and underground storage facilities. The captured CO2 could also be used for EOR. Early indications by state officials show that Montana's Popular Dome geological formation, east of Medicine Lake, offers the best storage site. The project goal is to capture 1.1 million tons of CO2, approximately 30 percent of the plant's emissions, over the next four years.

On May 6, 2009, Montana Governor Brian Schweitzer signed a bill that creates the regulatory guidelines for storing CO2 underground in Montana. The bill resolves the question of how long a company would be required to monitor a site and remain liable after finishing its CO2 injection in Montana. Under Senate Bill 498, a storage company could transfer a site to the state if it is problem free after 30 years, with the Montana Land Board having final authority to decide if the state should assume liability. If approved, the state would then assume site monitoring and liability obligations. Also, the bill gives ownership of underground pore space to surface landowners. The Montana Land Board is responsible for overseeing the management of 5.2 million acres of school trust land in Montana

Public CCS funding initiatives and partnerships - USA

US doe partnerships

US DOE Regional Carbon Sequestration Partnership[20] has the following timeline:

- Characterization- 2003-2005
- Validation 2005-2009
- Deployment 2009-2017

During the validation phase, each partnership will focus on conducting small-scale field tests in different geographic regions and geologies. Deployment, planned to begin in 2009 will focus on implementing several large volume sequestration tests. Proposals include 25 geologic sequestration tests to be conducted, and between 1,000 and 525,000 ton of CO2 will be injected at each site.

Permitting and regulation for R and D as well as full-scale deployment needs to be understood regionally before beginning field activity. The US environmental protection agency manages a federal program to oversee the states permitting programs for Underground Injection Control wells. Certain states have primacy for permitting UIC wells, while other states have allowed the EPA to retain authority to permit some or all UIC wells within their states. States that do have primacy must meet or exceed US EPA's regulatory requirements. This situation is reflective of the fragmented nature of decentralized decision making in the US. Because of this, it's critical for involved parties to have a deep understanding of what requirements the partnerships will face when they begin permitting projects.

Plains CO2 Reduction Partnership (PCOR)[21]

The PCOR are developing CO2 sequestration opportunities for the central interior of North America. The partnership includes University of North Dakota energy and environmental research center, Fisher oil and gas inc., Grand Forks, and North Dakota. The detailed account of this partnership is indicative of many other partnerships. Also, this partnership includes oil sand territory.

PCOR includes 50 partners from industry, government and NGOs (Non-Governmental Organization). PCOR is involved in sequestration issues and is one of 7 regional partnerships that the US DOE and the NETL established to assess carbon sequestration opportunities that exist in the United States and Canada. PCOR efforts support the president's global climate change initiative, which seeks to reduce CO2 intensity in the US by 18% by 2012.

The PCOR involves 1.3 million square miles in the central interior of North America and includes nine states and three Canadian provinces: Alberta, Saskatchewan, Manitoba, Montana, North and South Dakota, Minnesota, Nebraska, Iowa, Missouri, and Wisconsin.

In 2000, the PCOR generated nearly 911 million tones of anthropogenic CO2, about 13% of the US and Canadian total. As a whole, electric utilities contributed a greater share of the emissions than the other stationary sources. Regional has abundant geological sink opportunities. Data was gathered for over 1500 oilfields in the oil producing states and provinces of the region. Coalfields in the region were shown in phase I to have significant CO2 storage capacity. Oil fields are speculated to have the capacity to sequester 30 billion ton, saline formations evaluated have a sequestration capacity of 220 billion ton, and the capacity of the coal seams in the region have the capacity to sequester 7 billion ton.

[20] www.fossil.energy.gov/sequestration/partnerships/index.html

[21] www.undeerc.org/pcor

Region	Electric Utilities	Other Stationary	Transportation	Total
US region PCOR	297.83	118.23	117.89	663.95
Canadian PCOR partnership	72.84	128.67	45.40	246.91
PCOR Partnership	370.67	316.90	223.29	631.62
Canada and US Total				6305.85

Summary of major stationary CO2 sources in the PCOR partnership regions

Source Type	Quantity	% of all sources	Co2 Emissions, mTon/yr	% of all CO2 emissions
Electricity Generation	170	12.2	370.67	65.7
Paper and Wood Products	141	10.1	35.4	6.3
Petroleum and Natural Gas processing	32	2.3	28.94	5.1
Chemical and Fuels Production	43	3.1	24.16	4.3
Ethanol Production	63	4.5	16.43	2.9
Petroleum Refining	21	1.5	16.01	2.8
Cement production	16	1.1	13.94	2.5

Commercial oil and gas are present in five states and all of the provinces of the region. CO2 based EOR and ECBM are value-added sequestration technologies with the potential for expanded commercial scale development. In the near term, EOR is attractive because the oil and gas bearing geologic strata is well characterized and the cost of developing sequestration infrastructure can be offset by EOR. These lessons learned through EOR and ECBM can be applied to saline aquifers and coalfields of the PCOR partnership region that in some cases extend unbroken over thousands of miles.

Source and sink matching:

CO2 individual sources and sinks were matched, and were determined a single source depending on similar physical properties and relative close proximity. A distance of about 125 miles was drawn around the centre of the source and viable geologic sinks within the buffer were identified. Type of sequestration was identified (EOR or injection into a saline formation) was determined from the data. For each match of the geologic sink and consolidated CO2 source, the types of technologies that might be used to separate and capture the CO2 were identified. **KEY to note is that current capture and separation technologies are too expensive under current market conditions for many of the CO2 streams generated in the PCOR region, either because of the types or quantities of impurities present in the stream would prevent effective separation and capture or because the operating pressures of a particular stream composition are not appropriate for the technology.**

A geologic field validation test and oil terrestrial test will be conducted over a 4-year time frame during phase II of this project, including a Field Validation test at Zama (Apache's Zama Acid Gas Enhanced Oil Recovery (EOR) Project)[22]. Acid gas (about 67% CO_2, 33% H_2S) from a natural gas processing plant in northern Alberta will be injected into an oil-producing zone in an underground pinnacle reef structure. Results will help determine the best practices to support sequestration in these unique geologic structures as well as further PCOR's knowledge of the effects of H_2S on tertiary oil recovery and CO2 sequestration. This is only 1 of 4 projects the PCOR partnership region will be home to. Each field test has been designed to gather the data required for monetizing carbon credits for the respective activities, and each will result in a series of best practices manuals that can be used as guides for large scale development of CCS in the future.

The Plains CO_2 Reduction (PCOR) Partnership has begun drilling operations to determine the suitability of a North Dakota lignite coal seam to simultaneously sequester the greenhouse gas CO2 and produce coal bed methane.

The PCOR Partnership—one of seven partnerships in the Department of Energy's Regional Carbon Sequestration Partnership Program, which is managed by the National Energy Technology Laboratory—plans to inject at least 400 tons of CO_2 to a depth of approximately 1,200 feet into an unminable lignite seam in Burke County, ND.

The focus of the drilling operation will be to determine the long-term effect of CO_2 on the lignite and the potential for CO_2 to enhance the recovery of coal bed methane. This effort is important in that North Dakota alone has the capacity to store 380 million tons of CO_2 and the potential to recover an estimated 1.1 trillion cubic feet of methane.

During the drilling operation, researchers used sampling techniques to indicate the presence of gas in the vicinity of the coal seam. The initial core indicates the seam is about 8 feet thick.

The PCOR Partnership will drill five wells in south-eastern Burke County to complete a geologic characterization of the lignite coal seam, as well as the overlying geologic zones in the area. After the wells are lined with pipe and cement, they will be completed as CO_2 injection or coal bed methane recovery wells.

[22] www.apachecorp.com

Overall, the PCOR Partnership will focus on the following factors in the project:

- Methane content, CO_2 storage capacity, and methodology.
- Features of fluid transport in lignite.
- Stability of CO_2 stored within lignite coal seams.
- Factors controlling the success of sequestration and production in lignite.
- Economics associated with the project.

The Energy & Environmental Research Center, located at the University of North Dakota, manages the project and will conduct the 2-year test in two phases. The first phase will include data collection related to the coal seam and an evaluation of the seam's potential to produce coal bed methane. Previous investigations in the area pointed toward a potential for economically recoverable coal bed methane and CO_2 sequestration potential in these deep unminable lignite seams. In phase 2, CO_2 will be injected into the coal seam. During the test, the PCOR Partnership will be collaborating with Eagle Operating Inc., of Kenmare, N.D.

The PCOR Partnership expects to use the data generated from this test drilling to plan for similar sequestration operations throughout the region. The data can also provide information about the potential for additional coal bed methane recovery in the region.

The Plains CO2 Reduction Partnership has begun injecting CO_2 into a deep lignite coal seam in North Dakota to demonstrate the economic and environmental viability of geologic CO_2 storage in the U.S. Great Plains Region. PCOR's Lignite Field Validation Test, one of four tests PCOR is conducting under the Validation Phase of the RCSP program, will inject approximately 400 tons of CO_2 into a 10-foot thick lignite seam approximately 1,100 feet deep. In 2007, a five-spot well configuration was drilled in collaboration with Eagle Operating Inc., consisting of a center injection well surrounded by four monitoring wells. In addition to evaluating the lignite seam's CO_2 storage potential, the project will also study coalbed methane extraction. The results of PCOR's Phase I characterization activities, which showed that the region's low-rank coal seams have the capacity to store up to 8 billion tons of CO_2, also suggested that more than 17 trillion cubic feet of methane could be produced from low-rank coal seams. This will be the first field study conducted on the ability of lignite coal seams to store CO_2.

Southeast Regional Carbon Sequestration Partnership[23]

This partnership is using monitoring equipment installed two miles beneath the surface to track the movement of CO2 being injected for oil recovery. The project, led by the Southern States Energy Board and hosted by Denbury Resources, includes downhole pressure and temperature measurements conducted by the Gulf Coast Carbon Center at the Bureau of Economic Geology, University of Texas at Austin. The effort will examine the instrumentation necessary to ensure safe CO2 storage by verifying CO2 retention in the injection zone, quantify storage capacity, and quantify near- and far-field pressure response to injection. SECARB began injecting CO2 on July 15, 2008, at a depth of 10,300 feet for EOR at the Cranfield oilfield near Natchez, Mississippi. The naturally occurring CO2 is obtained from Jackson Dome and transported by pipeline to the injection site. SECARB plans to inject CO2 at a rate of 250,000 to 500,000 metric tons per year over the next several years into the lower Tuscaloosa Formation. The Tuscaloosa Formation has a potential storage capacity of 10 billion metric tons of CO2. The Cranfield test is one of four pilot tests that SECARB is conducting during the effort's Validation Phase to evaluate storage potential in advance of a large-scale injection that will occur during the initiative's Deployment Phase.

Midwest Regional Carbon Sequestration Partnership received the final permit needed from the Ohio Environmental Protection Agency for Battelle Memorial Institute to initiate the injection of 3,000 tons of CO2 at First Energy Corporation's R.E. Burger Plant in Shadyside, Ohio. Beginning in mid-September, MRCSP plans to inject CO2 over a three- to eight-week timeframe, dependant upon injection zone properties, project setup, and regulatory oversight and monitoring. The OEPA permit allows for the CO2 captured from the coal-fired power plant to be heated under pressure and injected underground for long-term storage. OEPA's well regulations are designed to protect underground sources of drinking water from the injected CO2.

Big Sky Carbon Sequestration Partnership[24]

BSCSP, headed by Montana State University-Bozeman, plans to conduct a large-scale test in the Nugget Sandstone formation at the Riley Ridge Unit on the LaBarge $66.9 million was awarded to the partnership, the last of seven awards administered for the third phase of the Regional Carbon Sequestration Partnership Program's large-scale carbon sequestration projects. Platform in Southwest Wyoming. The test will demonstrate the ability of a geological formation to safely, permanently, and economically store more than 2 million tons of CO2, examine the entire CO2 injection process from pre-injection characterization, injection process monitoring, and post-injection monitoring; and provide the groundwork for future CCS opportunities in the region. The sandstone formations present throughout the region offer the opportunity to store more than 100 years of CO2 emissions from regional point

[23] www.secarbon.org
[24] www.bigskyco2.org

sources. BSCSP plans to drill a CO2 injection wells and inject up to 1 million tons of CO2/year into the Nugget Sandstone formation at an approximate depth of 11,000 feet. The CO2 will be supplied by Cimarex Energy Company's planned helium and natural gas processing plant at Riley Ridge. Including the partnership's cost share, the project is estimated to cost $130.6 million subject to Congress.

As part of the first phase of a joint, pilot-scale project headed by the Big Sky Carbon Sequestration Partnership, Boise Inc. and Battelle researchers have started drilling a layer of basalt approximately three-quarters of a mile underground near Wallula, Washington, to determine if the formation can store CO2. If successful, the Pacific Northwest National Laboratory-based researchers will apply for a state permit to inject nearly 1,000 tons of CO2 into the well, which they are building at Boise Inc. pulp and paper mill. The basalt formation, believed to be 13 million years old, is a result of 300 lava flows and includes layers of rock abundant with sponge-like holes. According to researchers, the CO2 will flow through the layers covered with holes, infusing itself with non-potable water that is trapped in the rock. The carbonated water would then react with the basalt elements and turn into calcium carbonate, allowing the top layer of hard basalt to serve as a caprock.

Midwest Geological Sequestration Consortium / Regional Carbon Sequestration Partnership[25]

The Midwest Geological Sequestration Consortium has nearly completed drilling the first large-scale CO2 injection well in the United States at the Archer Daniels Midland Company's ethanol facility in Decatur, Illinois. The injection well is being drilled into a test area approximately 2,000 feet thick in the Mount Simon Sandstone to a depth more than one mile beneath the surface where core samples of the sandstone will be acquired and analyzed to determine the best area for injection. Once the area is selected, up to 1 million metric tons of CO2 captured from ADM's ethanol production facility will be injected into a deep saline formation from 2010 to 2013. The results of the injection, which will be monitored to ensure safe and permanent storage of the CO2, will provide analysis on the future of carbon sequestration as a viable option for CO2 storage. This is the first drilling into the Mount Simon Sandstone since oil and gas exploratory drilling was conducted some 15 to 40 years ago. Drilling operations for the injection well began in February 2009 and the 10-year life of the project is expected to create nearly 250 full-time jobs. The injection test is part of the Regional Carbon Sequestration Partnership Program's Development Phase managed by the National Energy Technology Laboratory for the U.S. Department of Energy's Office of Fossil Energy. MGSC is led by the Illinois State, Indiana, and Kentucky Geological Surveys and is one of seven NETL-managed RCSPs.

DOE's Midwest Regional Carbon Sequestration Partnership, led by Battelle, has begun injecting 50,000 tons of CO2 into the Michigan Basin near Gaylord, Michigan. The activity builds upon an initial injection project of 10,000 metric tons of CO2 in the same formation and will take place in a deep saline formation, the Silurian-age Bass Island dolomite. The project is expected to last six months, with injections happening at an average rate of 250 tons per hour up to a maximum rate of 600 tons. The first test will take place at an existing oil and gas field, which would also allow for continued EOR operations. This area is ideal for the injection test as it already contains CO2 compressors, injection systems, existing wells, pipelines, and other needed infrastructure. During the injection process, the team will record geochemical changes to the system and the distribution of the CO2 along the wellbore. The CO2 will be transported to the well via an eight-mile pipeline. As the depth of the injection is 3,500 feet, the injection will occur well below the 1,000-foot level of drinking water sources. When complete, the total 60,000-metric ton injection will mark the largest deep saline reservoir injection in U.S. history. The 6-month project and related activities are expected to create more than 230 jobs and 2,900 total project job years.

US DOE partnerships

The DOE released its "Methodology for Development of Geologic Storage Estimates for CO2," a document detailing the procedures used to produce the geologic resource estimates for CO_2 storage potential in the 2008 Carbon Sequestration Atlas of the United States and Canada (Atlas II). The document outlines the procedures for estimating CO2 storage potential in three types of geological formations found in the United States and Canada: saline formations, unmineable coal seams, and oil and gas reservoirs.

DOE announced a solicitation for up to $8.0 billion in Federal loan guarantees for projects that employ advanced technologies that avoid, reduce, or sequester GHG emissions resulting from coal-based power generation, industrial gasification, or advanced coal gasification facilities. This solicitation, marking the third round of solicitations for DOE's Loan Guarantee Program, will make $6 billion in loan guarantee authority available for the incorporation of CCS technologies into industrial gasification activities, as well as retrofitted or new coal-based power generation facilities. The selection criteria for the clean energy projects will focus on a project's ability to avoid, reduce, or sequester GHG emissions; the speed that the technologies can be commercialized; the prospect of repayment of the guaranteed debt; and the potential for long-term market success.

DOE released its second Carbon Sequestration Atlas of the United States and Canada, documenting more than 3,500 billion metric tons of CO2 storage potential in oil and gas reservoirs, coal seams, and saline formations. The second edition of the atlas updates the CO2 storage portfolio, documents differences in CO2 resource and CO2 capacity, and provides updated information on the RCSPs' field activities. It provides updated information on the location of stationary CO2 emission sources, the locations and storage potential of various geologic sequestration sites, and information about commercial opportunities for CCS technologies for each RCSP. NETL created the initial

[25] sequestration.org

atlas and developed it with the RCSPs, as well as the National Carbon Sequestration Database and Geographical Information System. DOE has published both print and interactive editions of the atlas[26].

GE Energy and the University of Wyoming (UW) reached an agreement for work to begin on a proposed development plan for the High Plains Gasification Advanced Technology Center. The center will enable researchers from both GE Energy and UW to develop advanced gasification and clean coal solutions for Powder River Basin and other coals. The agreement outlines the framework for the development, design, construction, engineering, and operation of the small-scale gasification facility. UW will perform a site selection and acquisition process that considers a number of factors, ranging from availability of land appropriate for the facility, availability of necessary utilities and waste disposal facilities, proximity to coal supply, and environmental permitting requirements. While UW owns the facility and retains responsibility for its operation, the agreement calls for GE Energy to lease the facility from the university, with options to renew.

As part of DOE's effort to establish a national "carbon atlas" (NATCARB)[27] in the US, seven research partnerships on CCS has been established. These are all focusing on identify the major sources of man-made CO2 in its territory; assess the status and cost of technologies for separating CO2 from process and exhaust gases at large industrial plants; determine the potential for storing captured CO2 in secure geologic formations; establish the extent to which changes in the management of forests, rangelands, and agricultural lands could increase carbon storage by plants and soil; and assess the logistics of building pipelines to move CO2 from the points of capture to the points of storage. Economic co-benefits will be estimated as well, such as improved timber resource values and increased oil and gas production through CO2-enhanced recovery.

Figure 2: US DEE Partnerships. Source: NETL[28]

Partnership	Description
West-Coast Regional Carbon Sequestration Partnership (Westcarb)[29]	70 public agencies; private companies and NPOs. Lead organization: California energy commission. Focus on CO2 source identification; capture technology and sequestration.
Southwest Regional Partnership on Carbon Sequestration[30]	21 State government agencies and universities, electric utilities, oil and gas companies, non-governmental organizations, the Navajo Nation, and federal agencies Lead organization: New Mexico Institute of Mining and Technology.
Big Sky Carbon Sequestration Partnership[31]	30 public agencies; private companies and NPOs. Lead organization: Montana state university
Plains CO2 Reduction Partnership[32]	50 private and public sector groups from nine states and three Canadian provinces. Lead organization: University of North Dakota, Energy and Environmental Research Center.

[26] http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/
[27] www.natcarb.org
[28] http://www.netl.doe.gov/coal/Carbon%20Sequestration/partnerships/index.html
[29] www.westcarb.org
[30] www.Southwestcarbonpartnership.org
[31] www.bigskyco2.org
[32] www.Undeerc.org/pcor

Midwest Geological Sequestration Consortium (MGSC)[33]	MGSC is a consortium of the geological surveys of Illinois, Indiana, and Kentucky joined by private corporations, professional business associations, the Interstate Oil and Gas Compact Commission, two Illinois state agencies, and university researchers to assess carbon capture, transportation, and storage processes, and their costs and viability, in the three-state Illinois Basin region. Lead organization: University of Illinois, Illinois state geological survey
Midwest Regional Carbon Sequestration Partnership (MRCSP)[34]	Lead organization: Batelle Memorial Institute
Southwest regional carbon sequestration partnership (SECARB)[35]	A diverse partnership involving Southern States Energy Board (SSEB) as project manager; regulatory agencies and geological surveys from eleven member states; the Electric Power Research Institute; the Tennessee Valley Authority; southern utilities; academic institutions; a Native American enterprise; and the private sector.Lead organization: southern states energy board

US DOE's Clean Coal Power Initiative (CCPI) - Round 3

The United States Department of Energy's CCPI has invited private industry to partner with government to demonstrate new clean coal tech at a commercial scale at the beginning of October. This has been released for public comment. Public comment begins immediately in November.

The CCPI is a ten-year $ 2 billion project initiated in 2002 in response to the Bush administration's support for clean-coal technology to demonstrate advanced coal-based power generation technology at the commercial scale. The DOE is seeking new and innovative technologies rather than new applications or minor improvements to existing technology. Potential projects must ensure a minimum of 75% fuel energy input from coal, and a minimum 50% of energy-equivalent output is from electricity.

The CCPI will conduct 4 solicitations through 2010, and 8 are currently active from the previous two rounds. The projects are cost-shared and the award recipient provides at least 50% of the project funds.

Round 3 specifically focuses on technologies that capture and sequester CO2 and put them to beneficial use. The DOE goals for this round are:

- technologies that capture and sequester at least 50% of CO2 emissions from the proposed facility
- technologies that show significant progress toward 90% carbon capture
- technologies that show significant progress toward CO2 capture and sequestration with less than 10% increase in electricity cost

This round also will be hopefully linked to current sequestration projects with the regional partnerships.

Release of the final funding opportunity announcement is expected at the end of November 2007, and projects will be due at the end of April 2008. Selections are expected to be announced in November 2008.

2007 US Roadmap[36]

The 2007 USDOE CCS Roadmap was released containing an industry overview including highlights and accomplishments. The USDOE CCS program aims to develop fossil fuel conversion systems by 2012 that achieve 90% CO2 capture with 99 percent storage permanence at less than a 10% increase in the cost of energy services.

US Department of Agriculture[37]

On January 15, 2009, the U.S. Department of Agriculture announced the approval of a $300 million loan to finance the modification of a coal-fired power plant to capture and sequester 3,000 tons of CO2 per day. The project, which will take place at Basin Electric Power Cooperative's Antelope Valley Station near Beulah, North Dakota, is expected to be the first of its type in the United States to operate on a commercial scale. Basin Electric will utilize a CO2 capture technology currently being tested on a pilot-scale basis; based on the tests results, the technology would be expanded to a demonstration project at the Antelope Valley Station. Antelope Valley Station is located adjacent to the Great Plains Synfuels Plant, which already captures and ships more than 3 million tons of CO2 per year to Canadian oilfields through a 205-mile long pipeline. The CO2 captured from the coal-fired power plant will be cleaned, sent to the Synfuels plant, and then placed into the pipeline for use during EOR. Bassin Electric also

[33] www.Sequestration.org
[34] www.mrcsp.org
[35] www.secarbon.org
[36] www.netl.doe.gov/publicatoins/carbon_seq/projects%20portfolio.2007/2007Roadmap.pdf
[37] www.carboncapturejournal.com/displaynews.php?NewsID=413&PHPSESSID=232

plans to inject a small percentage of CO2 into a deep saline formation. The demonstration project at Antelope Valley would capture about 1 million tons of CO2 per year.

Mississippi Power Clean Coal[38]

Mississippi Power announced plans to build a $2 billion, lignite-fired power plant in Kemper County, located north of Meridian in eastern Mississippi, which could become the first full-scale, clean coal generating plant in the United States. The plant would employ coal gasification technology to produce electricity and capture 50 percent of CO2 emissions. The captured CO2 would be compressed and sold to a company that would inject it into depleted oil wells around Mississippi for EOR. The plant is anticipated to open sometime between 2013 and 2015. Mississippi Power is currently negotiating with property owners in Kemper County for the mineral rights to approximately 12,000 acres. The proposed plant would use between 100 and 150 million tons of the Mississippi's 4 billion ton supply of lignite, a low grade of coal that gives off a smaller amount of heat. December 15, 2008,

Grant at Montana State University[39]

A $1.4 million DOE grant has been awarded to researchers at Montana State University, the University of Montana, and Montana Tech University to study the effects carbon sequestration sites may have on the surrounding environment. The researchers will study the effects of injecting large volumes of liquefied CO2 into porous rocks deep underground for storage. The injections could affect the rock's pore structures, material properties, or microbial activity, all of which play a role in how well the CO2 is sequestered. Project researchers will also monitor microbes and plants near the sequestration sites to determine whether a site is containing CO2. The grant is derived from DOE's Experimental Program to Stimulate Competitive Research (EPSCoR). January 22, 2009

$2.4 Billion USD from the Recovery and Reinvestment Act[40]

On May 15, 2009, U.S. Secretary of Energy Steven Chu announced that $2.4 billion from the American Recovery and Reinvestment Act will be used to expand and accelerate the commercial deployment of CCS technology. To issue this funding, DOE will post Notices of Intent supporting the Clean Coal Power Initiative ($800 million), industrial CCS projects ($1.52 billion), geologic sequestration site characterization ($50 million), and geologic sequestration training and research ($20 million). CCPI funding will expand the range of technologies, applications, fuels, and geologic formations for commercial-scale CCS tests. Industrial CCS funding will be used for a two-part, competitive solicitation for large-scale CCS from industrial sources, such as cement plants, chemical plants, refineries, steel and aluminum plants, manufacturing facilities, and petroleum coke-fired and other power plants. With respect to geologic sequestration site characterization, a competitive solicitation will be funded to characterize a minimum of 10 geologic formations to build upon the work done by DOE's RCSPs. Finally, geologic sequestration training and research funding will be used to educate and train a future generation of geologists, scientists, and engineers in geology, geophysics, geomechanics, geochemistry, and reservoir engineering

Canadian policy development

The national road mapping process combined with Canada's Energy Innovation Network (Energy INet)[41] and other industry led efforts appear to have resulted in convergence around the future shape of sustainable energy production in western Canada, however despite the efforts of federal and provincial governments a detailed regulatory framework for LFEs has yet to be put in place. The only place the convergence is apparent is in the industry-government efforts to develop a backbone pipeline.

Because Canada is a net exporter with a large oil sand reserve, Canada is in a unique position compared to other developed nations. Energy production from natural resources such as the sands will be a key economic driver, and consequently, policies that impact energy production has a strategic importance on the nation and on the provinces where this energy is produced. Policies developed to reduce environmental impacts, particularly those dealing with the sands, will need to be framed in a broad context. While CO2 is they key concern in the sands, there may be an opportunity to reduce a broader range of environmental impacts from energy production and demonstrate the sustainability of this sector.

The key factor in Canada, according to Energy INet, ARC and other CANMET[42] personnel is this: CCS projects will be driven by the necessity to demonstrate Canada's petroleum resources, including and especially its oil sands, can be developed in an environmentally sustainable manner.

[38] www.tennesseeanytime.org/energy/node/1737
[39] www.montana.edu/cpa/news/nwview.php?article=6548
[40] www.energy.gov/recovery/funding.htm
[41] www.energyinet.com
[42] Canada Energy technology Center – Ottowa: www.cetc.nrcan.gc.ca

Oil Sands

The upgrading of oil sands bitumen to Synthetic Crude Oil consumes substantial quantities of power and hydrogen, which are produced using fossil fuels. The resulting CO2 emissions from hydrogen and power production for bitumen upgrading make the oil sands industry one of Canada's largest GHG emitter. A study done by CANMET and the university of Waterloo identified the GHG emissions associated with the sands and how to mitigate them.

Upgrading of bitumen is extremely hydrogen intensive. The combined H2 required for upgrading is 5-10 more than that required to produce the equivalent refined products from conventional crude oil. Projected growth in oil sands operations over the next decade is likely to quadruple the current western Canadian H2 production capacity to an estimated 52.5 million NM3/d making the world's largest concentration of H2 plants in Alberta.

The oil sands operating model is built upon process specific data. Companies included include Syncrude Canada Ltd.[43], Suncor Energy Inc.[44] and Albian Sands[45]-Shell Canada Ltd. (all commercially extract and upgrade bitumen).

Oil sands operations model

OSOM (oil sand operations model):

The production of synthetic crude oil from oil sands in accomplished in 4 stages:

- Mining- oil sand is mined using hydraulic shovels and transported by truck to the next process stage
- Conditioning/hydro transport – the ore is mixed with hot water and chemicals and agitated to separate the bitumen from the sand
- Extraction – the resulting slurry is washed with hot water, after which air and steam addition cause the bitumen to rise to the surface in separation cells. Bitumen froth is separated from the sand slurry, deareated and diluted with naphtha. Diluted bitumen is then centrifuged to remove traces of sand water and is sent to upgrading
- Upgrading- naphtha solvent is distilled from the bitumen and pumped to stage 3. bitumen is distilled in a vacuum unit where the lighter oil fractions are recovered. The bottoms are then cracked either thermally or by H2 additions or by a combination of both.

The resulting products include naphtha, light and heavy gas oils, and petroleum coke. The oil fractions are then sent to hydro-treaters in which sulphur and nitrogen compounds are removed by hydrogen addition. The treated fractions are blended together into a high SCO2 with a high API number and low sulphur content.

OSOM 2 scenarios: 1. base case, and 2. CO2 free scenario.

The OSOM calculates the mass and energy balances of each of the above process stages for all the SCO producers in this study. The GHG emissions associated with the SCO production are calculated in the OSOM by determining each stage's net demand for the five fossil fuel intensive inputs. Each of these energy commodities is produced in specific plants or united. For example all the H2 required for upgrading bitumen at Suncor is produced at natural gas steam reforming plants. The OSOM calculated the amount of natural gas required to produce H2 and also the associated GHG emissions, among other pertinent model outputs.

OSOM Base Case represents the current manner of operation of the three SCO producers in Alberta under study. All plant operations are based on conventional technologies and no CO2 capture is considered in this case. Natural gas and steam reforming are the fuel and technology of choice for H2 production. All the steam and hot water is produced in natural gas fired boilers. Coal is employed for power generation in pulverized coal sub-critical plants and as process fuel upgrading.

The consumption in the base case is as follows:

	Hot water	Steam tonne/bbl	Power kW/bbl	Hydrogen tonne/BBL	Diesel l/bbl	SCO 1000 bbl/d
Syncrude-Mildred Lake	1.38	.17	26	.0031	1.9	155
Syncrude-Aurora	1.11	.15	11	.0031	1.6	77
Suncor	1.39	.14	24	.0028	2.0	213
Shell-Albian Sands	0.93	.10	24	.0044	1.3	94

The H2 in the Shell-Albian sands is highest of all. This is attributed to their upgrading scheme, which solely uses hydro cracking (LC-Fining) unlike Suncor, which uses thermal cracking (delayed coking) requiring no H2 for upgrading, only for hydro-desulphurisation.

[43] www.syncrude.ca
[44] www.suncor.com
[45] www.albiansands.com

The figure 3 below shows the calculated GHG intensity according to producer and process stage. It shows the bulk of GHG comes from the bitumen-upgrading step, which accounts for 70 percent of emissions on average. The other stages, including hydro transport conditioning and mining contribute to 15% of the GHG.

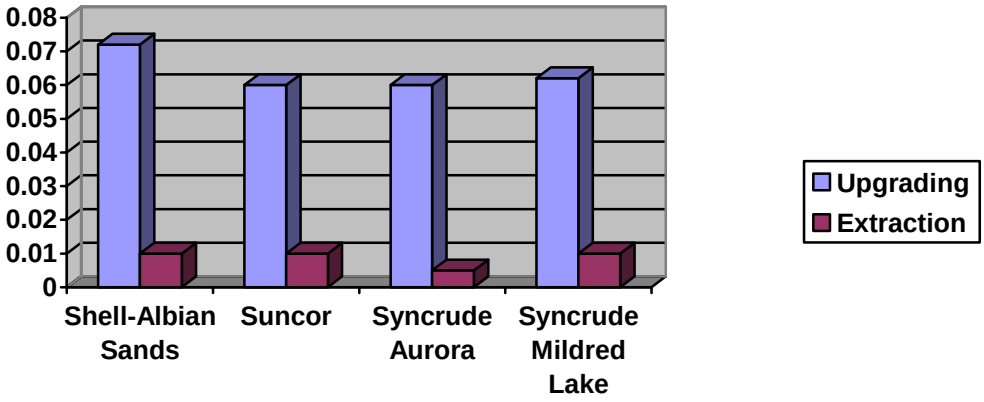


Figure 3: tonne CO2 eq/bbl SCO (above)

The four companies are responsible for 77% of all emissions in the Athabasca oil sands operations. The individual contribution of each of the above is 32%, 25%, and 20% of the total GHG emissions respectively. The results also showed that 95% emissions are CO_2, the rest are CH_4 and N_2O. CH4 and N_2O are emitted by power and H2 plants which represent upstream emissions due to natural gas and coal production and transport. Process fuel consumed in upgrading is relatively low accounting for about 5% of the total.

GHG emissions per energy commodity for all SCO producers in tonne CO2 eq/h (2003 average)

	Hot water	Steam	Power	H2	Diesel	Process	CH4+N2O	Total
Syncrude-Mildred Lake	70	183	142	188	34	6	29	652
Syncrude-Aurora	21	79	30	93	14	3	13	252
Suncor	72	199	182	233	47	77	36	846
Shell-Albian Sands	21	65	79	165	14	16	24	385
Fleet total	**183**	**526**	**434**	**679**	**108**	**103**	**102**	**2135**

The OSOM results suggest GHG abatement efforts in oil sands operations should concentrate on the upgrading stage. Considerable opportunities exist for less GHG intensive production of H2, steam and power in the oil sands industry.

StatoilHydro ASA shelved a $4-billion upgrader, the latest (December 4) in a string of producers to cancel or delay new bitumen upgraders, citing the worsening economic climate and the high cost of development. The company's withdrawal of its application for provincial approval of the project brings the total value of stalled or halted upgraders to at least $45-billion. Companies increasingly see converting U.S. refineries to handle Alberta's heavier crude as a cheaper alternative for processing bitumen.

Statoil cited "prohibitive construction costs, the state of the global economy, an uncertain oil price outlook and lack of legislative clarity" in a statement outlining its reasons for the decision not to build the Kai Kos Dehseh upgrader, which would have been completed in 2016.

Statoil said it still plans to build its oil sands extraction project, which would produce 100,000 barrels a day of unprocessed bitumen by 2015 and 200,000 barrels a day by 2020. The company bought into the oil sands last year when it bought closely held North American Oil Sands Corp. for $2.2-billion.

"This decision does not impact the progress of StatoilHydro's upstream oil sands activities," StatoilHydro Canada president Geir Jossang said in a statement. "StatoilHydro's long-term view of the Canadian oil sands development remains unchanged."

The CO2 free scenario

Motivation for a CO2 free scenario can be easily illustrated in 5 points:

1. The high growth in bitumen upgrading to SCO will drive H2 demands in the region to historical highs.
2. Long-term availability of natural gas, the primary feedstock for H2 production is uncertain, which prices continue to rise
3. Alternative feedstock such as pet coke, coal and bitumen are readily available in the Athabasca region at a low cost
4. Gasification technology, combined with CO2 capture has a large potential for low GHG intensive oil sands operations when used for power and production
5. Alberta's geology is suited for CO2 sequestration, storage or EOR.

The high availability of low GHG intensive H2 has potential to spawn a local hydrogen based economy benefiting both the regional economy and the environment.

The optimal mix of H2 plants, power plants, feedstock and CO2 capture processes will need to be employed to meet GHG targets at minimal cost while satisfying syncrude needs and H2 demands.

CURRENT CCS PROJECTS IN CANADA

The Canadian CO2 Capture and Storage Technology Network (CCCSTN)[46] lists 48 Canadian projects related to CCS; including pre- and post-combustion capture; oxy-fuel combustion and storage (injection, reliability and assessment). Most of these are studies and analysis, and only a few are large-scale demonstration projects relevant for this report.

The following is a list of significant demonstration projects for CCS in North America.

Weyburn-Midale CO2 Project[47]

The $1.1 billion Encana Weyburn CO_2 enhanced oil recovery project in which CO_2, pipelined from the Dakota (coal) Gasification Company in Beulah, North Dakota, will be pumped into the Weyburn field to reduce the viscosity of the oil and thereby increase its recoverability. An incremental 120 million barrels of oil will be recovered over the next 15 to 20 years, at the same time storing about 20 million ton net of CO_2 underground. This IEA activity, chaired by Canada and with offices in the U.K., brings together the interests of 16 countries and the Commission of European Communities. As well, BP Amoco, DMT-FP, EPRI (Electric Power Research Institute, California), Mobil Oil, RWE AG and Shell International are sponsors.

In October 2000, EnCana began injecting significant amounts of CO2 into a Williston Basin oilfield (Weyburn) in order to boost oil production. EnCana is operator of the oilfield and holds the largest share of the 37 current partners. Initial CO2 injection rates amounted to ~5,000 ton or 95 million scf/day (2.7 million m3/d); this would otherwise have been vented to the atmosphere. Overall, it is anticipated that some 20 Mt of CO2 will be permanently sequestered over the lifespan of the project. The gas is being supplied via a 205 mile long pipeline (costing 100 million $) from the lignite-fired Dakota Gasification Company synfuels plant site in North Dakota. The company is a subsidiary of Basin Electric Power Co-operative. EnCana is taking ~40% of the synfuels plant's capacity. At the plant, CO2 is produced from a Rectisol unit in the gas cleanup train. The CO2 project adds about $30 million of gross revenue to the gasification plant's cash flow each year.

Another key feature of the project is that the CO2 comes from fossil fuel use. There are currently 74 CO2-EOR projects operating in the USA, however, most of these rely on naturally-occurring sources of CO2. Thus, the Weyburn project represents a significant increase in the use of anthropogenic CO2 in EOR projects in both the USA and Canada. It is estimated that 50% of the injected CO2 will be permanently sequestered in the oil that remains in the ground, the remainder coming to the surface with the produced oil. From here, it is being recovered, compressed and reinjected.

During its life, the Weyburn project is expected to produce at least 122 million barrels of incremental oil, through miscible or near-miscible displacement with CO2, from a field that has already produced 335 million barrels since its discovery in 1955. This will extend the life of the Weyburn field by approximately 20-25 years. It is estimated that ultimate oil recovery will increase to 34%. CO2 sequestration carried out on the scale of the Weyburn Enhanced Oil Recovery Project is potentially a low-cost, practical and long-term management option for national and international CO2 emissions.

Pembina Enhanced Oil Recovery Project[48]

Penn West has been working with a large industrial emitter of CO_2 on an economic CO_2 capture and pipeline transportation project. The CO_2 will be supplied to Penn West in sufficient quantities to support commercial applications of enhanced oil recovery technology in phases over a significant portion of land in Pembina.

[46] www.nrcan.gc.ca/es/etb/cetc/combustion/co2network/htmldocs/projects_e.html
[47] www.ptrc.ca/weyburn_eor.php
[48] www.pennwest.com/operations/crude_pembina.html

Currently, Penn West is working toward the construction of a pipeline spine from the CO_2 source to the Pembina field, a distance of about 150 kilometers. Spine will be used not only to supply Pembina, but also other fields in Central Alberta including fields where Penn West has interests.

The first phase of the Pembina Enhanced Recovery Project will include construction of a CO_2 supply pipeline, infill drilling, well re-completions, and field facility upgrades. Estimated cost of this work to Penn West will be $200 to $250 million. We anticipate that production from the first phase will commence in 2009 and will average 5,000 to 8,000 barrels per day. Multiple additional phases are planned. The additional phases will not require the per-unit expenditure of the first phase since the supply pipeline and the proportion of the facility upgrades are part of phase one.

Saskpower's clean coal project[49]

A new clean coal power plan will produce 300 MW of electricity. This will create enough liquefied CO_2 to extract millions of new barrels of oil from Saskpower's oilfields. If successful, the advanced clean coal unit will be the first of its kind in a utility scale application in the world. A decision on whether to proceed with the project will be made in mid-2007, with an in service date of 2011. Saskpower will focus further engineering efforts for its Clean Coal Project on expansion of the Shand Power Station near Estevan. Should the project proceed, Shand will be the location for the first clean coal unit. When the impacts of local coal characteristics, mining costs, CO_2 transportation, transmission system interconnection, cooling water, and provision for existing coal supply agreements are considered, initial deployment at the Shand site presents a number of advantages - which include both capital and lifecycle cost savings - over initiating the technology at the Poplar River site near Coronach.

Plans to proceed at the Shand site are pending successful negotiations with key stakeholders in the Estevan area. The Poplar River Power Station near Coronach will be reconsidered if problems occur with development of the Estevan site. Saskpower, Babcock & Wilcox Canada (B&W) and Air Liquide will jointly develop an oxyfuel separation technology as the core process for this project.

The $1.5 billion, 300 MW lignite powerplant will capture 90% of the CO_2 emission at a rate of 8,000 tons per day.

Saskpower announced in early September 2007 their plans to put the Clean Coal project on hold for now. They are opting for cheaper natural gas fired generation, wind power and renewables to meet needs until 2014. The near-zero 300 MW thermal generating station couldn't be built in time. By 2010, there will be a need to have new generation on line and the Clean Coal plant wouldn't be ready. The option will still be generously pursued, as will cogeneration. The next supply decision is expected by 2009. The plant was estimated to cost $1.5 billion dollars when the project was designed, but costs increased substantially in the last few months due to recalculation. Saskpower will spend $225 million to install 400 megawatts of natural-gas turbines over the next 5 years.

Holisitic Systems Awarded in the Oil Sands[50]

The NorthWest Upgrader has just been approved to enhance bitumen production by value added products: ultra low sulphur diesel, diluent (naphtha or condensate added to bitument so it can travel efficiently down a pipeline), low sulphur vacuum gas oil, butane and CO2. Close proximity to major crude oil and diluent pipelines. A 450 km pipeline will transport the gas to the Enhance Clive fields. The first of three phases, which has been approved, will have a 77,000-barrel-per-day capacity by 2011, and is estimated to cost $4.2-billion.

Key to the merchant upgrader is its gasification technology, which burns the heaviest and least desirable ends of bitumen to produce hydrogen, and its carbon-capture design. North West already has an agreement in place to supply Enhance Energy Inc. with two-thirds of the CO_2 released during their process.

Long Lake Opti-Nexen[51]

The Long Lake Project is a "Next Generation" oil sands development that integrates established and proprietary technologies in a way that is expected to produce a premium synthetic crude oil at operating costs of just $5 to $9 per barrel, a major cost advantage. Shell's gasification process will be used for CO2 capture for EOR.

[49] www.saskpower.com/cleancoal
[50] www.northwestupgrading.com
[51] www.longlake.ca

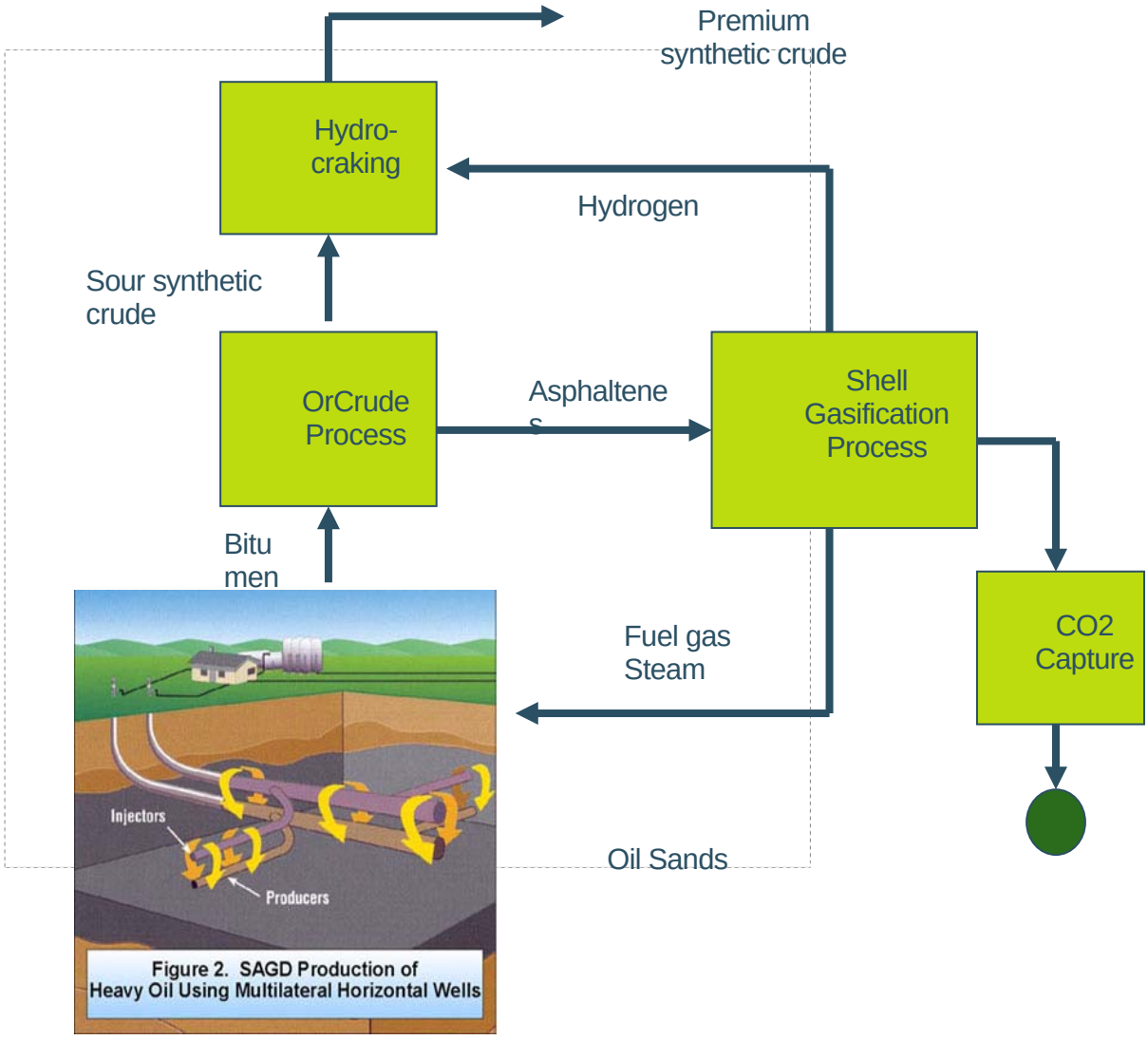


Figure 4: Long Lake project

International Performance Assessment Centre

Shell, University of Regina and other stakeholders are working on putting together a CCS risk assessment centre to be named the "International Performance Assessment Centre" (for political reasons). Stakeholders feel there could be quite a bit of cross-industry interest and financial support for this endeavor. As The first step for the project team was to attend the IEA—Greenhouse Gas Programme's "CCS Financing Workshop" to help generate exposure, and perhaps financial support, for this next U of R Centre effort. The Canadian federal and Saskatchewan provincial governments are contributing great amounts of money into this project, other US stakeholders are helping generate strategic, corporate and perhaps US government support for as well.

Bilateral CCS Pilot Project

Plans in the world to get a CCS Pilot Project off the ground using Saskatchewan's post combustion capture technology developed by Dr. Malcolm Wilson and team at the University of Regina. The US states of Montana, North Dakota and Wyoming have been approached as partners for pipeline reasons and many CO2 sources are here.

International Partnership Evaluates Feasibility of Major Carbon Capture and Storage in British Columbia[52]

The National Energy Technology Laboratory, Spectra Energy Transmission a natural gas infrastructure company, and the Energy & Environmental Research Center (EERC) in Grand Forks, North Dakota, announced their collaboration on a large-scale integrated carbon capture and storage (CCS) project near Spectra's existing Fort Nelson natural gas plant in northeastern British Columbia, Canada.

This project will aim to study CO2 in deep underground saline reservoirs. The project will be part of a technology demonstration program conducted by the EERC's Plains CO_2 Reduction (PCOR) Partnership. The Fort Nelson demonstration is one of two projects the PCOR Partnership will lead in its Phase III efforts (during 2007-2017).

Spectra Energy will drill two test wells to determine whether the surrounding geology is suitable for the permanent storage of CO2 and H2S.

Spectra Energy has been utilizing carbon capture and storage technology for more than a decade, and has been recognized by the United Nation's Intergovernmental Panel on Climate Change as a world leader in CCS technology. Currently, four of Spectra Energy's gas processing facilities in British Columbia and four in Alberta are equipped with CCS technology. Together, these facilities remove about 200,000 ton of greenhouse gases from the atmosphere each year.

Initial injections will begin in 2011.

TransAlta and Alstom Canada[53]

TransAlta and Alstom Canada announced an agreement to develop a large-scale carbon capture and storage (CCS) facility in Alberta. Project Pioneer is expected to deliver at least 20 per cent of the Government of Alberta's 2015 target of 5 megaton (Mt) in annual CO2 reductions. It will employ Alstom's chilled ammonia process. It will retrofit post-combustion capture technology to one of TransAlta's existing coal plants. It was chosen because of the lower power requirements and lower operating costs, which are all factors that should lead to rapid commercial deployment.

When complete, it should be one of the largest CCS facilities in the world and the first to have an integrated underground storage system. If proven, CCS technology may be deployed across Alberta's coal fleet, with the potential to eliminate up to 45 Mt of CO2 annually – roughly a third of the province's 2050 target of 139 Mt in reductions. If deployed across other sectors, such as the oil sands it's estimated the technology has the potential to capture another 20 to 30 Mt per year of high purity CO2 suitable for storage or enhanced oil recovery. FEED work has commenced and will be completed in mid-2009, with operation commencing by late 2012.

CO2 Solution Inc

CO2 Solution Inc from Quebec has developed a bio-technological platform for the efficient capture of CO2, from power plants and other large stationary sources of emissions using a bio-catalyst carbonic anhydrase. The Company is commercializing its technology for coal fired power generation, the oil sands and other CO2-intensive industries where a low-cost capture solution is key to meeting climate change legislation in a cost effective manner. CO2 Solution is seeking opportunities towards the commercialization of its CO2 capture technology in various markets including power generation, the oil sands, steel production and the cement industry.

Heartland Area Redwater Project (HARP)

Lead proponent: ARC Resources

Source: Industrial facilities

Area: Fort Saskatchewan–Heartland–Redwater area in central Alberta

Purpose: This project is designed to demonstrate the feasibility of safe CO2 storage in the Redwater Leduc Reef, situated northeast of Edmonton, Alberta. This site is located close to the Alberta Industrial Heartland region, where there are a number of large industrial sources of greenhouse gas emissions, including chemical and fertilizer plants and several oil sands upgraders that are operating, being built or in the planning stages. The Redwater Leduc Reef is also strategically located along a straight-line path between Fort McMurray and Edmonton, a potential route for a CO2 pipeline from Fort McMurray. Preliminary work estimates the total storage capacity of the saline aquifer portion of the reef to be one gigaton of CO2.

Over the long term, this project will demonstrate carbon capture and storage on a commercial scale (several million ton per year), contributing to a significant reduction in GHG emissions.

[52] http://www.undeerc.org/PCOR/products/newsitem.asp?id=299

[53] http://www.transalta.com/TransAlta/webcms.nsf/AllDoc/2D8D876D809831848725741F0076700F?OpenDocument

Integrated Carbon Capture and Enhanced Oil Recovery

Lead proponent: Enhance Energy

Source: Large fertilizer plant and an oil sands upgrading operation

Area: Alberta Industrial Heartland, northeast of Edmonton

Purpose: This project involves the capture of CO2 emissions from industrial sites in the Alberta Industrial Heartland. The captured CO2 will be transported to mature oil reservoirs in central Alberta, where it will be injected for enhanced oil recovery purposes and permanent sequestration. The project will capture CO2 from two sources: a large fertilizer plant and an oil sands upgrading operation (awaiting construction) in order to demonstrate the feasibility of a single network to collect CO2 from a large number of industrial emitters. This technology could be applied to many similar geological reservoirs throughout Alberta that are each capable of sequestering millions of ton of CO2. Within five years, this project could capture and sequester up to 1.9 megaton of CO2 annually, which is the equivalent of taking 358,000 cars off the road each year. There is a long-term potential for the capture and storage of up to 15 megaton of CO2 annually. The project could also lead to the recovery of significant amounts of oil that cannot be reached by conventional methods.

Fort Nelson Exploratory Project

Lead Proponent: Spectra Energy

Source: Natural gas processing plant

Area: Fort Nelson, B.C.

Purpose: This project represents the first phase of research toward a world-scale carbon capture and storage project associated with Spectra Energy's existing gas processing plant in Fort Nelson, B.C. Raw natural gas contains high levels of CO2, which processing strips away. If proven feasible, the CO2 would be compressed, dehydrated, cooled into a concentrated stream and then injected into deep saline formations more than two kilometers underground for permanent sequestration. This project is designed to demonstrate the technical feasibility of injecting large volumes of sour CO2 into deep saline formations for permanent storage. In the long term, it could lead to a reduction of 1.3 to 1.6 megaton of CO2 per year.

Pioneer Project

Lead proponent: TransAlta

Source: Coal-fired power plant

Area: 70 km west of Edmonton, Alberta

Purpose: Pioneer is a large-scale carbon capture and storage project proposed for the Keephills Thermal Electric Power Generation Plant. TransAlta is proposing to construct one of the world's first large-scale CCS facilities that will perform several functions: integrate leading-edge, post-combustion, chilled ammonia capture technology with a power plant to capture one megatonne per year of CO2; transport the CO2 for use in enhanced oil recovery and to a permanent geological storage site; demonstrate safe, secure, large-scale permanent storage in saline aquifers; and deliver significant reductions in CO2 emissions by 2012. TransCanada Pipelines, Ltd. announced plans to participate with TransAlta Corporation in the development of Project Pioneer, Canada's first fully-integrated CCS plant. The project will employ Alstom Canada's chilled ammonia process and will be designed to capture one megatonne of CO2 emissions from an existing coal plant in the Wabamun area located in western Edmonton. The CO2 will be used for EOR and injected into a permanent geological storage site. Preliminary FEED work has started on Project Pioneer and TransAlta hopes to receive funding commitments during 2009 that will allow for construction to begin in early 2010 and operations to commence in 2012. Project Pioneer is expected to deliver at least 20 percent of Alberta's 2015 target of five Mt in annual CO2 reductions.

Belle Plaine Integrated Polygeneration CCS Project

Lead Proponent: TransCanada

Source: Electricity power plant

Area: Belle Plaine, Saskatchewan

Purpose: This project proposes to conduct pre-front end engineering and design and other work as a prerequisite to a decision to go forward with a $5-billion project to build and commission a polygeneration facility in Belle Plaine, Saskatchewan. If the facility is constructed, large volumes of petcoke would be gasified and used to produce a number of products, including hydrogen, steam and sulphur, and to generate up to 500 MW in electricity to potentially displace aging coal-fired generation stations in Saskatchewan. Process CO2 would also be used by two large fertilizer plants located near the proposed polygeneration facility. Reductions in CO2 emissions would result from capturing and sequestering 80–90 percent of the CO2 from the polygeneration facility, as well as from

offsetting the use of natural gas to produce hydrogen and steam at the fertilizer plants. Captured CO2 would be sequestered at enhanced oil recovery sites and in saline aquifers in southeastern Saskatchewan.

CO2 Injection in Heavy Oil Reservoirs

Lead Proponent: Husky Energy Inc.

Source: Oil upgrader and ethanol plant

Area: Lloydminster, Saskatchewan

Purpose: This project will focus on targeted R&D activities to develop new knowledge and methods for enhanced oil recovery in heavy oil reservoirs, using injected CO2 that could be permanently stored in the reservoirs, a new approach in heavy oil extraction. This work will help lead to the capture of CO2 from Husky's upgrader and ethanol plant and transport and inject it into heavy oil reservoirs located adjacent to the upgrader to enhance oil recovery.

This project could lead to the collection of 300,000 ton of CO2 per year from the Husky upgrader and ethanol plant by purifying, dehydrating, compressing and transporting the CO2 to a heavy oil reservoir in the Lloydminster area.

Alberta Saline Aquifer Project (ASAP) / Genesee Post-Combustion Demonstration Plant

Lead proponents: Enbridge and EPCOR

Source: Coal-fired power plant

Area: West of Edmonton, Alberta

Purpose: EPCOR's Genesee Post-Combustion Demonstration Plant involves the construction of a demonstration facility that will capture CO2 from a greenfield coal-fired power plant (150 MW net) in Alberta. The captured CO2 will be transported through collaboration with Enbridge and the Alberta Saline Aquifer Project (ASAP). Enbridge will be designing the pipeline route for transporting the CO2 as well as the CO2 injection facilities. The company will also conduct pilot injections to test the characteristics of the proposed storage site to optimize the project's operation. The CO2 will be used for enhanced oil recovery operations or sequestered in a saline formation located within 100 km of Genesee. ASAP is also responsible for measuring and monitoring the CO2 that will be stored in the saline aquifer.

The Genesee plant would commence operation in 2015, capturing 3,000 ton of CO2 per day, or nearly one million ton per year.

CO2 Transport and Storage Infrastructure

Source: Coal-fired electricity power plant and other industrial sources

Area: West of Edmonton, Alberta

Purpose: Purpose is to locate CO2 storage sites along anticipated pipeline routes to enhanced oil recovery projects, collect CO2 from existing and future emissions locations, and develop the capability to simultaneously provide CO2 to EOR projects and store excess CO2 in saline aquifers. Phase I was completed in 2009, when the project members identified suitable saline aquifers for storage. Phase II will see members obtain all the regulatory approvals to develop a pilot project to actually inject CO2 into the identified aquifers. Depending on the result of Phase II, Phase III will involve expanding the project into a large-scale long-term commercial option.

CURRENT CCS PROJECTS IN US

DOE financed projects

The US Department of Energy's (DOE) Office of Fossil Energy typically manages more than 500 active research and development projects spanning a wide range of coal, petroleum and natural gas topics, including 90 projects (March 2007) related to CCS[54].

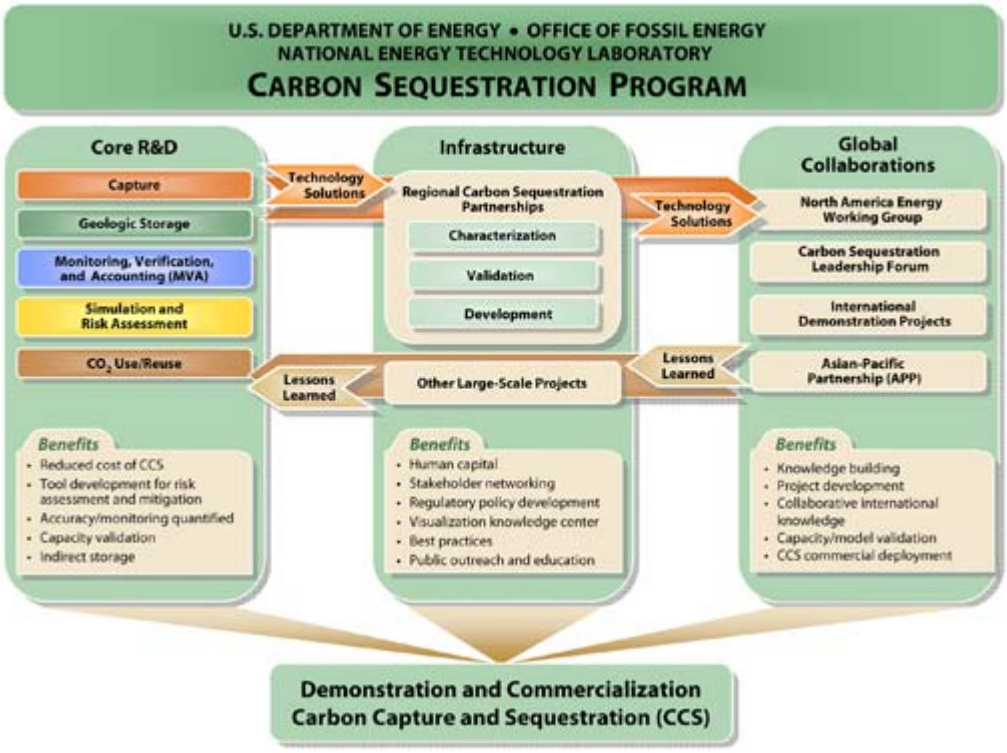
DOE Secretary Samuel W. Bodman announced October 23 2006 the selection of nine projects totaling nearly $24 million aimed at developing novel and cost-effective technologies to capture the CO_2 produced in coal-fired power plants so that it can be safely and permanently sequestered. Grant recipients will contribute nearly $8 million in cost-sharing for the program. The projects are listed below:

Company	Project description	Budget
Carbozyme, Inc. (Monmouth Junction, N.J.)	To evolve a second generation of their enzyme-based membrane design for	DOE share: $944,807; Recipient share: $229,863

[54] www.fossil.energy.gov/fred/feprograms.jsp?prog=Carbon+Sequestration

	capturing CO2 from the flue gas of coal-fired power plants.	
Membrane Technology and Research, Inc. (Menlo Park, Calif.)	To develop a cost-effective, membrane-based process to separate CO2 from the flue gas of coal-fired power plants. They also intend to deliver condensed, high-pressure, supercritical CO2 to a pipeline for sequestration.	DOE share: $788,266; recipient share: $197,067
University of Akron (Akron, Ohio)	To develop a highly efficient, low-cost CO2 capture system. Built on integration of metal monoliths, material synthesis, and low-cost fabrication techniques, the researchers anticipate a breakthrough technology for the removal of CO2 from the flue gas of coal-fired power plants.	DOE share: $764,995; recipient share: $156,702
Carbozyme, Inc. (Monmouth Junction, N.J.)	To design, construct, test, and demonstrate a simple, efficient, and readily scalable enzyme-based flue gas cleanup technology for CO2 capture and will demonstrate a method for reasonable-cost treatment of other pollutants to achieve near-zero emissions from pulverized coal power plants.	DOE share: $4,799,175; recipient share: $1,370,430
Praxair, Inc. (Tonawanda, N.Y.)	To develop an oxy-combustion process using an oxygen transport membrane to capture CO2 from coal-fired power plants.	DOE share: $4,742,780; recipient share: $2,553,806;
Research Triangle Institute (Research Triangle Park, N.C.)	To expand on the process they have developed to capture CO2 from power plant flue gas using an inexpensive, dry, regenerable sorbent.	DOE share: $3,211,997; recipient share: $803,175
SRI International (Menlo Park, Calif.)	To fabricate a technically and economically viable CO2-capture system based on a promising membrane material for pre-combustion-based capture of CO2.	DOE share: $4,047,695; recipient share: $1,036,159
University of Notre Dame (Notre Dame, Ind.)	To focus on the development of a new liquid absorbent for efficient post-combustion capture of CO2 from coal-fired power plants.	DOE share: $2,214,590; recipient share: $793,861
UOP LLC (Des Plaines, Ill.), a Honeywell Company	To develop a process that uses novel microporous metal organic frameworks having extremely high adsorption capacities for the removal of CO2 from coal-fired power plant flue gas.	DOE share: $2,238,171; recipient share: $559,543;

National Energy Technology Lab Industrial Projects



Innovations for Existing Plants (IEP)

In 2008, the IEP Program redirected its focus to include CO2 emissions control for existing coal combustion-based plants, e.g. conventional pulverized coal-fired plants. The focus on CO2 emissions control technology – both post-combustion and oxy-combustion – and related areas of CO2 compression and CO2 beneficial reuse is in direct response to the priority placed on advancing technological options for the existing fleet of coal-fired power plants for addressing climate change. In addition to funding R&D projects conducted externally, DOE/NETL also conducts in-house research to develop new breakthrough concepts for carbon capture that could lead to dramatic improvements in cost and performance relative to today's technologies. The IEP CO2 emissions control R&D activity also sponsors systems analysis studies of the cost and performance of various carbon capture technologies. The program goal is to develop advanced CO2 capture and separation technologies for existing power plants that can achieve at least 90% CO2 removal at no more than a 35% increase in cost of energy services.

Post-Combustion

DOE/NETL's post-combustion CO2 control technology R&D includes projects directed at the use of solvents, solid sorbents, and membranes. Amine-based solvent systems are in commercial use for scrubbing CO2 from industrial flue gases and process gases. However, solvents have not been applied to removing large volumes of CO2 as would be encountered in a PC-fired utility boiler flue gas. Solid sorbents can be used to capture CO2 from flue gas through chemical adsorption, physical adsorption, or a combination of the two effects. Possible configurations for contacting the flue gas with solid sorbents include fixed, moving, and fluidized beds.

Following is a list of current DOE/NETL projects:

Post-Combustion External Researchers					
Project Number	**Performing Organization**	**Project Title**	**Performance Period**	**Research Pathway**	**Scale**
DE-NT0005498	Board of Trustees of the University of Illinois (ISGS)	Development and Evaluation of a Novel Integrated Vacuum Carbonate Absorption Process	10/1/08 - 9/30/11	Chemical Solvent	Laboratory

DE-NT0005310	GE Global Research	Novel High Capacity Oligomers for Low Cost CO2 Capture	10/01/08 - 9/30/10	Chemical Solvent	Laboratory
FG02-06ER84592	AIL Systems, Inc.	A Low Energy, Low Cost Process for Stripping Carbon Dioxide from Absorbents	6/28/06 - 3/27/07 Complete	Chemical Solvent	Laboratory
FG02-06ER84625	Trimeric Corporation	Advanced Amine Solvent Formulation and Process Integration for Near-Term CO2 Capture Success	6/28/06 - 3/27/07 Complete	Chemical Solvent	Laboratory
DE-NT0005497	TDA Research, Inc.	Low Cost Sorbent for Capturing CO2 Emissions Generated by Existing Coal-Fired Power Plants	11/1/08 - 10/31/11	Chemical Sorbent	Laboratory
DE-NT0005578	SRI International	Development of Novel Carbon Sorbents for CO2 Capture	10/1/08 - 9/30/11	Chemical Sorbent	Laboratory
DE-NT0005649	ADA-ES, Inc.	Evaluation of Solid Sorbents as a Retrofit Technology for CO2 Capture from Coal-Fired Power Plants	9/30/08 - 12/31/10	Chemical Sorbent	Laboratory
FC26-07NT43089	RTI International	Development of a Dry Sorbent-Based Post Combustion CO2 Capture Technology for Retrofit in Existing Power Plants	3/7/07 - 3/6/10	Chemical Sorbent	Laboratory
FC26-07NT43086	University of Akron	Metal Monolithic Amine-Grafted Zeolites for CO2 Capture	2/1/07 - 1/31/10	Chemical Sorbent	Laboratory
FG02-04ER83885	Advanced Fuel Research, Inc.	CO2 Recovery from Flue Gas using Carbon-Supported Amine Sorbents	7/13/04 - 4/12/05 Complete	Chemical Sorbent	Laboratory
FC26-02NT41440	University of Texas at Austin	Carbon Dioxide Capture by Absorption With Potassium Carbonate	7/9/02 - 8/31/07 Complete	Chemical Sorbent	Laboratory
FC26-00NT40923	RTI International	Carbon Dioxide Capture From Flue Gas Using Dry Regenerable Sorbents	8/31/00 - 6/30/07 Complete	Chemical Sorbent	Laboratory
FC26-07NT43092	UOP LLC	CO2 Removal from Flue Gas Using Microporous Metal Organic Frameworks	4/1/07 - 3/31/10	Chemical & Physical Sorbent	Laboratory
FG26-04NT42121	UOP LLC	Carbon Dioxide Separation with Novel Microporous Metal Organic Frameworks	8/5/04 - 2/4/08 Complete	Chemical & Physical Sorbent	Laboratory
DE-NT0005313	RTI International	CO2 Capture Membrane Process for Power Plant Flue Gas	10/1/08 - 9/30/10	Membrane	Laboratory
DE-NT0005312	Membrane Technology & Research, Inc.	Membrane Process to Capture CO2 from Power Plant Flue Gas	10/1/08 - 9/30/10	Membrane	Laboratory
FG26-04NT42120	University of New Mexico	Novel Dual Functional Membrane for Controlling Carbon Dioxide Emissions From Fossil Fueled Power Plants	4/30/08 - 4/30/09	Membrane	Laboratory
FC26-07NT43085	Membrane Technology & Research, Inc.	Membrane Process to Sequester CO2 from Power Plant Flue Gas	4/1/07 - 3/31/09	Membrane	Laboratory
FC26-07NT43084	Carbozyme, Inc	Development of Biomimetric Membrane for Near Zero PC Power Plant Emissions	3/28/07 - 3/27/10	Membrane	Laboratory
FG26-06NT42824	Carbozyme, Inc	Biomimetric Membrane for CO2 Capture from Flue Gas	5/10/06 - 5/31/07 Complete	Membrane	Laboratory
FG02-04ER83925	Compact Membrane Systems, Inc.	Carbon Dioxide Capture from Large Point Sources	7/13/04 - 7/10/05 Complete	Membrane	Laboratory
FC26-04NT42206	FuelCell Energy, Inc.	Combined Power Generation and Carbon Sequestration Using Direct FuelCell Technology	9/30/04 - 12/31/05 Complete	Other	Laboratory
DE-NT0005287	Georgia Tech Research Corporation	Reversible Ionic Liquids as Double-Action Solvents for Efficient CO2 Capture	11/1/08 - 10/31/11	Physical Solvent	Laboratory
FG26-05NT42488	Hampton University	CO2 Capture from Flue Gas by Phase Transitional Absorption	6/30/08 - 6/30/09	Physical Solvent	Laboratory
FC26-07NT43091	University of Notre Dame	Ionic Liquids: Breakthrough Absorption Technology for Post-Combustion CO2 Capture	3/1/07 - 6/30/10	Physical Solvent	Laboratory

FG26-04NT42122	University of Notre Dame	Design and Evaluation of Ionic Liquids as Novel Absorbents	7/16/04 - 7/15/07 Complete	Physical Solvent	Laboratory

Post-Combustion Internal Research

Project Number	Performing Organization	Project Title	Performance Period	Research Pathway	Scale
ORD-08-220671 (Task 6)	NETL/ORD	CO2 Capture Sorbent-based Device Simulation	10/1/07 - 9/30/08	Chemical Sorbent	Laboratory
ORD-07-220614 (Subtask 2.3)	NETL/ORD	Reactor Design for CO2 Capture using Sorbents	10/1/06 - 9/30/08	Chemical Sorbent	Laboratory
ORD-07-220614 (Subtask 2.1)	NETL/ORD	Sorbent Development for CO2 Removal for Flue Gas Applications	10/1/06 - 9/30/08	Chemical Sorbent	Laboratory
ORD-07-220614 (Subtask 2.2)	NETL/ORD	Surface Immobilization Nanotechnology for CO2 Capture Sorbents	10/1/06 - 9/30/08	Chemical Sorbent	Laboratory
OST-03-04 (Task 1)	NETL/ORD	Molecular Design and Evaluation of CO2 Adsorbents (Novel Amine Sorbents)	10/1/05 - 9/30/06 Complete	Chemical Sorbent	Laboratory
OST-14-06	NETL/ORD	Novel CO2 Capture Concept (carbonic anhydrase & amine-enriched solid sorbents)	10/1/05 - 9/30/06 Complete	Chemical Sorbent	Laboratory
04-N062	NETL/ORD (CRADA w/ Powerspan)	Ammonia-based Process for Multicomponent Removal from Flue Gas	6/8/04 - 9/30/07 Complete	Chemical Solvent	Pilot
OST-07-04	NETL/ORD	Low Temperature Sorbent Development of CO2 Separation from Post-Combustion Gas Streams	10/1/03 - 9/30/06 Complete	Chemical Sorbent	Laboratory
ORD-07-220662	NETL/ORD	Materials and Catalyst Research (MOF CO2 Membranes)	10/1/06 - 9/30/08	Membrane	Laboratory
06-N076	NETL/ORD (CRADA w/ RITE, Inc.)	CO2 Capture from Flue Gas with a Membrane Module	12/20/05 - 12/20/06 Complete	Membrane	Laboratory
ORD-07-220614	NETL/ORD	Carbon Dioxide Capture & Separation	10/1/06 - 9/30/08	Misc.	Laboratory
ORD-07-220614 (Task 5)	NETL/ORD	Electrochemical Beneficiation of Flue Gas	10/1/06 - 9/30/08	Other	Laboratory

Oxy-fuel CO2 Control

DOE/NETL is currently funding multiple oxy-combustion CO2 emission control projects. These R&D efforts are being performed both externally by research organizations and academic institutions and internally through NETL's Office of Research and Development, specifically the Separations and Fuels Processing Division and the Office of Computational Dynamics.

Oxy-Combustion External Researchers

Project Number	Performing Organization	Project Title	Performance Period	Scale
DE-NT0005289	Ohio State University Research Foundation	Coal Direct Chemical Looping Retrofit for Pulverized Coal-Fired Power Plants with In-Situ CO2 Capture	1/1/09 - 12/31/09	Laboratory
DE-NT0005286	Alstom Power, Inc.	Alstom's Chemical Looping Combustion Prototype For CO2 Capture from Existing Pulverized Coal Fired Power Plants	10/1/08 - 9/30/09	Pilot
DE-NT0005288	Reaction Engineering International	Characterization and Prediction of Oxy-Combustion Impacts in Existing Coal-fired Boilers	10/1/08 - 9/30/09	Pilot

DE-NT0005309	Air Products and Chemicals, Inc.	Flue Gas Purification Utilizing SO_X/NO_X Reactions During Compression of CO2 Derived from Oxyfuel Combustion	10/1/08 - 9/30/10	Laboratory
DE-NT0005341	Praxair, Inc.	Near-Zero Emissions Oxy-Combustion Flue Gas Purification	10/1/08 - 12/31/11	Laboratory
DE-NT0005290	Alstom Power, Inc.	Oxy-Combustion Boiler Development for Tangential Firing	10/1/08 - 9/30/09	Pilot
DE-NT0005262	Foster Wheeler NA, Corp.	Oxy-Combustion Boiler Material Development	10/1/08 - 9/30/09	Laboratory
FC26-07NT43088	Praxair, Inc.	OTM-Based Oxycombustion for CO2 Capture from Coal Power Plants	3/30/07 - 3/31/10	Laboratory
FC26-06NT42811	Jupiter Oxygen Corporation	Jupiter Oxycombustion and Integrated Pollutant Removal for the Existing Coal Fired Power Generation Fleet	9/28/06 - 3/31/08	Laboratory
FC26-06NT42747	Babcock & Wilcox Company	Development of Cost Effective Oxy-Combustion Technology for Retrofitting Coal-Fired Boilers	3/31/06 - 3/31/08	Pilot
FC26-06NT42748	The BOC Group, Inc.	Pilot-Scale Demonstration of a Novel, Low-Cost Oxygen Supply Process and its Integration with Oxy-Fuel Coal-Fired Boilers	3/31/06 - 9/30/09	Pilot
FC26-05NT42430	Southern Research Institute	Oxygen-Fired CO2 Recycle for Application to Direct CO2 Capture From Coal-Fired Power Plants	9/27/05 - 9/26/08	Pilot
FC26-04NT42205	Alstom Power, Inc.	Commercialization Development of Oxygen Fired CFB for Greenhouse Gas Control	9/28/04 - 3/31/07 Complete	Pilot
FC26-04NT42207	Foster Wheeler NA, Corp.	Conceptual Design of Supercritical Oxygen-Based PC Boiler	9/14/04 - 9/30/06 Complete	Study
FC26-03NT41736	Foster Wheeler NA, Corp.	Conceptual Design of Oxygen-Based PC Boiler	2/24/03 - 9/30/05 Complete	Study
FC26-01NT41146	Alstom Power, Inc.	Greenhouse Gas Emissions Control by Oxygen Firing in Circulating Fluidized Bed Boilers	9/27/01 - 10/31/04 Complete	Study
FC26-01NT41147	Praxair, Inc.	Advanced Oxyfuel Boilers and Process Heaters for Cost Effective CO2 Capture and Sequestration	9/24/01 - 3/31/07 Complete	Laboratory
IEA-CANMET-CO2 (International Agreement)	Natural Resources Canada-CANMET	CANMET CO2 Consortium-O_2/CO2 Recycle Combustion	9/30/99 - 8/15/08 Complete	Pilot
FWP49539	Argonne National Laboratory-IL	Evaluation of CO2 Capture/Utilization/Disposal Options	10/1/97 - 12/31/10	Laboratory

Oxy-Combustion Internal Research

Project Number	Performing Organization	Project Title	Performance Period	Scale
ORD-08-220671 (Task 7)	NETL/ORD	Chemical Looping for Combustion and Hydrogen Production	10/1/07 - 9/30/08	Laboratory
ORD-08-220693	NETL/ORD	Oxy-Combustion of Fossil Fuels with Carbon Capture	10/1/07 - 9/30/08	Laboratory
ORD-08-220671 (Task 8)	NETL/ORD	Oxy-Fuel Combustion (Modeling & Optimization)	10/1/07 - 9/30/08	Laboratory
ORD-07-220614 (Task 4)	NETL/ORD	Chemical Looping Techniques	10/1/06 - 9/30/08	Laboratory
ORD-07-220616	NETL/ORD	Chemical Looping Advanced Concepts	9/1/06 - 9/30/07 Complete	Laboratory
OST-03-06	NETL/ORD	Fluidized Bed Chemical Looping Applications	7/1/05 - 9/30/06 Complete	Laboratory

CO2 Compression

The compression of CO2 represents a potentially large auxiliary power load on the overall power plant system. For example, in an August 2007 study conducted for DOE/NETL, CO2 compression was accomplished using a six-stage centrifugal compressor with interstage cooling that required an auxiliary load of approximately 7.5 percent of the

gross power output of a subcritical pressure, coal-fired power plant. As a result, DOE/NETL is sponsoring R&D to develop novel methods that can significantly decrease the power requirements for CO2 compression.

Project Number	Project Manager	Performing Organization	Project Title	Performance Period
FC26-06NT42651	Alsup	Ramgen Power Systems	CO2 Compression Using Super Sonic Shock Wave Technology	5/10/06 - 1/9/11
FC26-05NT42650	Alsup	Southwest Research Institute (SwRI)	Novel Concepts for the Compression of Large Volumes of Carbon Dioxide	9/28/05 - 3/31/08

BP Carson project[55]

BP, in partnership with Edison Mission Group is planning to develop a first-of-its-kind plant which would convert petroleum coke produced at California refineries into hydrogen and CO2 with around 90% of the CO2 being captured. They hydrogen gas stream would be used to fuel a gas turbine to generate electricity. The captured CO2 - about 4 million ton of CO2 per year - would be transported by pipeline to an oilfield where the injected CO2 would stimulate additional oil production and permanently trap CO2. The project would require total capital investment of about $1 billion. Front-end engineering will start in early 2007 and it is anticipated that the plant will be operational by 2011.

Serious questions have been raised about BP's Carson Project, and for that matter, most of BP's CCS project and technology decisions. BP pulled the plug on their Petershead project in Scotland, some feel they are getting cold feet because of the cost of several of these 'good' initiatives. Company is extremely secretive. Network knew nothing, including those at the Westcarb partnership, and BP is refusing phone calls.

The Future project[56]

FutureGen is an initiative to build the world's first integrated sequestration and hydrogen production research power plant. The $1 billion dollar project is intended to create the world's first zero-emissions fossil fuel plant. It is a public-private partnership with alliance members including American Electric Power, Anglo American, BHP Billiton, the China Huaneng Group, CONSOL Energy Inc., E.ON U.S., Foundation Coal, Rio Tinto Energy America, Peabody Energy, Southern Company, and Xstrata Coal..

Restructured Future Gen

The Restructured FutureGen program is a cost-shared collaboration between the Government and industry to accelerate commercial deployment of very low, or near-zero, emissions Integrated Gasification Combined Cycle (IGCC) or other advanced clean coal-based power generation technology with Carbon Capture and Storage (CCS).

The goals of Restructured FutureGen are to:

- accelerate the deployment of CCS technology;
- establish the technical feasibility and economic viability of producing electricity from coal with very low, or near-zero, emissions (including CO2) through a single, commercial-scale power train;
- verify the sustained, integrated operation and the effectiveness, safety and permanence of a coal conversion system with carbon sequestration;
- achieve a goal of approximately 90 percent capture of carbon content in the syngas or flue gas;
- establish technologies and protocols for CO2 monitoring, mitigation and verification.

FutureGen's three-part focus on coal gasification, hydrogen production and CCS, DOE will concentrate on research, development and demonstration of CCS, leaving the demonstration of gasification technology to power developers.

Canadian and American industry insiders are smugly saying that they were right all along, and that the original Futuregen program was completely infeasible.

On June 24, 2008, The U.S. DOE issued a Funding Opportunity Announcement (FOA) to invest in multiple commercial-scale IGCC or other clean coal power plants with cutting-edge carbon capture and storage technology under the Department's restructured FutureGen program. The solicitation is seeking multiple cost-shared projects to advance coal-based power generation technologies that capture and store the greenhouse gas carbon dioxide.

[55] www.bp.com/sectiongenericarticle.do?categoryId=9013460&contentId=7026447
[56] www.futuregenalliance.org

The Department anticipates $290 million will be available for funding of selected projects through fiscal year 2009 and an additional $1.01 billion is expected to be available in subsequent years, subject to appropriations by Congress.

The FOA provides instructions for submitting applications and outlines the mission need and background, project description, and the primary technical goals and performance requirements. The announcement also provides the evaluation criteria, terms and conditions of a model cooperative agreement, as well as cost-sharing required for public-private cooperation under the restructured FutureGen projects. Applications are due October 8, 2008 and the selection of projects is targeted for the end of calendar year 2008.

The restructured approach FutureGen project aims to accelerate the near-term deployment of advanced clean coal technology by equipping new IGCC or other clean coal commercial power plants with CCS technology. By funding multiple projects DOE expects at least to double the amount of CO2 sequestered compared to the amount under the concept announced in 2003. When these plants are operational, they will be the cleanest coal-fired power plants in the world - each capturing and storing an expected 1 million metric tons of carbon dioxide per year.

Subject to compliance with the National Environmental Policy Act, the FOA envisions commercial operation of IGCC or other clean coal power plants equipped with CCS technology to begin as soon as the plants are commissioned by the end of 2015. The restructured FutureGen approach will focus on the challenges associated with avoiding and reducing carbon emissions through sequestration. Technical, economic, and operational results from multiple projects will inform and guide the promulgation of regulations related to wide-scale carbon sequestration activities and at the same time will help establish technologies and protocols for CO2 monitoring, mitigation and verification.

DOE's FOA requires that at least 50 percent of the energy output of the project's energy conversion system must be used to produce electricity and the project must be located in the United States. In addition, the FutureGen goal is 90 percent capture of carbon content in the syngas or flue gas. Projects must also remove at least 90 percent of the mercury emissions based on mercury content of the coal, and reduce sulfur, nitrogen oxides and particulate emissions to very low levels.

To ensure safe and permanent sequestration, DOE also includes in the FOA monitoring and verification performance requirements for FutureGen projects, including quantifying and assessing CO2 capture, transport, and storage during a 3-5 year demonstration of at least one million metric tons of CO2 injected per year in a saline formation; monitoring and reporting to DOE the plumes of injected CO2 for a minimum of two years after cessation of the injection demonstration; and developing information necessary to estimate costs of future CO2 management systems.

Permian Basin EOR projects[57, 58]

The oil and gas producing regions of the Permian Basin, in New Mexico and West Texas (RR Districts 8 and 8A) have an original oil endowment of 95.4 billion barrels. Of this, 33.7 billion barrels or 35% will be recovered. As such, nearly 61.7 billion barrels of oil will be left in the ground, or "stranded", following the use of today's oil recovery practices. A major portion of this "stranded oil" is in reservoirs that appear to be technically and economically amenable to enhanced oil recovery (EOR) using CO_2 injection.

According to the DOE report "BASIN ORIENTED STRATEGIES FOR CO2 ENHANCED OIL RECOVERY: PERMIAN BASIN" approximately 50 (Feb. 2006) CO2-EOR projects are underway in the Permian Basin, three in New Mexico (e.g. Vacuum field) and 46 in Texas (e.g. Salt Creek field). Together, the CO2-EOR projects are producing 170 MBbls of oil per day, accounting for 20% of the Permian Basin oil production. To date, CO2-EOR in the Permian Basin has recovered about one billion barrels of incremental oil.

In the late 1990's, a number of new companies entered the CO2-EOR industry in the Permian Basin, including Oxy Permian and Kinder Morgan. Approximately 0.2 Tm^3 of CO_2 has been sequestered in the Permian Basin and over 1,500 miles of major CO2 pipelines have been built.

[57] www.fossil.energy.gov/programs/oilgas/publications/eor_co2/Permian_Basin_Document.pdf
[58] www.co2.no/files/files/co2/12.pdf

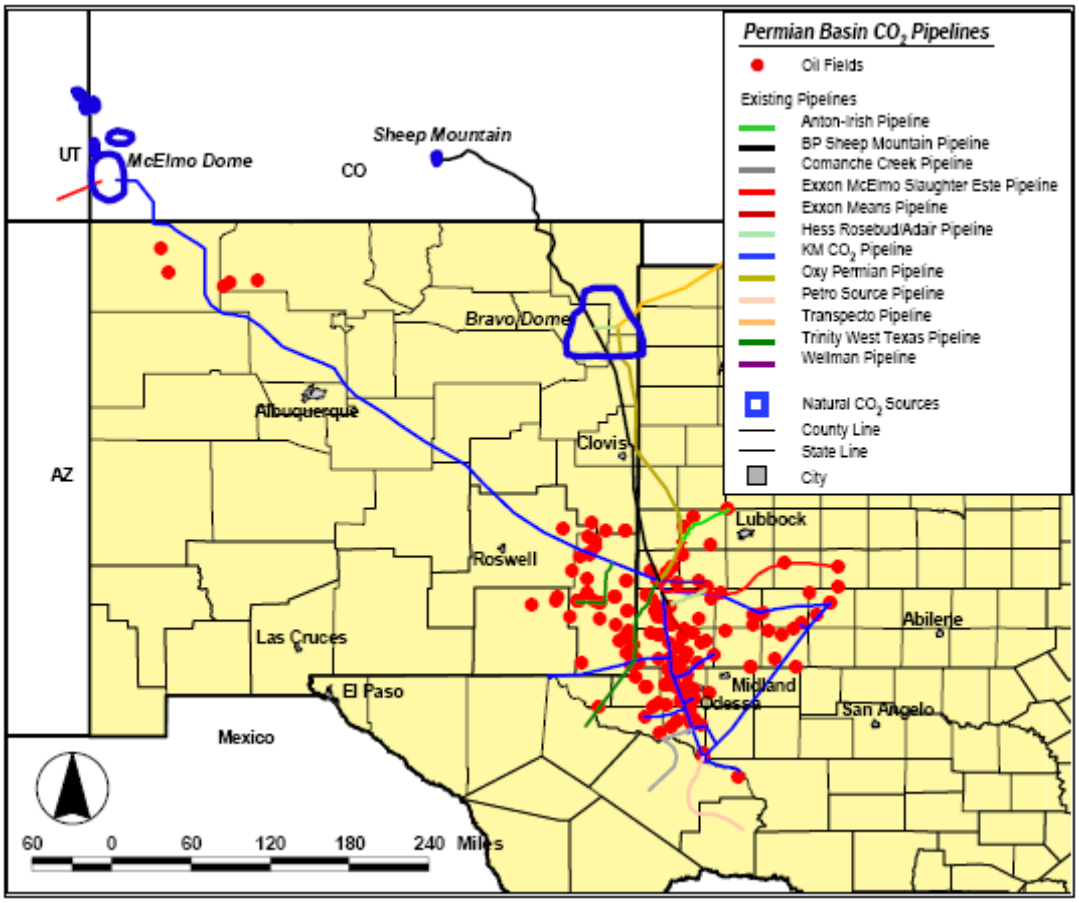


Figure 5: Permian Basin overview.

Other projects

The IEA Greehouse Gas R&D Project's website on CO2 Capture and Storage Projects[59] lists (March 2007) a number of projects related to CCS in North America in the following categories:

CO_2 Capture Commercial Projects (6 projects). 4 projects on solvent absorptions; one related to CO2 capture and transport to the Weyburn field (see above under Canadian projects); and the BP Carson project (see above).

CO_2 Capture R&D projects (22 projects). These projects focus on development of new technologies for pre-combustion capture (oxyfuel, gasification) and post-combustion capture (absorption, membranes, solid sorbents). One interesting project:

BP Corporation of Anchorage, Alaska, is heading a seven-member international team to demonstrate the feasibility of capturing CO2 from a variety of fuel types and combustion sources and storing it in un-minable coal seams and saline aquifers. Proposed DOE cost: $5 m; cost share: $8.8m.

CO_2 Geological Storage Demonstration Projects (4 projects); including the Weyburn Project (described above), which involves a number of US projects where CO2 is captured and transported to Canada/Weyburn for storage/EOR.

CO_2 Geological Storage R&D Projects (31 projects), and CO_2 Deep Ocean Storage R&D Projects (5 projects)

Clean-Coal in Orlando, Florida[60]

In the middle of September, ground was broken on a 285-megawatt IGCC facility in Orlando, Florida (middle of the state). Commercial operation is scheduled for 2010.

This facility will use KBR's Transport Integrated Gasification Technology (TRIG) which has been in development for over a decade. TRIG was developed by Southern Company and Power Systems Development Facility in Wilsonville,

[59] www.co2captureandstorage.info/cont_northamerica.php
[60] www.kbr.com

AL., through a DOE partnership. It is best known for handling high moisture and high ash coals, and is a simpler more robust method of producing power than most existing coal gasification technologies.

The Transport Gasifier is an advanced circulating fluidized bed system designed to operate at higher circulation rates, velocities, and riser densities than a conventional circulating bed unit. The high circulation rates result in higher throughput, better mixing, and higher mass and heat transfer rates. Since the gasifier uses a dry feed and does not slag its ash, it is particularly well-suited for high moisture fuels such as sub-bituminous coal and lignite.

Alstom and AEP

Alstom and American Electric Power signed a Memorandum of Understanding to bring Alstom's chilled ammonia process for CO2 post-combustion capture to full commercial scale of up to 200 MW by 2011.

In phase one, Alstom and AEP will jointly develop a 30 MWth product validation that will capture CO2 from flue gas emitted from AEP's 1300 MW Mountaineer Plant located in New Haven, West Virginia. It is targeted to capture up to 100,000 ton of CO_2 per year. This pilot is scheduled for start-up at the end of 2008 and will operate for approximately 12-18 months.

In phase two, Alstom will design, construct and commission a commercial scale of up to 200 MW CO2 capture system on one of the 450 MW coal-fired units at its North-eastern Station in Oologah, Oklahoma. The coal-fired system is scheduled for start-up in late 2011. It is expected to capture about 1.5 million ton of CO2 a year. This will be used for EOR.

BP and Powerspan Collaborate

On August 3, 2007, BP Alternative Energy and Powerspan Corporation announced their collaboration on Powerspan's CO2 capture technology for power plants called ECO2. This will include sequestration of the CO2 captured into an 8,000 foot test well. This will be associated with the Midwest Regional Sequestration Partnership. BP and Powerspan will conduct pilot testing of the ammonia based CO2 capture technology. This technology would be used as a retrofit solution on coal-fired plants.

CCS TECHNOLOGY COMPANIES IN CANADA

Institution/company	Website
Alberta Province	www.gov.ab.ca
Alberta Science and Research Authority	www.asra.gov.ab.ca
Babcox and Wilcox	www.babcock.com
Brasileiro S.A, - Petrobras	www2.petrobras.com.br/ingles
E.On - United Kingdom	www.eon-uk.com
EnCana Corporation	www.encana.com
EnergyINet	www.energyinet.com
EPCOR Utilities Inc.	www.epcor.ca
Fluor Canada Ltd.	www.fluor.com/canada
HTC Hydrogen Thermochem Corp., Regina	www.htcenergy.com
HTC Purenergy	www.htcenergy.com/may2405.htm
KIER, South Korea (Korea Institute of Energy Research)	www.kier.re.kr/english/index.html
Luscar Ltd.	www.luscar.com
Natural Resources Canada	www.nrcan.gc.ca
Nexen Canada Ltd.	www.nexeninc.com
Saskatchewan Industry & Resources	www.ir.gov.sk.ca
SaskPower Corporation	www.saskpower.com
Saudi Aramco	www.saudiaramco.com
Shell Canada Ltd	www.shell.ca
The University of Regina	www.uregina.ca
Transalta Utilities Corporation	www.transalta.com

CCS RESEARCH AND DEVELOPMENT

Electric Power Research Institute[61]

Electric Power Research Institute announced that five electric utilities will participate in a series of studies to determine the impact of retrofitting amine-based, post-combustion CO2 capture technology to existing coal-fired power plants. The five host companies and sites are Edison Mission Group's Powerton Station in Pekin, Illinois;

[61] www.epri.com

Great River Energy's Coal Creek Station in Underwood, North Dakota; Nova Scotia Power's two units at its Lingan Generating Station in Lingan, Nova Scotia; Intermountain Power Agency's Intermountain Generation Station in Delta, Utah; and FirstEnergy's Bay Shore Plant's circulating fluidized bed boiler Unit 1 in Oregon, Ohio. The studies will examine challenges such as the limited space for new plant equipment, limited heat available for process integration, additional cooling water requirements, and potential steam turbine modifications. The sites were selected because they present a variety of unit sizes and ages, existing and planned emissions controls, fuel types, steam conditions, boilers, turbines, cooling systems, and options for CO2 storage. A report for each site will: (1) assess the CO2 capture efficiency configuration based on site constraints; (2) determine the space required for the CO2 capture technology; (3) estimate performance and costs; and (4) assess the features of each plant that affect retrofit cost and feasibility.

The International Test Centre for CO2 Capture (ITC)[62]

The ITC at the University of Regina has two main components: a pre-commercial scale chemical absorption technology demonstration pilot plant at the Boundary Dam power plant near Estevan, and a technology development pilot plant at the Petroleum Technology Research Centre (PTRC)[63], University of Regina.

Contributors include Natural Resources Canada, Saskatchewan Energy and Mines, the Government of Alberta, and the Canada/Saskatchewan Western Economic Partnership Agreement. Industry partners include Sask Power, Fluor Daniel, Luscar, BP Amoco, EPCOR, TransAlta Utility Corporation, Canadian Occidental and Encana.

At the pilot plant and demonstration plant scales, ITC have established baseline operating conditions and costs for CO2 capture from flue gases (produced at either a coal-fired or natural gas-fired power plant) using an MEA solvent. After base operating standards and costs for MEA systems were established, cost and operating improvements were investigated for the base MEA process. Results indicate that the overall parasitic energy penalty to operate a retrofit MEA CO2 capture facility could be reduced to 50% of the previously reported values. Mixed-amine (MEA-MDEA) has also been examined to investigate cost/energy optimization beyond the base and optimized MEA process. This research indicated that even further reduction in reboiler heat duty is achievable.

ITC project on flue gas treatment

The objective of this project is to develop and demonstrate cost effective, state of the art CO2 emissions control technologies by treating the flue gas after its combustion in air. The post combustion CO2 capture technologies of this nature are needed to help Canadian industry cope in a transitional marketplace where nearly complete replacement of existing and partially paid-off capital infrastructure with other competing capture technologies may be risky and costly.

CO2 Storage Capacity of Canadian Coal Seams

This modestly funded project ($38,000 in 2000/2001) is being carried out from the Calgary office of the Geological Survey of Canada[64]. It seeks to understand the adsorptive capacity for CO_2 of representative coal samples from coal seams in Canada using laboratory isotherm experiments. Detailed studies are required on the areas in Canada, including the east coast, with the highest potential for storage but current funding is inadequate for this project.

Clean Coal Power Coalition[65]

This activity is still at the proposal stage. An association of leading Canadian coal and coal-fired electricity producers, known as the Canadian Clean Coal Power Coalition, has proposed a program with the aim of securing a future for coal-fired electricity generation, within the context of Canada's multi-fuelled electricity industry, by proactively addressing environmental issues in cooperation with government and our stakeholders. Current members of the Coalition are EPCOR, Luscar Ltd., SaskPower, the Alberta Research Council and TransAlta Utility Corporation. The proposal includes:

- Construction and operation of a full-scale demonstration project for the removal of greenhouse gas and all other emissions of concern from an existing coal-fired power plant by 2007;
- Development of low-emission technology for new power plants; and
- Integrated air-quality covenant that tackles the entire portfolio of air quality issues related to coal-fired power generation.

Costs over the next 10 years for the full-scale demonstration project and demonstration of low-emission technology for new power plants are estimated to be nearly $1 billion.

[62] www.co2-research.ca
[63] www.ptrc.ca
[64] gsc.nrcan.gc.ca/index_e.php
[65] www.canadiancleanpowercoalition.com

Advanced Brayton-Cycle-Based Zero-Emission Power Plants Burning Fossil Fuels

A promising means of reducing emissions from power plants burning fossil fuels is a Brayton-cycle-based semi-closed O2/CO2 cycle, with or without a bottoming Rankine cycle (zero-emission plant). Carleton University, in collaboration with the sponsor of this project, CANMET Energy Technology Centre (CETC)[66], has been studying such a cycle.

Partners are Environment Canada[67], Deloro Stellite[68] and Carleton University[69].

Increasing Gasifier Availability via Improved Refractory and Injector Designs

The objective of the project is to address one of the major technical hurdles facing the widespread adoption of IGCC for power production - low gasifier availability. At present IGCC plants have average availabilities of 85% for power production. This availability is unacceptable to a large number of electrical power utilities, power regulators, and consumers. Low availability translates into an increased cost for power production and/or the need for backup power plant.

Novel integrated gasification concepts with CO2 capture could potentially result in electrical power production efficiencies as high as 65%. These concepts generally involve gasification, advanced shift reactors, multi-pollutant capture operations, and electrical power production operations (steam turbines, gas turbines, fuel cells. etc.). This work is targeted to provide improved technology for western Canadian feedstocks to improve the business case for the construction of a demonstration gasification plant showcasing clean coal, hydrogen and electrical power production in Canada. This research is conducted by Albany Research Center[70], LxSix Photonics[71] and CANMET Energy Technology Center in Ottawa[72].

CO2 Hydrate Process for gas separation[73]

The project is concerned with development of the low temperature SIMTECHE process. This process utilizes the formation of CO2 hydrates to remove CO2 from a gas stream. Under the proper conditions, CO2 forms similar hydrates. In Phase 1, a conceptual process flow scheme was developed. The thermodynamic limits of such a process were confirmed by equilibrium hydrate formation experiments for shifted synthesis gas compositions and rapid hydrate formation kinetics were demonstrated in a bench-scale flow apparatus. Performance projections were then made for a few selected process configurations, and encouraging preliminary economics were developed. Phase 2 will conduct an engineering.

Analysis of the concept, and develop updated estimates of the process performance and cost of carbon control and phase 3 will use data developed in the lab to design and build a pilot plant using a slipstream in an operating IGCC plant. Current efforts focus on demonstrating performance and the design point. Partners include Nexant, Los Alamos National Laboratory, and SIMTECH. Project cost- $14,385,000. Flue-shifted syngas, H2, Co2 and other gases 40% CO2, 60% H2.

National Energy Technology Lab[74]

Novel Dual Functional Membrane for Controlling CO2 Emissions From Fossil Fueled Power Plants.

Partner: University of Mexico

Total Project Value: $886,827

Completely funded by the DOE

The goal of this project is to improve CO_2 capture technology is to develop a dual-function amine modified membrane capable of economically and efficiently removing CO_2 emissions from the flue gas of coal-fired power plants. The use of such an amine-modified membrane, with high CO_2 permeance and selectively, holds promise for reducing costs by avoiding the expensive absorber/stripper system required with existing amine-based technology.

Design and Evaluation of Ionic Liquids as Novel Absorbents

Partner: University of Notre Dame

Total Project Value: $404,106

[66] www.cetc.nrcan.gc.ca
[67] www.ec.gc.ca
[68] www.stellite.com
[69] Project Manager: Dr. Donald Gauthier at Carleton University donald_gauthier@carleton.ca
[70] www.alrc.doe.gov
[71] www.lxsix.com
[72] Project Manager: Ben Anthony CANMET Energy Technology Centre – Ottawa Email: banthony@nrcan.gc.ca
[73] carbonsequestration.us/FRED-projects/htm/FRED-2005-DE-AC26-99FT40248.htm
[74] www.netl.doe.gov/

Completely funded by the DOE

This project purpose is to find a more economical means of CO_2 capture using ionic liquids as CO_2 absorbents in natural gas- or coal-fuelled power plants. This design would reduce costs through higher CO_2 loading in the circulating liquid and lower heat requirements for regeneration, compared to existing amine-based technologies. The use of ionic liquids as CO2 adsorbents holds promise for reducing costs by developing a process with higher CO2 loading in the circulating liquid and lower heat requirements for regeneration. Both these effects would lower process costs.

A New Concept for the Fabrication of Hydrogen Selective Silica Membranes

Partner: University of Minnesota

Total Project Value: $237,393

Completely funded by the DOE

In this project, researchers at the University of Minnesota's Department of Chemical Engineering and Materials Science will investigate a new method for making extremely thin, high-temperature, hydrogen-selective silica membranes with high hydrogen (H_2) selectivity, flux, and stability in a water gas shift reactor environment. The proposed membrane will rely on the use of layered microporous silicates that have very limited pore openings perpendicular to the layers. The largest pore openings that are perpendicular to the layers are ideal for hydrogen (H_2) molecular sieving membranes. If it is successfully developed, the membranes could be used for economical production of H_2 from coal-supplied synthesis gas, while simultaneously producing a concentrated CO_2 stream for capture and storage

CO2 Separation with Novel Microporous Metal Organic Frameworks

Partners: UOP LLC (A Honeywell Company), University of Michigan, Northwestern

Total Project Value: $900,000

Completely funded by the DOE

In this project, researchers will work to develop novel microporous metal organic frameworks (MOFs) as sorbents for the removal of CO2 from flue gas and gasifier streams in coal-fuelled power plants. MOFs have previously exhibited exceptional adsorption capacity for methane, hydrogen, and other gases. MOFs are hybrid organic/inorganic structures – essentially scaffolds made up of metal hubs linked together with struts of organic compounds – a structure designed to maximize surface area. MOF sorption properties can be readily tailored by modifying either the organic linker and/or the metal hub. The desired sorbent would have high selectivity, high adsorption capacity, and good adsorption/desorption rates, and would be tailored to minimize the CO_2 binding energy in the interest of reducing the energy required for regeneration. Successful completion of this program could lead to a low-cost, novel sorbent to remove CO2 from flue gas and gasifier streams in electric power plants. The captured CO2 could then be sequestered.

Neutralizing Carbonic Acid in Deep Carbonate Strata below the North Atlantic

Partners: Harvard, Colombia, Carnegie Mellon

Total Project Value: $801,374

Completely funded by the DOE

This project is designed to provide an economical means of CO_2 disposal depends upon the feasibility of long-term CO_2 sequestration in deep-sea calcium carbonate sediments. If deep-sea injection of neutralized CO_2 works as expected, the CO_2 would react to form bicarbonate ions that would be permanently trapped as a "pore fluid." Among the advantages this project would provide is to expand the limited options for disposal of the large volume of CO_2 produced along the densely populated Eastern Seaboard. The East Coast of the U.S. generates a large volume of CO2, however sequestration sites are somewhat limited. An obvious sink is the Atlantic Ocean, but technical and environmental concerns for most ocean sequestration options make their implementation difficult. An option that appears to avoid most concerns is to inject CO2 into ocean carbonate sediments. The CO2 would react to form bicarbonate ions which should be permanently trapped. Even if they should slowly migrate to ocean waters, their impact on the ocean should be minimal. Thus, this project is exploring an option that could be very beneficial in meeting the US goal of reducing CO2 intensity by 18% by 2012.

Zero Emissions Hydrogen Production via Gasification (ZEHP)

Partners: Canadian Clean Power Coalition (CCPC)[75], Alstom[76], University of Toronto[77], University of Ottawa[78], University of BC[79], Instituto de Carboquimica (Spain)[80].

The objective of the project is to develop a process with the following attributes:

[75] www.canadiancleanpowercoalition.com
[76] www.alstom.com
[77] www.utoronto.ca
[78] www.uottawa.ca
[79] www.ubc.ca
[80] www.icb.csic.es

- A product fuel gas stream consisting of greater than 95% pure hydrogen suitable for oil sands upgrading and for use in fuel cells. Particulate and alkali concentrations in this stream will be reduced to such an extent that the stream will be suitable for feed to fuel cells, gas turbines, and membrane separation processes.
- A product gas stream consisting of greater than 95% pure CO2 with CO2 capture greater than 90%, suitable for sequestration.
- A product solids stream suitable for feeding to a cement kiln. The product stream will consist of calcium species, coal ash, and additional mineral species.
- Ability to process a variety of Canadian solid and liquid fuels including coal (high & low rank), petroleum coke, bitumen, and liquid residue.
- Near-zero airborne emissions.
- In-situ monitoring of H2, CO, CO2, H2O, and CH4 within the gasifier reactor.

The technology is expected to be able to supply very large volumes of hydrogen for oil sands upgrading, for electrical power production, and for the transportation sector with no CO2 emissions in the 2015 to 2030 time frame.

Development and demonstration of cost effective amine based solvent scrubbing technologies for CO2 capture from combustion flue gases

Partners: Alberta Province[81], Alberta Science and Research Authority[82], Babcox and Wilcox[83], Brasileiro S.A, - Petrobras[84], E.On - United Kingdom[85], EnCana Corporation[86], EnergyINet[87], EPCOR Utilities Inc.[88] (one year only), Fluor Canada Ltd.[89],HTC Hydrogen Thermochem Corp.[90], Regina HTC Purenergy[91], KIER[92] (Korea Institute of Energy Research), Luscar Ltd.[93], Natural Resources Canada[94], Nexen Canada Ltd.[95], RITE (Japan - Research Institute of Innovative Technology for the Earth)[96], Saskatchewan Industry & Resources[97], SaskPower Corporation[98], Saudi Aramco[99], The University of Regina[100], Transalta Utilities Corporation[101]

The objective of this project is to develop and demonstrate cost effective, state of the art CO2 emissions control technologies by treating the flue gas after its combustion in air. The post combustion CO2 capture technologies of this nature are needed to help Canadian industry cope in a transitional marketplace where nearly complete replacement of existing and partially paid-off capital infrastructure with other competing capture technologies may be risky and costly.

Non-Thermal Plasma Multi-Pollutant Control Technology for Flue Gas Pre-Cleaning before Amine-CO2 Scrubbing Operation

Partners: SaskPower[102], Ontario Power Generation (OPG)[103], Nova Scotia Power (NSPI)[104]

This proposed research work will explore the use of the radical shower plasma generating technology as a flue gas cleaning technology prior to an amine reactor as an effective control technology to remove SO2, NOx and Hg from

[81] www.gov.ab.ca
[82] www.asra.gov.ab.ca
[83] www.babcock.com
[84] www2.petrobras.com.br/ingles/index.asp
[85] www.eon-uk.com
[86] www.encana.com
[87] www.energyinet.com
[88] www.epcor.ca
[89] www.fluor.com/canada
[90] www.htcenergy.com
[91] www.htcenergy.com/may2405.htm
[92] www.kier.re.kr/english/index.html
[93] www.luscar.com
[94] www.nrcan.gc.ca
[95] www.nexeninc.com
[96] www.rite.or.jp/English/E-home-frame.html
[97] www.ir.gov.sk.ca
[98] www.saskpower.com
[99] www.saudiaramco.com
[100] www.uregina.ca
[101] www.transalta.com
[102] www.saskpower.ca
[103] www.opg.com
[104] www.nspower.ca

the coal-fired flue gas. This technology has been identified as a cost effective method to clean flue gas by the utilities.

In this program a plasma radical shower reactor will be designed and tested on a coal-fired flue gas stream to obtain the radical shower plasma multi-pollutant control performance versus the operation conditions such as flue gas temperature, plasma discharge voltage and reagent amount.

Amine-CO2 scrubbing technology is one of the technologies being developed and evaluated as a future CO2 mitigation technology platform by Canadian Power Utilities. To achieve acceptable performance from the amine-CO2 scrubbing technology, the pollutants in the flue gas, such as SO2 and NOx, must be removed prior to the amine reactor in order not to diminish the effectiveness of the amine solution.

Degree of Coal Swelling and Loss of Permeability Associated with Sequestration of CO2, H2S and Flue Gas - Selecting Optimum Coals for Sequestration

Partners: MGV[105], EnCana[106]

Coal seams are being currently investigated as potential sequestering sites for CO2. Coal is a microporous material that possesses a very high surface area and sorption capacity for gas. In the subsurface coal, there are commonly economically significant amounts of sorbed methane (coalbed methane). Because coal has a greater sorption affinity for CO2 than methane, injection of CO2 with simultaneous production of methane may be viable.

Electrical Power Production from Circulating Fluidized Bed Combustor (CFBC) Boilers with CO2 Capture

The objectives of this project are to demonstrate CO2/O2 firing in a CFBC (circulating fluidized bed combustion) boiler using the 1MWt CETC pilot-scale CFBC boiler with a range of Canadian feedstocks. The program will allow the concept to be fully tested at a reasonable pilot scale level, verifying that low conventional emissions (NOx, SOx, CO, mercury and unburned hydrocarbons) can be achieved alongside the production of a near pure CO2 stream for sequestration.

This work will allow Canadian utilities to test Canadian fuels, and to verify that a CO2/O2 strategy can be applied to an advanced CFBC boiler. A commercial plant is anticipated by 2015.

Potential CO2 reductions are on the order of 1.5e6 Mt/yr by 2015 and 8e6 Mt/yr by 2025.

[105] www.mgvenergy.com
[106] www.encana.com

Legislation That Could Affect Carbon Sequestration Projects in US:

Legislation	Description
National Environmental Policy Act (NEPA, 1969)[107]	Requires the preparation of an environmental impact statement when federal funds are used for a project or when a federal government agency is the developer of, or issues a permit for, a project.
Clean Water Act (CWA, 1977)[108]	The objective of this act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Sets the standard of nondegradation of the beneficial uses of water. An example is the "Total Maximum Daily Load" approach.
Clean Air Act (CAA, 1963, 1970, 1990, 1997)[109]	Requires control of 1) particulate matter from industry combustion sources, 2) total reduced sulphur compound emissions, and 3) hazardous air pollutant emissions from production sources. New Source Review (NSR) is a preconstruction permitting program that is operated at federal and state levels.
Safe Drinking Water Act (SDWA, 1974)[110]	EPA sets standards for drinking water quality and oversees the states, localities, and water suppliers implementing those standards. The SDWA led to EPA's Underground Injection Control (UIC) Program, setting requirements for different Class Injection Wells.
Endangered Species Act (ESA, 1973)[111]	Administered by the U.S. Fish and Wildlife Service (USFWS) of the U.S. Department of the Interior and the National Marine Fisheries Service (NMFS) of the U.S. Department of Commerce. The purpose of the ESA is to conserve the ecosystems upon which endangered and threatened species depend and to conserve and recover listed species.
The Migratory Bird Treaty Act (MBTA, 1918)[112] Bald Eagle Protection Act (BEPA, 1940)[113]	Both acts are administered by the USFWS. The first act protects migratory birds from unlawful taking. The second act protects the bald eagle and the golden eagle by prohibiting, except in specified conditions, their taking, possession, and commerce. In January 2001, an Executive Order was issued to further protect migratory birds by requiring federal agencies that take actions having a negative effect on these populations to develop and implement a Memorandum of Understanding (MOU) to promote their conservation (Executive Order, 2001).
Executive Order on Invasive Species (EOIS, 1999)[114]	Federal resource agencies are required to develop invasive species management strategies, as well as strategies to restore native species and habitat conditions in invaded ecosystems.

[107] www.eh.doe.gov/nepa/policy/policy.htm
[108] www.epa.gov/region5/water/pdf/ecwa.pdf
[109] www.epa.gov/oar/oaq_caa.html
[110] www.epa.gov/safewater/sdwa
[111] endangered.fws.gov/esa.html
[112] laws.fws.gov/lawsdigest/migtrea.html
[113] laws.fws.gov/lawsdigest/baldegl.html
[114] www.invasivespecies.gov/laws/execorder.shtml

Legislation That Could Affect Carbon Sequestration Projects in Canada

Legislation	Description
Canadian Environmental Assessment Act (CEAA, 1992)[115]	The purpose of the act is to encourage responsible authorities to take actions that promote sustainable development and achieve or maintain a healthy environment and economy.
Canadian Environmental Protection Act (CEPA 1999)[116]	The primary purpose of this act is to contribute to sustainable development through pollution prevention.
Transportation of Dangerous Goods Act (1992)[117]	This act applies in relation to all matters within the legislative authority of Parliament, including dangerous goods outside Canada that are carried on a ship or aircraft registered in Canada. This act does not apply in relation to commodities transported by a pipeline governed by the National Energy Board Act or the Oil and Gas Production and Conservation Act or by the law of a province; or dangerous goods confined only by the permanent structure of a ship.
National Energy Board Act (1985)[118]	This act establishes the National Energy Board, an independent federal agency that regulates several aspects of Canada's energy industry. Its purpose is to promote safety, environmental protection, and economic efficiency in the Canadian public interest within the mandate set by Parliament in the regulation of pipelines, energy development, and trade.
Fisheries Act (1985)[119]	This act applies to fish habitat protection and pollution prevention as well as several other aspects of fishery regulation.
Canada Labour Code (1985)[120]	An act to consolidate certain statutes respecting labour, including industrial relations and occupational health and safety.

[115] laws.justice.gc.ca/en/C-15.2/
[116] laws.justice.gc.ca/en/C-15.31
[117] laws.justice.gc.ca/en/T-19.01/
[118] laws.justice.gc.ca/en/N-7/
[119] laws.justice.gc.ca/en/F-14/
[120] laws.justice.gc.ca/en/L-2/

Brazil

Governmental strategy

Brazil has drawn up its climate control plan, formulated by several Brazilian government ministries and the Brazilian Forum of Climate Change which is an umbrella organization aiming to stimulate public awareness and dialogue, and incorporate climate change issues into public policies. Goals include getting 7,000 MW of power from renewable energy between 2008 and 2010, increasing production of ethanol from 25.6bn liters in 2008 to 53.2bn liters by 2017, and preventing the release 570m ton of CO2 between 2008 and 2017 by using biofuels.

Brazil is a developing nation, and so is not currently required to take specific action to meet targets established by the Kyoto protocol. Brazil ratified the protocol in 2002. Though there are a couple CCS projects listed below, the country is dealing with climate change issues through usage of biofuels and other biomass projects.

Petrobras CCS

Reconcavo Basin Injection began in the Rio Pojuca aquifer and Buracica fields for EOR in 1987. 130,000 ton CO2/year was injected from ammonia/urea and ethylene dioxide plants. In 2007, there were studies by Petrobras to examine the results of the EOR activities. In Rio Pojuca the neural network was monitored, and in Buracica phenomena studies, modeling, well integrity and other MMV activities took place.

In the first phase of the study results will be applied to an additional 43,000 ton CO2/year injection in the Rio Pojuca Aquifer.

The second phase will see CCS and EOR in the Miranga field. Petrobras will do research on hybrid membranes and amines. The testing will take place on an oxyfuel unit at the Petrobras shale refinery.

Germany

GOVERNMENTAL PROGRAMS AND STRATEGIES

General policy and overall situation

Energy and Climate

At the heart of Germany's energy policies, just as in many other European countries, is the need to create a frame for the development of a future energy sector that will meet the emerging challenges of energy security, competitiveness and climate change.

Germany, being Europe's largest emitter of greenhouse gas (GHGs) emissions[121] is meeting its Kyoto target within the overall European target of 8% and committed itself under the Burden Sharing Agreement to cut CO_2 emissions by 21% in the period 2008-2012 on the basis of 1990 levels. Germany's self imposed mid term goal is however even more ambitious, to cut CO_2 emissions by up to 40% of their 1990 level by 2020 whilst simultaneously phase out nuclear energy by 2021. In July 2009 Germany also agreed with G8 leaders to cut emissions by 80% by 2050 in order to limit global temperature rise to two degrees.

In Germany these targets pose a remarkable challenge, since the German energy production is characterized by the special dominance of coal and lignite. Hard coal and lignite together represented almost 50% of the fuel basis for the gross electricity production in 2007. Gas accounted for 12 %, nuclear 22%, 14% came from renewable energy sources, with the dominant renewable energy source being wind. Whilst the expansion of gas fuelled power generation is currently questionable due to high gas prices, import dependencies and supply insecurities, coal and lignite are likely to play a major role in the future energy mix of Germany, since they offer a cost effective source of secure energy due to indigenous resources and large worldwide reserves[122]. Of the 53 power plants currently under construction or in detailed planning in Germany (with a combined capacity of 26,400 MW) due to start up in the period 2010 -2020, 25 plants are coal based technology (hard-coal or lignite). Clearly, the extensive use of coal stands in contrast to Germany's ambitious climate targets and if lignite and coal burning power stations are to have a future over the medium to long term, given the tightening of reduction targets, the development of power stations with high efficiencies and CCS technologies seem inevitable.

Whilst Germany's climate targets imply a decarbonised economy by 2050 in the absence of CCS, there is a window of opportunity for Germany since, just as for Europe, there is a tremendous need for re-investments in generation capacity over the next two decades. Determined by the lifecycle structure of the existing power generation system in Germany and including the projection of nuclear phase –out over the next 15 – 16 years, power stations with a capacity of around 40 GW will have to be replaced in the next 15 to 20 years in order to meet the conservatively estimated future demand of about 550 TWh per year in 2020[123]. Since these new power stations will then operate for a full life cycle of approximately 40 years, the investment decisions made in the next few years will strongly influence the structure of electricity generation, as well as the future GHGs path of Germany.

Political Framework

German climate policy and hence the political framework for the development of CCS is embedded in European energy and climate policies. The European energy and climate package, which was first presented in January 2007 and passed by the European Parliament and Council in December 2008, focuses on three major policy areas: greenhouse gas emissions, renewable energy and energy efficiency. Correspondingly the package contains quantitive targets for renewable energy (20% by 2020), energy efficiency (an increase by 20% by 2020) and the reduction of GHGs (20% by 2020).

CCS entered the European Commission's portfolio of climate mitigation options as part of the Energy and Climate Package, in January 2007. On January 23rd 2008, the Commission proposed a Directive to enable CCS technologies in the EU. A legal framework to manage possible environmental risks and liability issues and economic incentives for CCS as well as a network of demonstration plants are at the heart of the CCS framework directive. In October 2008, the European Parliament's Environment Committee voted in favor for the amendments proposed in the Davies report, which creates a concrete legal framework for CCS. Among others, the Committee voted in favor of Emissions Performance Standard legislation which limits emissions for all new coal plants built in the EU after

[121] with 994 million tones of CO_2 equivalent in 2005

[122] German lignite deposits currently secure 25% of the country's electricity supply.

[123] These estimates represent a conservative compromise between more extensive growth rates and energy savings potential through widespread use of efficiency gains (EWI/Prognos).

2015. The limit of annual CO_2 emissions to a maximum of 500 g/KWh essentially rules out traditional coal plant technologies and mandates the use of CCS. The Committee also adopted an amendment to support the financing of 12 large-scale commercial CCS demonstration projects. The final proposal calls for funding mechanism that set aside 300 million carbon allowances from the ETS new entry reserve to co-finance the construction of CCS demonstration plants. The value of this support depends on the price of allowances and could range between € 6 – 9 billion. Power plants with an output of more than 300 Megawatts are required to assess whether storage sites and transport facilities are available and if it is technically and economically feasible to retrofit the power station for carbon capture.

The German government is implementing these fundamental European policy decisions at a national level by means of the German energy and climate protection package, which was decided in Meseberg in August 2007, called the *Integrated Energy and Climate Program*. The implementation of the energy and climate program will ensure that Germany's climate targets are achieved in a continuous process by 2020 and the requisite measures are organised cost effectively. Proving the feasibility of CCS is one important pillar of the climate package.

Although Germany initially considered CCS with skepticism, during 2008 the concept increasingly became a key component of a national *"Clean Fossil Fuel Strategy"* and the German Government has decided to take on a "No regret" policy regarding CCS. To prove the feasibility of CCS, increased R&D efforts have been funded and initiated in 2007 and the construction of at least two or three of the 12 demonstration CCS power station that are to be built across Europe are envisaged, as well as further storage projects. Taking into consideration the results of relevant R&D projects, the German Government has in this context stated that it would consider proposals for a "capture ready" standard for future fossil fuel power plants. In order to translate the European CCS directive into German national legislation, considerable political effort has been undertaken in the end of 2008 and the first half of 2009.

Challenges

One important prerequisite for the deployment of CCS in Germany is the availability of storage capacities. Among the different options available for geological storage of CO_2 in Germany, deep saline aquifers currently provide most of the storage potential. Other storage possibilities such as depleted gas fields and the storage in deep unminable coal seems, e.g. in the Ruhr district, are available but seem currently less attractive in Germany. Therefore current estimates of the BGR[124] (Bundesanstalt für Geowissenschaften und Rohstoffe) aggregate to a storage potential of approximately 20 ± 8 Gt for saline aquifers alone, of which one quarter is located in the northern parts of Germany, providing storage capacities for emissions for about 50 – 80 years. However, because estimates of storage capacity of saline aquifers are subject to preconditions and assumptions regarding the structural conditions, considerable uncertainty exist in this respect. Currently, efforts are being undertaken to improve the estimates of the storage capacity in Germany, however because of the North South divide of sources and sinks, onshore storage remains a limited and complex issue for Germany.

The development of CCS demonstration plants furthermore postulates the development of a suitable legal framework for CCS in Germany. Currently, the mining and environmental law provide a basis for the conduct of CCS research projects. In 2008 the German government announced that it intended to be the first European country with a national legal framework for the deployment of CCS and has since been working on a suitable legal framework for underground storage on an industrial scale (including the planned demonstration power stations), transport and capture in parallel to and on the basis of the European legal framework. After 6 month of intense negotiations between the two involved ministries, the Federal Ministry of Economics and Technology and the Federal Ministry of the Environment, the legislation should have been passed by the Parliament in June 2009. However, regional political dispute, public protest against storage projects in Schleswig Holstein and the upcoming elections brought the process to a halt.

Germany is a federal republic of sixteen states with own constitutions and political systems, providing the potential for conflicts associated with regionalisation and possibly "eco dumping". First signs have already been observed with storage pilots in Saxony Anhalt and Schleswig Holstein, where politicians of the state governments, which are responsible for the permitting process of storage projects, have hindered both storage projects and federal CCS legislation. Also the construction of so called climate pipelines that run through several different states provide challenges as governments from different states are part of the negotiation process. The legislation will be taken on the agenda after the elections in September, however it is possible that it will be not before 2010 that a national legislation for CCS is in place in Germany.

As has been observed in the case of the legislation for CCS, the ultimate risk in Germany remains how an electorate with a negative view of nuclear waste storage responds to the concept of CO_2 storage. Pubic acceptance will be decisive for the implementation of CCS in Germany. A recently published study undertaken by the Wuppertal Institute[125], which covers social and acceptability issues and analyses the potentials of public risk-perception as well as the perception of CCS, finds that currently CCS is not broadly discussed in Germany and that the NIMBY Effect (not in my back yard) is likely to trigger a strong reaction, particularly regarding storage in Germany, once projects are getting started. The concerns are wide ranging and include the negative effects on tourism and the devaluation of land, as well as safety for human health and drinking water.

[124] www.bgr.bund.de

[125] Socio Economic Research on Acceptance pf Carbon Capture and Storage at national and international level. Wuppertal Institut (2008)

Further acceptance problems result from a strong movement against coal which is growing in Germany. Public concern not only results from the negative climate impact associated with coal, but also from land degradation and loss of local communities resulting from lignite exploration in Germany. Public protest has inhibited several coal projects, including Ensdorf, Ingelheim, Lubmin, Dörpen, Kiel and Moorburg and projects such as the IGCC CCS in Hürth meet first negative reactions from local action groups. CCS could be seen as just another possibility for power generation companies to pursue their coal strategies.

Therefore, NGOs are likely to play an important role in the public discussion. However, just as in the rest of Europe, "green groups" split over CCS. Whilst CCS is seen by some environmental groups as just another end of pipe solution ("False Hope" study by Greenpeace) with the aim to continue to invest in coal on the expenses of climate targets, others such as the WWF Deutschland, German Watch and others see CCS as a possible bridging technology that paves the way for a decarbonised energy sector. Raising public awareness and providing sufficient information will be pivotal in the coming years if CCS is to be implemented in Germany.

Private sector engagement

There is generally agreement between the political and business communities that climate protection is a central element of environmental policy and an integral part of economic and energy policy. German businesses have a self imposed objective of making a special effort, on a voluntary basis to reduce specific CO_2 emissions by 35% by 2012. Additionally, major players in the energy sector are signing up to the 3C – Combat Climate Change – initiative of business leaders with the commitment to draw a road map to a low emitting society and develop carbon strategies, such as Vattenfall that has the aim to reduce emissions by 50% by 2030.

German electricity producers are examining the potential of low emission power stations in the view of these commitments and due to their obligation to reduce emissions under the EU-ETS and the associated changes in the energy sector.

Especially for companies like RWE, which are heavily invested in lignite and coal fired power plants (65% in 2006), CCS could prove a viable technology under stricter climate regulation in the long-term. In the short term however utilities are asset heavy with the lion share of valuation vested in assets in the ground, making them particularly vulnerable to risk, whilst deciding on long-lived investments that exceed the current climate policy planning. Current techno – economic prerequisites, including the rise in cost of power plant construction due to high demand and rising commodity prices, render therefore the operation of CCS power plants not profitable. Clearly, CCS technologies will only be realised with the perception of long –term high price expectations, both of electricity and carbon prices and if the EU regulatory framework provides the appropriate incentives and security for these investments. The probably most challenging aspect in this context will be the high degree of uncertainty regarding future political development, also beyond 2012, for companies that are facing upcoming investment decisions. Not surprisingly several power plant projects have been put on hold until a concrete framework is in place in Germany.

The sentiment between German industry and government is therefore mixed. A clear governmental commitment regarding the legal framework for CCS might not only yield a more favorable investment environment but also could increase public acceptance in Germany, which today provides another decisive investment risk for power companies.

Unfavorable economics and politics or not, seizing opportunities and pursuing innovative technologies have benefits in terms of reputation and shareholder value. CCS clearly provides a valuable opportunity for Germany's large power generators that are currently in an image crisis, to improve their reputation and three of the large power companies are embracing CCS with several pilot and demonstration projects having been announced. RWE furthermore opened an "Innovation Centre Coal" at its power plant Niederaussem and called for reliable climate policies after 2012 to ensure that power plant investments in Europe guarantee security of supply in future. Companies involved in the development of CCS projects such as Alstom Germany, Babcock Borsig, EnBW, E.ON, RWE and Vattenfall Europe furthermore try to accelerate the pace of the development of a national legal framework for CCS in Germany.

R&D activities from utilities, technology companies and trading companies in Germany are not solely orientated for the European market. Power plants "made in Germany" stand for highest standards and are an internationally demanded product. Germany is the second largest exporter in the power generation plant sector. CCS technologies might become an interesting export commodity especially when considering emerging markets such as China as a possible, coal dependent trading partner. In September 2005 Chinese-European collaboration was initiated for the development of clean coal technologies. Until 2020 low emission power plants are planned in China, whereby technologies will be provided by European power plant builders.

Public CCS funding initiatives and partnerships

R&D is the key to establish a reliable, economic and environmentally compatible energy supply. The first R&D program for energy research was initiated in 1974. Today, German R&D efforts in energy research are governed by the 5th energy research program "*Innovation and New Technologies*" and its amendment the "*High Tech Strategy*". Main topics include energy efficiency, renewable energies, fuel cells and hydrogen and fossil fuel power plants and CCS.

Increased national interest in CCS as a possible technology to mitigate climate change, and the ambition to demonstrate the technology in Germany, postulates an increased level of activity in research and development in

this area. Currently, the BMWi and the BMBF are working in cooperation with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) on a detailed roadmap for CO_2 capture (BMWi/BMU) and storage (BMBF/BMU) as part of the development of an *Integrated Energy and Climate Program* for Germany. A total sum of € 2.6 billion is available for climate policy under the federal budget for the 2008 financial year, which represents an increase of about € 1.8 billion or 200% to 2005. In April 2008, the German government announced that it would increase the funding for energy related research by €50 million compared to 2007, which translates into a total funding of € 328 million. Consequently, CCS research and development activities can expect increased funds in the coming years.

Regarding CCS, the majority of public funding to fundamental research and demonstration projects originates from two Ministries, the Federal Ministry of Economics and Technology[126] BMWi and the Federal Ministry for Education and Research[127] BMBF.

Geotechnologien

Since 2005, the BMBF supports as part of its geo-scientific research and development program *GEOTECHNOLOGIEN* research projects on CO_2 storage. CO_2 storage in geological formations is investigated within the research theme "Investigation, Use and Protection of the Underground". The projects are undertaken in the form of collaborations from Universities and industry and in the first phase (2005-2008) nine interdisciplinary projects with the focus on technological, ecological and economic perspectives concerning CO_2 storage and monitoring in geological formations were funded with a financial volume of € 6.9 million. 12 Universities as well as 13 companies of the German energy sector were involved.

To quantify the CO_2 storage potential for Germany further, a second funding phase (2008-2011) for the national R&D program *"Geological Storage of CO_2 in Germany"* was initiated in 2007. The financial volume is € 19.6 million per year and 17 research institutions and 11 companies are involved. The main objectives are the extension of basic research on storage and surveillance technologies, complementary to the pilot projects. Basic R&D activities without site specification will be supported from 2008 with a budget of €8 million per year. Research fields include, monitoring and modeling tools, trapping mechanisms, CO_2 mobility, stability and integrity of reservoir and injection wells. Site specific pilot projects as public private partnerships will be funded with € 9 million per year, starting from 2008. Activities include, the "Altmark Gasfield" as a large scale demonstration site in Northern Germany, as well as the development of other pilot projects to prove saline aquifers for CO_2 storage.

COORETEC

The BMWi is supporting the development of capture technologies with the research and development concept *COORETEC*, which aims to reduce the emissions of fossil fired power plants to near zero. *COORETEC* (CO_2 Reduction Technologies for Fossil Fuelled Power Plans) was initiated in 2002 due to the high demand for new investments in power plants in Germany. The concept rests on the two pillars of efficiency increase and avoidance of CO2 emissions and intends to create the basis for satisfying at the highest possible technical level standards for new and replacement plants in the power generation sector foreseeable after the year 2010. In 2007 COORETEC launched additionally the "Lighthouse Concept". The technological objectives of the lighthouse concept are to sink costs involved in CO_2 capture and storage from current rates of € 50 -70 per ton of CO_2 to below €20 in the future, while simultaneously reducing efficiency losses from 9 -13 percentage points today to 6 – 11 percentage points in the future. Consequently, five technologies related working groups have been created in the covering natural gas combined cycle, steam cycle power plants, IGCC with carbon capture, Oxyfuel and storage. The research projects are in general collaborative projects between research institutions and industry. The level of funding varies with the projects, and whilst industry can receive coverage of up to 50 % of their costs, academia will be funded with 100 %. In 2007, CCS research projects on capture technologies were funded with approximately € 26 million, 2008 approximately € 30 million and a funding of € 35 million annually is envisaged for 2010.

RWE's Coal Innovation Centre

Apart from the large German research programs, there have been smaller, regional initiatives in Germany such as RWE's "Coal Innovation Centre" in Niederaussem. The aim is to perceptibly lower CO_2 emissions in coal based power generation. The intention is to invest some €90 million in the coming years in research and development for CO_2 reduction and conversion technologies. Besides specific projects that practically go straight from the lab to the workbench, the "Coal Innovation Centre" is designed to give international experts a platform for exchanging ideas. Starting in spring 2009 and in collaboration with the RWTH Aachen Technical University, the Juelich Research Centre and the TÜV Rheinland technical inspection agency, practice-related symposia are held both with international experts and with students from the region. Four major projects are already up and running, such as a prototype plant, to test pre-drying lignite using the fluidised-bed method, which has the potential to increase efficiency rates in power generation using lignite by 10% to over 47%. In a joint project with BASF, Linde and RWE Power, a pilot plant for CO_2 scrubbing is operated at Niederaussem as well as a pilot algae plant.

[126] www.bmwi.de/English/Navigation/root.html
[127] www.bmbf.de/en/index.php

International Fora

Germany has a great interest in international exchange of know-how regarding CCS. Within the EU, Germany is supporting R&D activities within the framework programs, the ZEP (Zero Emission Fossil Fuel Power Plants Technology Platform) and the ERA-NETs such as FENCO. Internationally, Germany, i.e. the BMWi became member of the Carbon Sequestration Leadership Forum (CSLF) in 2003 and has since then played an active role in the CSLF task forces and projects and is participating actively in the programs of the IEA working party fossil fuel and the IEA implementing agreements, the IEACCC and IEAGHG program.

CURRENT CCS PROJECTS IN GERMANY

Although Germany has been approaching CCS cautiously at first, both R&D and pilot projects are increasingly catching up and several demonstration projects have been officially announced and are in the concrete planning process. Overall, the power sector in Germany is at a turning point and power plant operators are today already asked to design their new power plants in such a way that later retrofit with a suitable CCS system is possible. Due to the growing public resentment against new coal fired power plants, several coal power plant projects in planning have announced to implement CCS as soon as the technology is available, which in some cases has been part of the concession process, such as in the case of Vattenfall's coal power plant Moorburg in Hamburg.

In order to provide proof to the public and to official bodies that the planning or erection of a new power plant has been carried out in such a way that it is possible to retrofit a carbon capture system at a later date, the German TÜV, Germany's independent inspection organisation, has developed a capture ready certification and a binding catalogue of requirements for carbon capture readiness. The criteria were developed taking the current state of knowledge and European legislation into consideration, and collated in the TÜV Climate Change Standard TN-CC 006. The Standard TN-CC 006 contains 12 criteria concerning requirements in particular regarding the technological and site-specific feasibility of retrofitting a CC system at the power plant location, the availability of the space which will be needed for the system, the possibility of transporting CO_2 away from the site and of CO_2 storage and also the possible effects on plant safety and the environment. The contract duration is set at 5 years after which a revision will be conducted to renew the certificate. The four first Carbon Capture Readiness Certificates have been awarded to E.ON's new coal power plants in Wilhelmshaven, Staudinger, Kingsworth and Antwerp.

Vattenfall's Oxyfuel Pilot Plant " Schwarze Pumpe"[128]

Figure 6: Source: Vattenfall

Vattenfall initiated the project in 2001 with a long term research and development project to develop the oxyfuel technology to a commercial application level. By May 2006 Vattenfall could start with the construction of the 30 MW (thermal) lignite oxyfuel pilot plant near its existing 1,600 MW lignite – fired power plant in the industry park "Schwarze Pumpe" near Spremberg in Brandenburg south of Berlin. The investment costs were initially estimated at € 60 million, however according to Vattennfall construction amounted to € 90 million and further € 30 million are

[128] http://www.vattenfall.com/www/vf_com/vf_com/365787ourxc/366203opera/366779resea/366811co2-f/index.jsp?WT.ac=advertise

being invested in research activities during the project. On 9 September 2008, Vattenfall officially inaugurated the plant and some 45 t CO2 have successfully been separated during the first weeks of operation.

The plant is expected to be in operation for 3 years and will produce about 9 metric tonnes of CO_2 per hour, which translates into 75,000 metric tonnes of CO_2 per year at full load, approximately 0.6% of the volume of the larger Schwarze Pumpe power plant (10 million ton CO2 annually), currently at a cost of € 80 – 90 per tonne.

Linde AG provided the cryogenic air separation and air processing unit, as well as the CO2 liquefaction plant, the boiler has been developed in cooperation with Alstom. Other components, such as a new web based I&C system SPPA-T3000 and connections to the airs separation unit, the CO2 liquefaction facility and the main power plant as well as the field instrumentation was provided by Siemens. The pilot plant is supported by research undertaken at the University of Cottbus (CEBra project with a 0.5 MW test facility) and the University of Dresden (ADECOS project with a 0.5 MW test facility). In September 2008 Linde Group and Vattenfall Europe Technology Research GmbH have further entered into a wide ranging technology partnership with the aim of collaborating on the testing of oxyfuel combustion processes. Linde is supporting Vattenfall with scientific and technical expertise during the first trial phase unit 2011.

Originally, the separated and liquefied CO_2 produced by the pilot plant should have been transported by truck to the 350 km distant storage site in Altmark. Public protest in combination with the lacking federal storage legislation has brought the Altmark project to a halt. Vattenfall is investigating in alternative storage sites in Brandenburg and has been considering to send the separated CO2 to the storage project in Ketzin. In the mean time however, at least some parts of the CO2 are trucked off for use in industrial application.

The insights gained during the pilot phase will be utilised to plan a large demonstration power plant with a 250 to 300 MW electrical capacity, around 2012-2015. Then, efficiency and economic aspects will be further investigated and finally the plan is to set up a commercial power plant with the capacity of approximately 1000 MW, around 2015-2020. Progress can be monitored online[129].

Vattenfall Oxyfuel and Post combustion Demonstration Plant in Jänschwalde

In Mai 2008, Vattenfall announced its plans to build a demonstration plant for CCS technologies at one of the 500 MW blocks of the conventional lignite power plant Jänschwalde in the State of Brandenburg, Germany. The investment for the demonstration is estimated to be € 1 billion. The Jänschwalde lignite power plant consists of six 500 MW blocks. For the demonstration plant one of the blocks, consisting of two boilers, will be equipped with carbon separation technologies. One boiler will be newly built with an oxy-fuel technology; the other will be retrofitted with a post-combustion technology.

Whilst the oxyfuel technology used in the boiler is identical to the one used in the pilot plant "Schwarze Pumpe", the post combustion technology will be based on a chilled ammonia process.

To compensate the loss of efficiency of approximately 10% in the generation process, incurred by the installation of additional components, Vattenfall is developing methods for increasing efficiency by using higher temperatures and pre drying of lignite as well as operational excellence. The demonstration plant will produce 300 MW.

The project has a very ambitious time schedule. In February 2008, a feasibility study was undertaken. Permits are expected to be issued 2009, ground breaking is scheduled 2010/2011 and the start of operation is planned 2015.

Vattenfall has furthermore announced its cooperation with Gaz de France Production and Exploration GmbH for storing the captured CO_2 from Schwarze Pumpe and Jänschwalde in the gas field in the Altmark. Initially the separated and liquefied CO_2 produced should have been transported by truck, later by pipeline to the gas field.

For both projects of Vattenfall uncertainties however exist regarding the storage of the separated CO_2. Not only is the national legal framework not expected to be in place before end of 2009, and hence permission procedures are stalling, but in Saxony Anhalt resistance is emerging on a state level. The government of Saxony Anhalt is currently considering whether it will import CO_2 from other Bundesländer or instead binds the storage permission to a new power plant project, located in Saxony Anhalt. Vattenfall is therefore considering alternative options, including alternative countries such as Poland for the location of their demonstration plant as well as alternative storage sites in Germany.

In this context Vattenfall has announced that it will investigate storage sites in Brandenburg. Together with VNG Gas AG and Schlumberger Carbon Services, Vattenfall has initiated exploration of two different possible storages sites in Brandenburg, the 556 km^2 area at Beeskow and a 300 km^2 area in Neutrebbin.

The sedimentary rocks in the North German Basin were already screened between 2004 and 2008 and both structures Birkholz Beeskow and Neutribbin were promising in terms of capacity, injectivity and storage integrity. The storage capacity of the two structures is estimated to be more than 100 million tons.

The exploration program to screen the structures will begin in 2009, if permission will be granted, and end in 2011 and will be implemented in three phases: seismic studies, exploration drilling and simulation of the flow properties within the sediment strata in a test program. If the exploration is successful, the storage sites will be developed.

The connection system between the injection drill hole and the transport pipeline will be implemented in the period 2011 to 2015. This will be followed by transport via a gas pipeline from the demonstration plant in Jänschwalde to

[129] www.vattenfall.de/co2frei

the storage site. The pipeline of 150 km length will be built with a distribution system but no pressure boosting system.

RWE IGCC Plant with CO2 Storage[130]

As early as April 2006 RWE announced its plans for the development of a CCS demonstration plant in Germany. As announced in 2008, RWE is planning to construct an IGCC lignite fuelled power plant at the Goldenbergwerk location in Hürth, nearby Cologne in North Rhine Westphalia.

Since the location is well connected to open cast mines, raw lignite will be the fuel of this power plant. To reduce the water content pre drying will be applied to bring down the moisture content to 12%. The power plant is expected to have a gross output of 450 MW, with an efficiency of 36% and integrate CO_2 capture. Capture rates are expected to be about 92% or 100g/Kwh_{net}.If successfully implemented, the plant will be scaled up to produce 1000 MW.

RWE is planning to operate the plant by 2014 and was initially planning to invest some € 1 billion in this project. Today, the costs of the project have risen to € 2 billion. By choosing an IGCC technology, RWE is building up on its experience with this technology from the early 1990s. In order to cater for CO_2 separation, processing is adjusted.

The power plant development will be accompanied by the development of a storage project. RWE plans to store some 2.6 millions ton of CO_2 annually, amounting to a total of 104 Mt and is currently investigating different locations in the North of Germany for adequate storage capacities. Currently three different regions in Northern Germany are under investigation, which are Nordfriesland, Ostholstein and offshore storage outside the 12 mile zone of Northern Germany. In March 2008, RWE started the exploration phase with site screening, consisting of regional and feasibility studies of the reservoirs. If permission is granted, seismic studies will be undertaken in 2009.

The storage project which is coordinated by RWE Dea, is accompanied by the research project COAST, which provides the accompanying R&D for clarification and assuring of standards and methods for commercial scale CO_2 storage in deep saline aquifers.

To connect source and sink, RWE is planning to build a pipeline of about 530 km from North Rheine Westphalia to Schleswig Holstein. The liquefied CO2 will be under the pressure of 200 bar directly transported to the storage site. Currently this project is in the regional planning procedure. According to RWE end of 2009 will be an important milestone for the IGCC CCS demonstration project until which decisive internal and external project fundamentals will have to be established. However, just as Vattenfall, RWE is facing problems regarding storage sites in Schleswig Holstein and receiving the required permissions might prove to be difficult.

RWE's Scrubbing Pilot Plant in Cooperation with BASF and Linde[131]

Figure 7: Source: RWE

In addition to the IGCC CCS demonstration plant, RWE also agreed on a cooperation with BASF and Linde Group, for the development of a CO_2 scrubbing pilot plant at the power plant Niederaussem. The project entails the construction and operation of a pilot plant, which started in July 2009. At the pilot plant all aspects of CO2 scrubbing are to be trialed for 18 months under real power plant conditions to examine their functioning state and gain experience for later commercial scale systems. The aim of the project is to reduce efficiency losses and costs

[130] www.rwe.com/generator.aspx/konzern/fue/strom/co2-freies-kraftwerk/co2sink/language=en/id=272116/page-co2sink.html
[131] www.rwe.com/generator.aspx/konzern/fue/strom/co2-freies-kraftwerk/co2-waesche/language=en/id=272122/page-co2-waesche.html

associated with post combustion technologies to €30/t of CO_2 through energy optimised Amine scrubbing solvents supplied by BASF, and improvements in the process and plant technology.

Linde is responsible for engineering and the construction of the pilot plant and has been constructing the pilot at the 1,000-MW lignite-fired unit BoA 1. BoA 1 is with a net efficiency of over 43% the most advanced and efficient lignite-fired unit worldwide. It is equipped with optimized plant technology and is the forerunner to the two power plant units BoA 2&3 being built at the Neurath site. In Niederaussem, the carbon capture technology to be developed can thus be adapted to this type of power plant in an ideal manner.

The height of the pilot CO2 scrubbing plant (40 m) corresponds to that of the future commercial plant. The plant also comprises all individual components of large plants, but on a smaller scale. The diameter of the absorber column was limited to the size required to obtain representative results.

To operate the pilot plant a small amount of the flue gas (0.05%) is diverted from the BoA unit and fed into the pilot plant. Depending on the set test parameters, up to 300 kg CO2 per hour can be separated from a flue gas bypass (corresponds to a capture rate of 90 %). The scrubbed CO2 is fed back into the fluegas stream of the BoA unit, since currently no storage options exist at the site.

The cost of the project mount to € 9 million, to which the Federal Ministry of Economics and Technology is contributing 40%.

Provided that the pilot phase is completed successfully, it is planned to have a demonstration phase immediately afterwards, during which a demonstration plant is to be built. Current plans involve a 30 to 40 MW plant with capture and storage.

The project will be linked to other pilot projects undertaken at the site such as the WTA process developed by RWE in order to compensate for the efficiency losses associated with capture. The goal is to make carbon capture technology utilizable for the retrofit of existing modern plants or new power plants by 2015.

E.ON's Post Combustion – Wilhelmshaven and Heyden

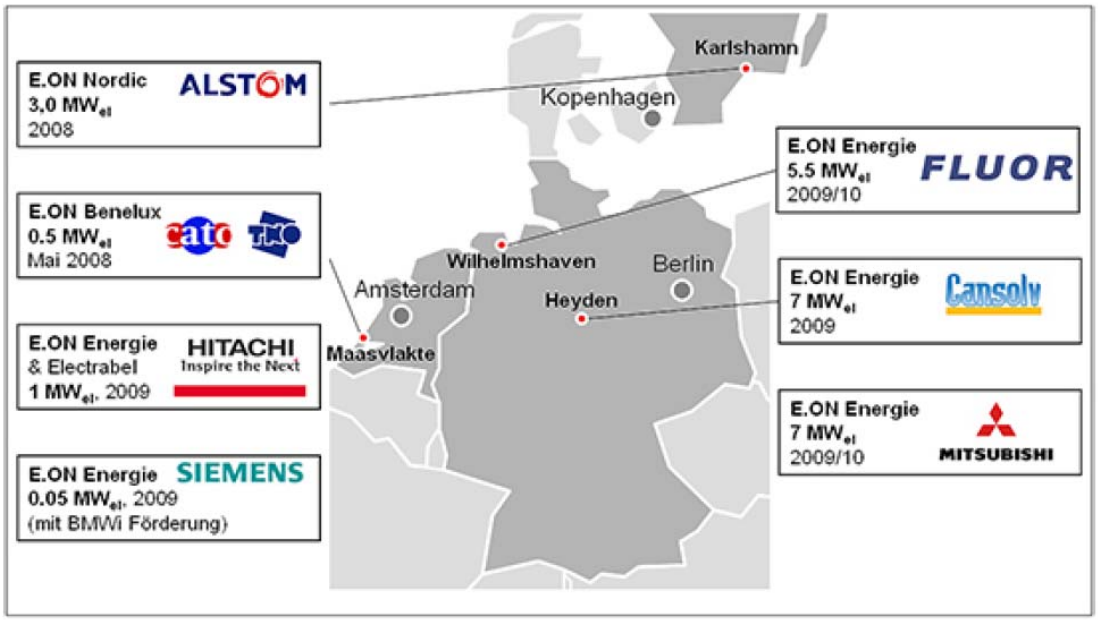
Although E.ON has been approaching CCS technologies carefully, E.ON is now planning seven smaller pilot plants, all of which are aiming to optimize post combustion methods for capturing CO_2. E.ON plans to pursue the development of post combustion technologies with a budget of € 100 million until 2014. Four of the projects are planned in Germany in cooperation with Siemens, Flur, Consolv and Mitsubishi.

One of the projects is located at E.ON's coal fired power plant in Wilhelmshaven and is scheduled to start operation in 2010. Flor and E.ON Energy have formed a strategic partnership for the development of a retrofitted pilot plant using Flour's Econamine FG+ technology. The technology uses monoethanolamine as the solvent for efficient capture of CO_2. The pilot plant will be small in scale with only 5.5 MW and has a budget of € 10 million.

In North Rhine Westphalia E.ON Energy will work together with Canadian Cansolv Technologies at its location in Heyden. The objective of this project is again to improve efficiency of post combustion by testing different solvents. The pilot plant which is expected to commence its operation in 2009 is planed to produce 7 MW.

In cooperation with Siemens E.ON is planning a pilot at the Staudinger power station near Hanau east of Frankfurt. The pilot plant will have a capacity of 1 MW and will be run with part of the flue gas from Staudinger's unit block 5 between 2009 and 2010. The project has a budget of € 10 million.

Another pilot unit is planned in cooperation with Mitsubishi Heavy Industries. The location of the pilot plant will be at a coal fired power station in Germany and will begin test operations in 2010. It will be the first unit to test, under realistic operating conditions, the latest carbon scrubbing processes and solvent technology developed by Mitsubishi Heavy Industries. The pilot will operate at a flow rate of 20,000 cubic meters of flue gas per hour and will provide important insights into the integration of carbon scrubbing into power plant operations.



Quelle: E.ON

CO2 SINK[132]

The CO_2SINK integrated project, which is the first European Showcase for Onshore CO_2 storage, is supported under the FP6 framework by the EU commission with a budget of € 14 million. 18 institutions from 9 European countries are involved. The project started in April 2004 and aims to develop the basis for onshore storage techniques by injecting CO_2 into a saline aquifer near the town of Ketzin, west of Berlin. The project's aim is to demonstrate long-term geological storage of CO_2 in a saline aquifer. The project developed an *in situ* laboratory for CO_2 storage to fill the gap between the numerous conceptual engineering and scientific studies on geological storage and a fully-fledged onshore demonstration. To characterize the underground and understand the processes that happen there, detailed analysis are being made of samples of rocks, fluids and micro-organisms from the underground. The project involves intensive monitoring of the injected CO_2 using a broad range of geophysical and geo-chemical techniques, the development and benchmarking of numerical models, and the definition of risk-assessment strategies.

The test storage system is a sandstone reservoir at depths below 600 meters. This facilitates geophysical monitoring, since part of the CO_2 is in a gaseous state. Within a two year period, 60.000 t of highly pure (› 99%) CO_2 is being injected to depth of 700m. Linde AG supplies the necessary CO_2.

Whilst the first phase of the project was mainly occupied with attaining the necessary approval for injections, drilling started February 2007 and an injection well and two observation wells have been lowered to depth of 800m. Injections of CO_2 started in June 2008 and up to July 2009 some 18417 tons of CO_2 have been successfully injected. First results, concerning the feasibility of CO2 storage in saline aquifers are expected no later than 2009.

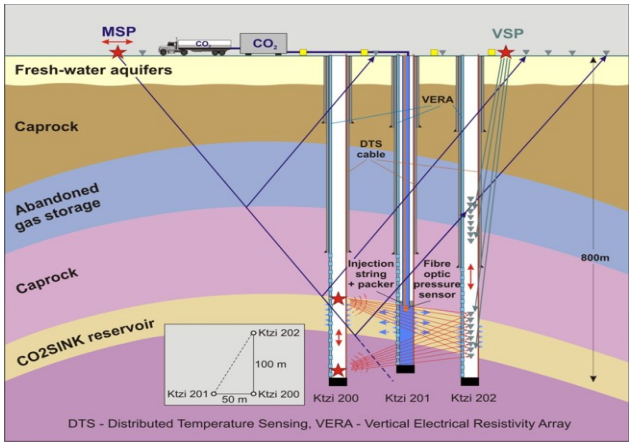


Figure 8: Source: CO2 Sink

[132] www.co2sink.org

Being close to a metropolitan area, the site provides a good opportunity to raise public awareness and accelerate acceptance. The site is therefore equipped with an information centre which is open to the public.

Enhanced Gas Recovery in the Altmark gas field

From 2008, the Erdgas Erdöl GmbH, Gaz de France's wholly owned exploration and production affiliate, planned in cooperation with Vattenfall to explore the possibilities of Enhanced Gas Recovery (EGR) in the nearly exhausted gas field in the Altmark.

The Altmark gas field has a long tradition of exploitation, which started in 1969 and became Europe's second largest onshore gas field with a yield of over 9 billion m^3 of natural gas. In 1994, Gaz de France bought the gas reservoir of the size of about 1000 km and in 2007 Gaz de France announced its plans to engage in a CO2 storage project.

With a storage potential of 508 MMt, the reservoir currently has the largest storage volume available in depleted gas fields in Europe and is the only nearly exhausted gas field capable of storing the CO_2 from a power plant over its entire lifespan. Being already investigated, explored and developed, this gas field therefore provides very favorable conditions to explore the possibilities of the entire CO_2 value chain. Vattenfall planned to inject up to 10.000 tons of CO2 in the 3000 m deep gas storage.

The project is accompanied by the research project CLEAN (Geotechnologien), which will provide support for the development of technologies and methods for CO2 storage and EGR. 17 research institutions and companies are involved. During a three year period (2008 -2010) the technologies for injection, the characterisation of the geological system and process monitoring are being investigated. CO_2 from Vattenfall's test facilities should have been transported by truck to the Altmark field and injected into one compartment of the Altmark field, however currently the process has been brought to a halt due to the failure to create a federal legislation for the storage of CO_2.

Other Projects

The Danish company Dong Energy[133] has announced plans to construct a 1.500 MW coal plant with CCS in Lubmin close to the city of Greifswald. CO_2 will be retained via post combustion, based on the experiences gained during the CASTOR project at the coal plant in Esbjerg, Denmark.

CCS TECHNOLOGY COMPANIES IN GERMANY

Company/association	Web site	Relevant business/technology
ALSTOM Power Boilers	www.power.alstom.com	Extensive knowledge of steam generation, combustion, fuel technology and heat recovery systems. ALSTOM, the Electric Power Research Institute (EPRI) and We Energies are combining forces to build a pilot plant to demonstrate a unique CO_2 capture process in US. ALSTOM carbon capture process uses chilled ammonia to capture CO_2.
BASF AG	www.basf.com	BASF Operating Division Intermediates is taking part in EU research projects on CO_2 capture. BASF has extensive expertise amine scrubbing technology.
DBI GAS and Environmental Techniques	www.dbi-gut.de	DBI participated in the RECOPOL project with drilling and completion of CO_2 injection well, as well as engineering and monitoring of CO_2 injections.
Deutsche Shell	www.shell.de	Active in employing CCS technologies for their refineries and process plants. Working with Coal Gasification Technologies.
Deutsche Steinkohle AG	www.deutsche-steinkohle.de	The Deutsche Steinkohle Aktiengesellschaft has been participating in the European CO_2 ECBM (Investigation into the Basic Scientific Phenomena of CO_2 Injection ad Tetention in Coal for CO_2 Storage and Enhanced Coal Bed Methane Recovery).
E.ON Germany	www.eon.com	E.ON has been deeply involved in climate protection for many years and is engaged in numerous German and EU projects on CCS.
EEG- Erdgas Erdöl GmbH	www.gasdefrance.de	Expertise in the upstream sector, exploration and production. Involved in the Altmark EGR project. Affiliate of Gaz de France.
Fichtner GmbH & CO Kg	www.fichtner.de	Fichtner offers a comprehensive range of technical and economic expertise in the energy sector, ranging from

[133] www.dongenergy.com

		power generation engineering to all inclusive solutions for power supply. Fichtner is administering the Post combustion technology screening of Karstø.
G.E.O.S Freiberg Ingenieurgesellschaft mbH	www.geosfreiberg.de	The GEOS Freiberg is participating in a variety of R&D projects within CCS in Germany, such as the CO_2 Sink project. It is a Consulting and Monitoring company.
Krupp Uhde GmbH	www.uhde.biz	Turbines/ICGG involved in COORETEC projects
Linde AG	www.linde.com	Linde has a long established expertise in the treatment of CO2 including separation, purification, compression, liquefaction and storage in tanks. Lind operates CO_2 transport in the Netherlands via pipelines, supplies air separation units for oxyfuel processes.and is involved in the development of solvents and membranes for separation processes.
Lurgi AG	www.lurgi.com	Lurgi is participating in the R&D program such as ENCAP (FP6) and COORIVA, sponsored by the German Ministry of Economics ad Technology and is working on both Zero Emission Syngas Technology and Zero emission IGCC.
Mannesmann Anlagebau AG	www.mannesmann.com	Engineering and technologies.
Doosan Babcock Energy (former Mitsui Babcock)	www.doosanbabcock.com	Major Power Plant constructor. Oxyfuel Boiler Technologies.
RWE Power AG RWE DEA	www.rwe.com/en	CO_2 free power plants – mainly coal based. Engaged in, and forerunner of several CCS projects including storage.
Siemens AG Power Generation	www.powergeneration.siemens.com/en	Siemens power is one of the leading specialists for power plant construction and equipment and offers a wide range of technologies, ranging from gasification technologies with multifuel capability and gas turbines, to post combustion technologies and options for retrofit as well as transport and storage equipment.
TÜV Nord	www.tuev-nord.de	Inspection Organisation - Carbon Readiness Certification
Vattenfall Europe	www.vattenfall.de	Forerunner with several CCS projects. Post combustion and Oxyfuel
Vattenfall Europe Technology Research GmbH	www.wintershall.com	Subsidiary of Vattenfall Europe providing research consulting services.
VDI – Technology Center	www.vdi.de	Handles and conceptionalises R&D activities and funding
VNG Gas AG	www.vng.de	VNG has long established expertise in high pressure gas grids and storage facilities.
Wintershall Holding	www.wintershall.com	Expertise in the upstream sector, drilling and pipelines.

CCS RESEARCH AND DEVELOPMENT

COORETEC[134]

One of the main technological objectives of the new COORETEC Lighthouse Concept of the Ministry of Economics and Technology BMWi is to sink the costs of CO_2 capture and storage, while simultaneously reducing efficiency losses. Research will focus on oxyfuel technologies, IGCC processes, post combustion processes, membrane technology and geological storage. Examples of major research programmes in this context are:

Program	Description
COORIVA	CO2 reduction by integrated gasification and separation. This research and development program with a budget of €4.6 million (2005-2008) is working with the development of a state of the art CO2 free IGCC process. Special attention is being paid to the optimisation of lignite gasification and overall construction, potential and overall concept of an IGCC CO_2 free power plant. Program partners are, RWE, Vattenfall, EON, Siemens, Linde, IEC, Uhde, and Lurgi. Coordinator of the project is TU Freiberg.
ADECOS	The ADECOS program (Advanced Development of the Coal-fired Oxyfuel Process with CO_2 separation) with a budget of €3.1 million (2004-2008) brings together 9 partners from the industrial and university sector for bringing forward oxyfuel processes with CO_2 separation. The ADECOS concept is based on contemporary power plant technology. Aim of this program is to proof the technical and economical feasibility of the oxyfuel technology with CO_2 separation for coal. This includes experiments in laboratory and technical scale as well as theoretical investigation, modelling work and component design. As part of the program a first oxyfuel pulverised combustion test rig for lignite is operated at the University of Dresden. Special technological focus is the oxyfuel burner for pulverized coal. Many suggestions from the ADECOS consortium concerning the process layout have already and are being considered in the planning process of Vattenfall's pilot plant. Partners are Vattenfall, RWE, EON, ALSTOM, BHI, Siemens, TU HH, and FH

[134] http://www.fz-juelich.de/ptj/projekte/index.php?index=1368

	Zittau/Görliz. Coordinator of the program is TU Dresden.
OXYCOAL	The OXYCOAL program with a budget of €5.9 million is also working with the oxyfuel technology. The research team consists of 6 Institutes of the RWTH Aachen and is predominantly working with the combustion of coal in an O_2/CO_2 atmosphere and the development of high temperature membranes in order to bring down the cost of oxygen in the process. As part of the program component tests and test operations of an oxyfuel research plant are conducted. Project partners are RWE, EON, Siemens, and Linde and WS. Coordinator of the program is RWTH Aachen.
HotVeGas	This COORETEC project is a basic investigation for the development of future high temperature gasification and gas cleaning processes for IGCC power plants with CO_2 capture and for the production of synthetic energy carriers. The project with a budget of €8.8 million in the period 2007-2011 has the goal to develop high efficient high temperature gasification processes with integrated hot gas cleaning and CO_2 capture for IGCC power plants and processes for the production of synthetic fuels, the extension of the basics of gasification kinetics and trace element behaviour and the development of integrated concepts as well as a general extension of the gasification competence in Germany. Project partners are EnBW, RWE, EON, Vattenfall,Siemens, Uhde, TUB Freiberg, Forschungszentrum Jülich, GTT Technologies. Coordinator of the program is the University of Munich.
POSEIDON	This post combustion project is occupied with the modelling and simulation of CO2 capture by wet chemical absorption, CO2 compression as well as with the analysis of the overall process under realistic boundary conditions. The project is coordinated by the TU Hamburg Harburg in cooperation with E.ON, RWE, Vattenfall, EnBW
Chemical absorption processes for CO2 capture from flue gas	Aim of the project is the development and optimisation of scrubbing columns, the analysis of earth alkali solvents and adaptation of corresponding processes. Coordinator of the project are the Universities of Stuttgart and Duisburg-Essen in cooperation with RWE, E.ON, Vattenfall, EnBW, Evonic and Hitachi
Carbonate Looping	The project will be coordinated by the University of Darmstadt and is currently in the definition phase.
CLock	The project investigates chemical looping combustion for coal. The project is expected to start Q3 2008
COORAL	The German Federal Institute for Materials Research and Testing (BAM). The German Federal Institute for Geosciences and Natural Resources (BGR), the German Fuel Institute (DBI) and the Universities of Halle Wittenberg and the Hamburg University of Technology are undertaking this project which covers the entire CO2 chain from generation, transport, injection to storage. Goals of the project are the estimation of expected flue gas composition from CO2 capture, the impact assessment of components in the transportation chain, especially corrosion, the assessment of the influence of pollutants on geochemical reactions underground and the techno economic optimisation of the complete chain from capture to storage. The project is currently in planning.

GEOTECHNOLOGIEN[135]

Since 2005, the BMBF has been supporting research projects concerning the development of new storage options and CO2 monitoring within the Geothechnoloien programme. Whilst the 9 interdisciplinary research projects of the first funding phase are almost completed, 12 news projects have been suggested. The following projects are currently and will be supported under the "CO2 Storage in Geological Formations" program:

Program	Description
CO2 TRAP	The project is concerned with the development and evaluation of innovative strategies for the sequestration and permanent immobilisation of CO_2 in geological formations. Partners are the RWTH Aachen, University of Bayreuth, University of Stuttgart, RWE DEA AG, RWE Power AG, SARR Energie GmbH, Deutsche Steinkohle AG, Herne, and Deutsche Montan Technology.
CSEGR	The project is a feasibility study on the potential of CO_2 storage for enhancing the recovery factor in mature gas reservoirs. Partners are TU Clausthal Zellerfeld, BGR Hannover, Vattenfall Europe, EEG Gommern, E.ON – Ruhrgas, and Wintershall.
COSMOS	The project is assessing CO_2 storage, monitoring and safety technologies. Research partners are GEOFoschungsZentrum Potsdam, Deutsches Brennstoff Institut, Vattenfall Europe Mining AG, University of Karlsruhe and RWE Power AG.
RECOBIO	The project investigates the recycling of sequestrated CO_2 by microbial-biogeochemical transformation in the deep subsurface. Partners are GEOS Freiberg Ingenieurgesellschaft mbH and Dresdner Grundwasserforschungszentrum.
CDEAL	The project investigates the possibility of CO2 elimination by using acid mine lakes and calcium oxide suspensions. Coordinator is the Technical University of Freiberg.
CDEAL	The project investigates the possibility of CO2 elimination by using acid mine lakes and calcium oxide suspensions. Coordinator is the Technical University of Freiberg.
CO2CRS	The project is developing high resolution images of subsurface CO_2 storage sites in time and depth by the CRS methodology. Partners are Trappe Erdöl Erdgas Consultant, the University of Karlsruhe and University of Berlin.
CHEMKIN	The project is monitoring the real time observation of chemical and kinetic behaviour of CO2 during

[135] www.geotechnologien.de

	geological sequestration. Partners are GEOForschungsZEntrum Potsdam, Environment and Engineering Technology GmbH, University Potsdam, Technological University of Clausthal, and Optimare GmbH.
PROBLEM ORIENTATED BENCHMARKS	The project numerically investigates CO_2 sequestration in geological formations. Partners are the University of Stuttgart and Deutsche Montan Technologie.
CO_2 – UGS – RISKS	The project assesses the long-term risk and sustainability of underground storage of CO_2 in Germany. It investigates current practices, future R&D needs and development of methodologies. Coordinator is the Gesellschaft für Anlagen und Reactorsicherheit (GRS)
CO2 MoPa	The project is working with the modelling and parameterisation of CO2 storage in deep saliniferous formations for dimension and risk analyses. The project has a budget of € 4.8 million during the period 2008-2010. Project manager is the Christian Albrecht University Kiel, partners are University of Stuttgart, Helmholtz UFZ, LANU (Kiel), University of Freiberg, ENBW, E.ON, Vattenfall, Wintershall, Stadtwerke Kiel, RWE DEA.
COAST	This project is connected the IGCC CCS project of RWE and provides the accompanying R&D for clarification and assuring of standards and methods for commercial scale CO_2 storage in deep saline aquifers. The project also contains a pilot site in North Friesland and currently 32 research institutions and companies are involved. The project is scheduled to start 01.01.2009 and projected injections in the second phase are 2.6 million t CO2 per year. It a funding of € 15 million from the BMBF and € 69 million from industry in the period 2008-2011.
CLEAN	This project is connected to the Altmark Gas field pilot site and has the objective to develop technologies and methods for CO2 storage and ERG. 17 research institutions and companies are involved. During a three year period (2008 -2010) the technologies for injection, the characterisation of the geological system and process monitoring are being investigated. CO2 from Vattenfall's test facility is transported by truck to the Altmark field and injected into one compartment of the Altmark field. Total injection volume is 100,000 ton of CO_2.
CO2 Sinus	CO2 storage in in –situ converted coal seams. RWTH Aachen, DMT GmbH & Co KG, Essen
ALCATRAP	Optimising CO2 storage through reactions with alkaline residues by the Alkaline Carbon Trapping process. University Bayreuth, RWTH Aachen,
RECOBIO2	Investigation of the biogeochemical transformation of injected CCO2 in the deep surface. TU Bergakademie Freiberg, DGFZ, BGR Hanover
CO2 SEALS	Integrity of cap rock formations for CO2 storage. RWTH Aachen, University of Karlsruhe, Shell international Exploration
COMICOR	Fault related CO2 fluid migration and its impact on the wall rock alteration and integrity of CO2 reservoir rocks. Investigation on the Buntsandstein of the Hessian Depression as a natural analogue for industrial CO2 sequestration. Coordinator University of Jena
COSONOSTRA	CO"-SO2-NOx stimulated rock alteration. Coordinator GFZ Potsdam
CO2 – SUGAR-A	Submarine Gashydrates as storage option for CO2
CO2 DEPTH	Software for accurate depth focussing, resolution and localization of CO2 storage and migration processes from 3 D seismic data. Coordinator University of Karlsruhe
COBOHR	Development and testing of CO2 resistant borehole cements and natural materials for the long term sealing of CO2 injection wells. DBI Gas und Umwelttechnik GmbH, University of Karlsruhe

EU projects

Germany and German companies and research institutions are participating in a variety of European research projects and platforms within the FP5 and FP6, which funded CCS research projects with over € 100 million. For the seventh research program, that covers the period 2007 – 2013, the EU announced a funding for CCS research and demonstration projects of € 500 million.

Program	Description
GESTCO[136]	The project was an early investigation of the geological storage of CO_2 from fossil fuel combustion for the enhanced recovery of oil in the North Sea. Germany's federal Institute for Geo science and Natural Resources (BGR) participated in this project.
RECOPOL[137]	The project investigated the reduction of CO_2 emissions by means of CO_2 storage in coal seams in the Silesian CIal Basin of Poland. The RWTH Aachen participated in this project.
CO2 STORE[138]	Aim of this project is to continue the development of geophysical monitoring methods. It is the continuation of the SACS project and the monitoring site is the SLEIPNER storage. As part of the project there are four case studies for CO_2 onshore storage in saline aquifers in Wales, Norway, Denmark and Germany. The federal institute for Geoscience and Natural Resources (BGR) investigated in this context the storage capacity in the case study "Schwarze Pumpe" in Brandenburg.
CASTOR[139]	From capture to storage. The work on capture is aimed at developing new CO_2 post combustion separation processes suited to the problems of capture of CO_2 at low concentrations in large volumes of

[136] www.nitg.tno.nl/projects/eurogeosurveys/projects/GestcoWeb
[137] recopol.nitg.tno.nl/index.shtml
[138] www.co2store.org

	gases at low pressure. The processes will be tested in a pilot unit in Denmark, capable of treating one to two tones of CO_2 per hour from real fumes. Germany research institutions and companies in this project are, BGR, University of Stuttgart, RWE Power AG, Siemens AG and BASF AG.
ISCC[140]	Innovative *in-situ* CO_2 capture technology for solid fuel gasification. The project aims to develop new processes for upgrading high moisture low rank lignite, i.e. development of high temperature sorbents. The University of Stuttgart is participating in this project.
ENCAP[141]	The ENCAP (enhanced capture of CO_2) is a 5 year integrated project in the period 2004 – 2009 with a total budget of € 22.2 million and an EC support of 10.7 € million. The research project is working on the development of pre-combustion technologies for enhanced capture of CO_2 in large power plants. It aims at technologies which meet a target of at least a 90% CO_2 capture rate and a reduction in the cost of capture of 50% compared to present. The ENCAP consortium consist of 5 large energy companies, including RWE Power, 11 leading technology provider and 12 high ranked research providers including the German University of Stuttgart.
GEO NET[142]	Germany, with the Federal Institute for Geosciences and Natural Resources (BGR) is also part of the CO_2 GeoNet, which was funded within the FP6 with € 6 million. The main objective is the formation of a partnership consisting of key European research centres and other expert collaborators in the area of geological storage of CO_2, and the identification of knowledge gaps in the long-term geologic storage of CO_2 as well as the formulation of new research projects and tools to eliminate these gaps. The CO_2 GeoNet project will result in re-alignment of European national research programs and prevent duplication of research efforts. It will also contribute to the knowledge base for CO_2 storage site selection, injection operations, monitoring, verification, safety, environmental protection, and training standards.
GEO NET[143]	Germany, with the Federal Institute for Geosciences and Natural Resources (BGR) is also part of the CO_2 GeoNet, which was funded within the FP6 with € 6 million. The main objective is the formation of a partnership consisting of key European research centres and other expert collaborators in the area of geological storage of CO_2, and the identification of knowledge gaps in the long-term geologic storage of CO_2 as well as the formulation of new research projects and tools to eliminate these gaps. The CO_2 GeoNet project will result in re-alignment of European national research programs and prevent duplication of research efforts. It will also contribute to the knowledge base for CO_2 storage site selection, injection operations, monitoring, verification, safety, environmental protection, and training standards.

Institutes

Apart from several German Universities, there exist a growing number of institutes that are working with CCS technologies.

Federal Institute for Geosciences and Natural Resources (BGR)[144]

The BGR, is the dominant research institute concerning geological storage of CO_2 and is part of the BMWi. It is participating in both European research projects as well as in a variety of national research and development programs.

Wuppertal Institute for Climate, Environment and Energy[145]

The Wuppertal Institute is working on a variety of issues concerning CCS technology, including socio and economic aspects. It is participating in workshops and conferences and is cooperating with the BMU.

Potsdam Institute for Climate Impact Research (PIK)[146]

The PIK is also following actively the discussion of CCS in Germany. Interestingly the head of PIK, one of Germany's leading climate change experts, is the advisor for Climate Change of the current government.

[139] www.co2castor.com
[140] www.eu-projects.de/ISCC
[141] www.encapco2.org
[142] www.co2geonet.com
[143] www.co2geonet.com
[144] http://www.bgr.bund.de/cln_030/nn_462770/EN/Home/homepage__node.html
[145] www.wupperinst.org
[146] www.pik-potsdam.de

GeoForschungsZentrum Potsdam[147]

The GFZ Potsdam is part of the Helmholz Association and the BMBF. The scientific projects are part of the major research fields "Earth and the Environment" and "Energy", and the Institute is coordinating the storage project "CO_2" Sink in Ketzin.

Frauenhofer Institut ISI[148]

The Frauenhofer Institute for System and Innovation Research ISI complements the techno – scientific spectrum of the Frauenhofer Society by economic and social aspects. Frauenhofer produces analysis of technological developments, their market potential and their impact on the economy. The Frauenhofer Institute has been producing reports covering CCS for the BMU.

Projektträger Jülich[149]

The Julich institute is also part of the Helmholz Association. It contains a research centre as well as project management. The project management Jülich (PTJ) undertakes project management of research projects of the different German Ministries. The PTJ is also a national contact for EU support research programmes and it coordinates activities for the International Energy Agency (IEA).

IZ Klima – Informationszentrum Klimafreundliches Kohlekraftwerk[150]

Since public acceptance is decisive for the implementation of CCS in Germany, German utilities and manufacturers have established the association IZ Klima, in Berlin. Members of the association are among others Alstom Germany, Babcock Borsig Services EnBW, E.ON, Hitachi Power Europe, RWE Power, Siemens Energy Sector and Vattenfall Europe. The IZ Klima is an information platform and works towards raising public awareness and acceptance for CCS technologies. The association is actively involved in the public debate and organises Seminars and information brochures about CCS.

[147] www.gfz-potsdam.de
[148] www.isi.frauenhofer.de
[149] www.fz-juelich.de
[150] www.iz-klima.de

UK

GOVERNMENTAL PROGRAMS AND STRATEGIES

In May 2002, the United Kingdom ratified the Kyoto Protocol with a goal of reducing Green House Gas (GHG) emissions to 12.5% below the 1990 levels by 2008-12. In 2007, it is estimated that emissions were 16.4% below 1990 levels, so effectively the country has already fulfilled its commitment. Note that this has come about as a result of the country's switch from coal to natural gas-fired electricity in the 1990s. In October 2008, the Government committed itself to a reduction of 80% in GHG emissions by 2050. Whether this goal will be attained is highly uncertain.

The current UK government is strongly focused on climate change and has implemented a number of policies, such as the Climate Change Levy, Renewable Obligation Certificates and Energy Efficiency Commitment. Equally, the UK has built on its experience of domestic policy to foster greater action at the international level – most notably with the introduction of the EU Emissions Trading Scheme

The UK Government has four long-term goals for energy policy:

- To put the UK on a path to cut CO2 emissions by 80% by 2050, with real progress by 2020;
- To maintain reliable energy supplies;
- To promote competitive markets in the UK and beyond,; and
- To ensure that every home is adequately and affordably heated.

Climate change is a subject that all three major political parties in the UK agree is important. The financial and economic crisis unleashed in 2008, which has had very negative consequences for the UK economy, does not seem to have had negative effects on the Government's targets. In fact, several new and positive developments for CCS have taken place in the UK in the past six months, most notably a ban on new coal fired power plants without CCS.

Partly as a result of the positive Government support for CCS recently, Ernst&Young places the UK 2nd in an international comparison of CCS attractiveness, after the US.

Some background

The figure below shows the composition of UK's electricity supply. A number of nuclear and coal fired power plants will be closed in the short- and medium- term but new ones are likely to come on-line as the country would face a shortage otherwise. It is likely that the UK will need around 30-35GW of new electricity generation capacity over the next two decades and around two thirds of this capacity by 2020[151]. New capacity will come from a combination of renewables, gas and nuclear. Renewables currently make up only about 5% of UK's electricity production.

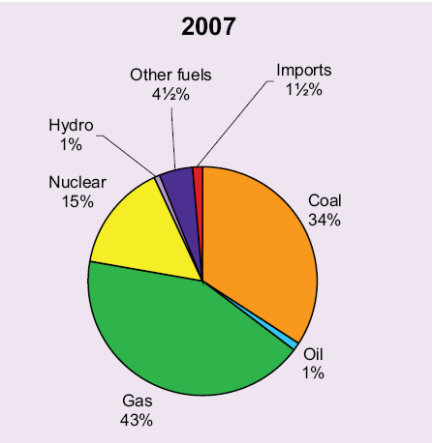


Figure 9: UK's supply of electricity. Source BERR[152].

[151] Source: Energy White Paper, May 23, 2007

[152] www.berr.gov.uk/files/file46983.pdf

Current UK energy policy is guided by the Energy White Paper of May 2007 – *Meeting the Energy Challenge* [153]- and by the Renewable Energy Strategy (which will be issued in the course of the summer of 2009). The 2007 White Paper sets out the Government's international and domestic energy strategy to respond to the changing circumstances in global energy markets and to address long term energy challenges. The strategy can be summarised as follows:

- establish an international framework to tackle climate change;
- reduce emissions progressively, via legally binding carbon targets;
- make further progress towards fully competitive and transparent international markets;
- encourage more energy saving through better information, incentives and regulation;
- provide more support for low-carbon technologies;
- ensure the right conditions for investment.

Chapter 5.4 in the 2007 White Paper discusses CCS and points out that demonstration of commercial-scale CCS on power generation in the UK could enable the technology to be proven and facilitate a better understanding of the costs. In turn this could contribute to the deployment of CCS on a national and international basis.

In January 2008, the UK Government announced its Energy Bill which, amongst other things, proposed primary legislation that for the first time will lay the foundations for a UK regulatory framework for CCS projects. The need for regulatory frameworks to support the operation of CCS- especially the storage of carbon dioxide offshore-has been identified as an important step towards the deployment of CCS and the UK is widely recognised to be amongst the world leaders in developing such a framework. The Energy Bill was passed into law as the Energy Act in November 2008.

In July 2008, the UK Government launched the consultation document: *Towards Carbon Capture and Storage*, on some of the details of the regulatory regime for CCS, which will help ensure that the final regulations are effective, safe and encourage investment in CCS. The Government's response to the Consultation was published in April 2009.

Another consultation document - *A framework for the development of clean coal.*- was launched on June 18th 2009 on CCS technologies. Under this proposal, new coal-fired power plants will not be given consent unless they demonstrate CCS on at least 25% of capacity from the beginning and 100% after 2025 (which is when it is estimated that CCS technology will be "proven"). The document also consults on whether the CCS requirement should apply to existing plants as well (retrofit). Finally, the document asks for views on the introduction of an emissions performance standard (EPS) which would limit the amount of carbon emitted per unit of electricity generated.

The closing date for the consultation is September 9th 2009. If the requirement to retrofit is passed, the Government concedes that a number of plants would close[154].

Finally, a new Energy Bill was proposed on July 2nd 2009 for the forthcoming session of Parliament. The Bill would enable the Secretary of State for Energy and Climate Change to introduce a financial mechanism to fund up to four commercial-scale CCS demonstration plants. The proposed Energy Bill was announced in 'Building Britain's Future', published by the Prime Minister, which outlines the Government's priorities and its draft legislative programme. This is now open for consultation before being finalised in the Queen's Speech in the autumn.

Scottish Government with procedure to regulate Carbon Capture

In May 2008 it was announced[155] that Scotland approved the UK Energy Bill, passed in the UK Parliament in November 2008. The Scottish Government introduced a Legislative Consent Motion to allow for the introduction of a common framework across the UK for carbon capture and storage.

The Scottish Government will licence storage activity out to 12 nautical miles, and will gain influence as the UK Government will have to consult Scottish Ministers for all licences between 12-200 nautical miles in Scottish waters.

The Scottish Government and UK Government will work on a Memorandum of Understanding on implementing the common framework and expect to jointly consult on regulations for the licensing regime this summer.

Finally, it is worth noting that the responsibility for climate change, energy and therefore CCS in the UK now lie in the newly created Department for Energy and Climate Change (DECC). Previously, these issues were dealt with separately by DEFRA (Department of Environment, Food and Rural Affairs) and BERR (Department for Business Enterprise and Regulatory Reform, now Department for Business, Innovation and Skills (BIS)). CCS decisions are also influenced by decisions made by Treasury (equivalent to the Norwegian Ministry of Finance) on financing.

[153] http://www.berr.gov.uk/energy/whitepaper/page39534.html

[154] The Guardian, June 18th 2009.

[155] www.scotland.gov.uk/News/Releases/2008/05/01151031

Public programmes and initiatives for CCS

CCS Demonstration Competition

The UK CCS Demonstration Competition was launched in November 2007 to build the world's first full scale CCS power plant in the UK.

The criteria against which proposals will be assessed are likely to include the need for any project proposal to:

- be located in the UK;
- cover the full chain of CCS technology on a commercial scale power station (capture, transport and storage);
- be based on sound engineering design (reliable and safe) underpinned y a full front-end engineering and design study;
- set out the quantum of financial support requested;
- be at least 300 MW, and capture and store around 90% of the CO_2 and thereby contribute at least an additional 0.25 Mt/yr of CO_2 savings to the UK's domestic abatement targets (relative to gas-fired power station of equivalent size without CCS);
- start demonstrating the full chain of CCS at some point between 2011 and 2014;
- address its contribution to the longer term potential of CCS in the UK, (for example, through the potential of shared infrastructure) and to the international development of CCS; and be supported by a creditworthy developer entity.

In the 2007 White Paper, the UK Government signalled support for up to three different demonstration projects. It was since decided (In the 2007 pre-budget report[156] in October 2007) that the competition will be restricted to a single post-combustion coal-fired project. In May 2009, however, the Government again signalled a greater appetite for projects and the funding of up to four demonstration projects. It is our understanding that the competition for the single post-combustion project will go ahead as planned and that the three other projects will be announced separately.

The 2007 decision to limit the competition to post-combustion was founded on the argument that post-combustion capture is the most relevant technology to the vast proportion of coal-fired generation capacity globally. The rationale is that a commercial-scale demonstration of this technology, as part of a full CCS chain, opens up huge possibilities, not just for UK but also for the world. The additional three projects can be pre- or post-combustion.

To incorporate an international dimension, project developers will be expected to include proposals for knowledge and know-how transfer to third parties. These will need to be sufficient to meet the Government's aims to encourage the wider deployment of CCS in the UK, Europe and internationally, particularly in countries with significant future energy needs such as China and India.

The UK is working with the EU Commission to ensure that the development of CCS in the UK fits with the objective agreed at the European Council in March 2007 to have in place up to 12 CCS demonstration projects in Europe by 2015.

After the dramatic change to the competition's design specifications was announced in October 2007[157] , the competition was officially launched 19h November 2007[158] by Prime Minister Gordon Brown. The industrial players focusing on pre-combustion technology (Shell, Centrica, ConocoPhillips, Marathon, PowerFuel and BP) protested heavily, but in vain.

Further details of the Competition are as follows:

- There is no upper limit on the size of the power plant or the scale of the capture facility, however the Government will only fund the capture of CO2 (and the subsequent transport and storage) contained in the flue gases produced by the generation of 300-400 MW.
- The CO2 capture plant will be required to capture around 90% of the CO2 in the flue gases dispatched to the CO2 capture plant. The precise rate will be a subject for negotiation. In certain limited circumstances a lower CO2 capture rate of 85% may be acceptable as a minimum, depending on the extent to which that would still achieve other Project objectives, but this could receive a lower mark in the evaluation process.
- Although the Government would prefer the Project to demonstrate the full chain of CCS technologies on the flue gases of 300-400 MW by 2014, it is prepared to consider proposals for phased scaling of the Project provided that the full chain is demonstrated by 2014. If a Bidder intends to take a phased approach, BERR envisages flue gases being captured from 50-100 MW by 2014 with the associated CO2 being transported and stored. The flue gases of 300-400 MW would then need to be processed as soon as possible thereafter. BERR is willing to discuss alternative approaches to meeting these target dates.

[156] http://www.gnn.gov.uk/environment/fullDetail.asp?ReleaseID=321108&NewsAreaID=2&NavigatedFromDepartment=True
[157] http://nds.coi.gov.uk/environment/fullDetail.asp?ReleaseID=321108&NewsAreaID=2&NavigatedFromDepartment=True
[158] http://nds.coi.gov.uk/environment/fullDetail.asp?ReleaseID=331669&NewsAreaID=2&NavigatedFromDepartment=True

- The Project Contract will set out the allocation of risks between the contracting parties. The allocation of these risks and the basis of any risk sharing will be the subject of discussions and negotiations between BERR and Bidders during the procurement process. The actual allocation of risks will be based on the principle that the risk will be allocated to the party that is best able to manage that risk.
- The Project Contract will include a payment mechanism to provide financial support for the Project Developer to support the undertaking of this project. The payment mechanism will be structured so as to create incentives for efficient operation of the capture plant and successful abatement of CO2.

By the deadline 31st March 2008, the UK Government had received nine bids in the competition. On June 30th 2008, the Government announced the pre-qualification of four applicants:

- BP Alternative Energy Ltd.
- EON UK Plc - Kingsnorth,
- RWE/Peel Power/Dong, - Hunterston, and
- Scottish Power - Longannet

BP subsequently decided to withdraw from the competition, so that there are only 3 bids left. namely those of Scottish Power (Longannet project), EON (Kingsnorth project) and RWE (Hunterston project). The projects are described in greater detail later in the chapter.

The CCS Demonstrator Competition[159] was intended to be closed by year-end 2009, but the Government has conceded that the decision to pick a winner has been delayed and will not take place until the autumn of 2010 at the earliest[160]. The Government still hopes to have the project operational by 2014.

Other Government Programs/Initiatives

In addition to the Competition, the Government in April 2009 announced it would support up to three additional full-scale demonstration projects. At least two of these are expected to use pre-combustion technology. They are likely to be funded by a levy on electricity suppliers.

Regional Networks: Development Agency "Yorkshire Forward" and Thames Valley Network[161]

Yorkshire Forward has signed up key partners from the energy sector including BP, Shell, E.ON, Drax and Scottish and Southern Energy in a partnership to develop CCS in the region. It is UK's largest partnership into looking at carbon capture and storage. The approach is different as the region has invited companies to come together and look at a project that will benefit all, including the three power stations in Yorkshire." The study *"A carbon capture and storage network for Yorkshire and Humber"* was published in 2008. It considers the provision of a transport system for the Yorkshire and Humber region. The study aimed to understand the options for the most economic network for transport of CO2 to storage from the emitters in the region, based mostly on publicly available data. The study has evolved the work of the North Sea Basin Task Force by focusing on a key region.

Note that there are other regional initiatives as well. E.ON has proposed a Thames Valley CCS network that would connect its Kingsnorth coal plant, RWE's Tilbury coal plant and 7 other sites in the region. The cluster would form a network that would collect CO2 from the individual sites and transport it to storage sites in the North Sea. By 2016 these sources will be emitting 28m tonnes of CO2 per year (some 16 m tonnes of which will come from Kingsnorth and Tilbury alone)[162]. According to E.ON, the Thames network is at an advantage as the Humber cluster would require a substantial underground pipeline network, while the Thames power plants ar located on the estuary, and CO2 emissions could be piped directly out to sea[163]

National Grid, manager of Britain's natural gas-delivery network, is looking into how to make use of its existing grid of gas pipelines to transport CO2. This would apply to the 300 km of pipelines in Scotland, as well as old and new pipelines in the Thames Valley and Yorkshire areas. The UK regulator Ofgem (Office of Gas and Electricity Markets) in February 2009 launched a public consultation regarding National Grid's CO2 plans. National Grid is planning a new business unit for this activity - National Grid Carbon.

The Government has established an *Advisory Committee on Carbon Abatement Technologies (ACCAT)* to "provide expert, independent advice to Ministers and [Ministries] on matters concerning technologies for reducing greenhouse gas emissions to atmosphere, particularly CO2 emissions from power generation and other large industrial processes using fossil fuel….". The committee is put together of representatives from academia, industry

[159] www.berr.gov.uk/whatwedo/energy/sources/sustainable/ccs/ccs-demo/docs-qa/page42503.html
[160] The Guardian, June 18th 2009
[161] ccsassociation.org.uk/docs/2008/Canada%20CCS%20Conf%2029%20Oct%2008/James%20Watt.pdf
[162] Source: New Energy Finance, Weekly Briefing, 22 April 2009
[163] Source: Recharge, 19 June 2009

and government and CCS experts are well represented[164]. Minutes of their last meeting in April 2009 is publicly available[165] and provides a good overview over the total activity within the UK CCS sphere.

In January 2007, the Government published a comprehensive report made by the consultancy Pöyry Energy Consulting with the title 'Analysis of carbon capture and storage cost-supply curves for the UK'. The report is a useful source for cost comparisons for different CCS solutions from a UK perspective.[166]

See the section on Research and Development later in the chapter for further information on government initiatives.

International cooperation on CCS

The basis for UK's current strong commitment to abating carbon emissions and developing CCS technology can be found in the international initiative taken during the **G8 meeting** in 2005[167] held in Gleneagles, Scotland under the UK's presidency. This move was made in parallel with a similar initiative taken under their EU presidency resulting in the 2020 targets on renewable energy, energy efficiency and carbon emission reductions.

Also important in setting the agenda for carbon abatement and CCS was the *STERN Review*[168] published in October 2006. In it, Sir Nicholas Stern refers to CCS as "essential to maintaining the role of coal in providing secure and reliable energy for many economies"

The UK has acted as a forerunner in EU and puts considerable effort into regulatory, funding and public perception work within the umbrella of the EU: It supports the planned deployment of 10-12 commercial-scale demonstration projects and the work of **The Zero Emissions Fossil Fuel Power Plant (ZEP) Technology Platform** (launched in November 2005).

India and China are important partners for the UK in the field of CCS. Part of the rationale for choosing post-combustion technology in the Demonstration Competition was that this was the technology with most immediate applications in countries such as China and India, where much of future GHG emission growth will take place and coal is relatively abundant. Prominent among the activities with these two countries is the joint **UK-China Near Zero Emissions Coal (NZEC)** initiative. The EU-China NZEC agreement was signed at the EU-China Summit under the UK's presidency of the EU in September 2005 as part of the EU-China Partnership on Climate Change. The agreement has the objective of demonstrating advanced, near zero emissions coal technology through carbon capture and storage (CCS) in China and the EU by 2020. The UK-China bilateral NZEC initiative was developed in support of this wider agreement. The EU is currently developing plans to fund a large-scale CCS plant in China, to be build by 2015.

The Carbon Sequestration Leadership Forum[169]

CSLForum is an international climate change initiative focusing on discussing the development of improved cost-effective technologies for CCS. The purpose of the CSLF is to make these technologies broadly available internationally; and to identify and address wider issues relating to carbon capture and storage. The CSLF is currently comprised of 22 members, including 21 countries and the European Commission. The UK will be hosting the 2009 CSLF Ministerial meeting in October 2009, in London

Cooperation with Norway

The UK and Norway are collaborating on the development of a set of regulatory principles for the geological storage of CO2 beneath the North Sea. The joint **North Sea Basin Task Force** was announced by the UK's then Minister for Energy, Malcolm Wicks and Norway's then Minister for Petroleum and Energy, Odd-Roger Enoksen in November 2005. Membership is made up of UK members BERR, DEFRA, BGS, BP and Shell; and the Norwegian Members MPE, ME, DnV and StatoilHydro. There are additional members from Germany and the Netherlands as well.

In a joint statement in June 2006 a study into the Development of a CO2 Transport and Storage Infrastructure in the North Sea was initiated by the UK's Chancellor of the Exchequer, Gordon Brown and Norway's Prime Minister, Jens Stoltenberg. A co-operation agreement was signed between the two countries to investigate the possibilities of developing an infrastructure in the North Sea to transport and store CO2 generated from on-shore industrial activity - mainly from fossil fuel power generation[170].

Announced at the High-Level CCS meeting in Bergen in May, a study of the role of the North Sea in providing storage space for CO2 from Europe will be undertaken jointly by the UK and Norway. The study will look at how

[164] www.berr.gov.uk/whatwedo/energy/sources/sustainable/carbon-abatement-tech/advisory-committee/page40400.html
[165] http://www.berr.gov.uk/files/file47554.pdf
[166] www.berr.gov.uk/files/file36782.pdf
[167] www.g8.gov.uk
[168] www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm
[169] www.cslforum.org
[170] http://www.berr.gov.uk/whatwedo/energy/sources/sustainable/ccs/nsbtf/page42482.html

quickly the base of the North Sea could be needed for CO2 storage and what the UK, Norway and other countries have to do to get it ready in time. The study will also consider how the offshore storage business might develop.

The CO2 Capture Project (CCP) is a partnership of eight of the world's leading energy companies and three government organisations undertaking research and developing technologies for CCS. It is an international project run since 2004 in two phases. In phase 2 there is a strong Norwegian participation (Statoil, Hydro and Norwegian Research Council). The British participation is from BP and Shell.

Financing CCS

It is the official policy of the UK Government that CCS projects in the long-run should be financed through a price on carbon, as regulated through the EU ETS or similar. In the meantime, however, the Government recognises the need for public funding of R&D projects.

In the UK CCS competition, the Government will pay for the cost of the CCS aspects of the chosen project. The funds, likely to run into £1 billion or more, will come from the (general) Treasury coffers. There is pressure from the industry to set aside the income from selling ETS allowances for CCS funding. However, given the current economic climate, the Government is unlikely to agree.

In the new proposals launched in the spring of 2009 to increase the number of research project to 4, the Government proposes a financial incentive funded by electricity suppliers. The details of such a scheme have not been worked out yet.

Through the EU economic stimulus package announced in January 2009, the UK will receive partial funding (€180 m.) for one of four CCS projects. The four projects under consideration are the three already participating in the UK Competition as well as the Hatfield project.

Note that EU funding sources received a boost when the EU ETS rules were amended in December to create a fund of up to 300 million EUAs, with an estimated value of between €6 and €9 billion, to finance up to 12 commercial-scale CCS demonstration projects.

Other sources of funding:

The UK Energy Technologies Institute (ETI) is a public-private consortium of which BP, Caterpillar, EDF Energy. E.ON, Rolls-Royce, and Shell are members. It considers CCS one of its future technology themes. With a potential billion pound budget for investment across a broad range of low carbon technologies, the ETI could contribute towards accelerating the development of low-carbon energy technologies, including CCS, towards commercial deployment.

Hydrogen, Fuel Cells and Carbon Abatement Technologies Demonstration Programme[171] :

This is a 4-year programme that opened in October 2006 with 50 million GBP allocated in total with 35 million GBP earmarked CCS. The funding is disbursed through programmes or competitions announced by the Carbon Trust or DECC.

See the section on Research and Development later in the chapter for further information on funding sources (for R&D)

Private sector activities

Carbon Capture & Storage Association[172]

Established in October 2005 by 11 founding companies, its aims are:

- To encourage development of CCS in the UK and internationally and to support business interests in global developments.
- To inform the public, professions and policy makers about the environmental, technical, socio-economic and commercial benefits of carbon capture and storage.
- To provide advice to policy makers on regulatory issues and potential incentive mechanisms associated with CCS.
- To promote industry priorities on financial, technical, research and policy issues related to CCS.
- To liaise with other industry and professional groupings having interests in energy conservation and CCS.

[171] www.hfccat-demo.org

[172] www.ccsassociation.org

- To provide a forum to encourage information exchange, networking and enhanced capability in relation to CCS.

The members are listed in the table below.

Air Products	EDF Energy	Progressive Energy
Aker Clean Carbon	EON	PWC
Alstom	ERM	Reliance Industries Limited
AMEC	GDF Suez	Renew
Anthony Veder	General Electric Int	Rio Tinto
Arup	Herbert Smith	RPS
BG Group	HTC	RWE
BP	Hydrogen Energy	Sasol
BOC	Ingen	Schlumberger
British Geological Survey	Linklaters	Scottish & Southern
Camco	Lloyd's Register	Scottish Centre for Carbon Storage
Chevron	Lovells LLP	Scottish Enterprise
Clean Energy Systems	Maersk Oil & Gas	Scottish Power
Climate Change Capital	Marathon Oil	Senergy
CO2 DeepStore	Masdar	Shell
Coal Authority	Mitsubishi Heavy Industries (MHI)	Siemens
ConocoPhillips	Mitsubishi Corporation	SLR Consulting Ireland
Denbury Resources	MMI Engineering	IM Skaugen
Denton Wilde Sapte	MPA Cement	Statoil
DNV	National Grid plc	Total Holdings
Doosan Babcock	Nexen Exploration	Yorkshire Forward
Drax Power	Norton Rose	Zurich
	PowerFuel	
	Poyry Energy Consulting	

Table 1: Member of CCSa[173]

[173] http://www.ccsassociation.org.uk/our_members/our_members.html

CCS PROJECTS IN UK

Some 12 projects have been proposed in the UK. The map below shows a map of the locations of the ones identified on CCSa's webpage. The three projects in the UK Competition are marked by a green circle.

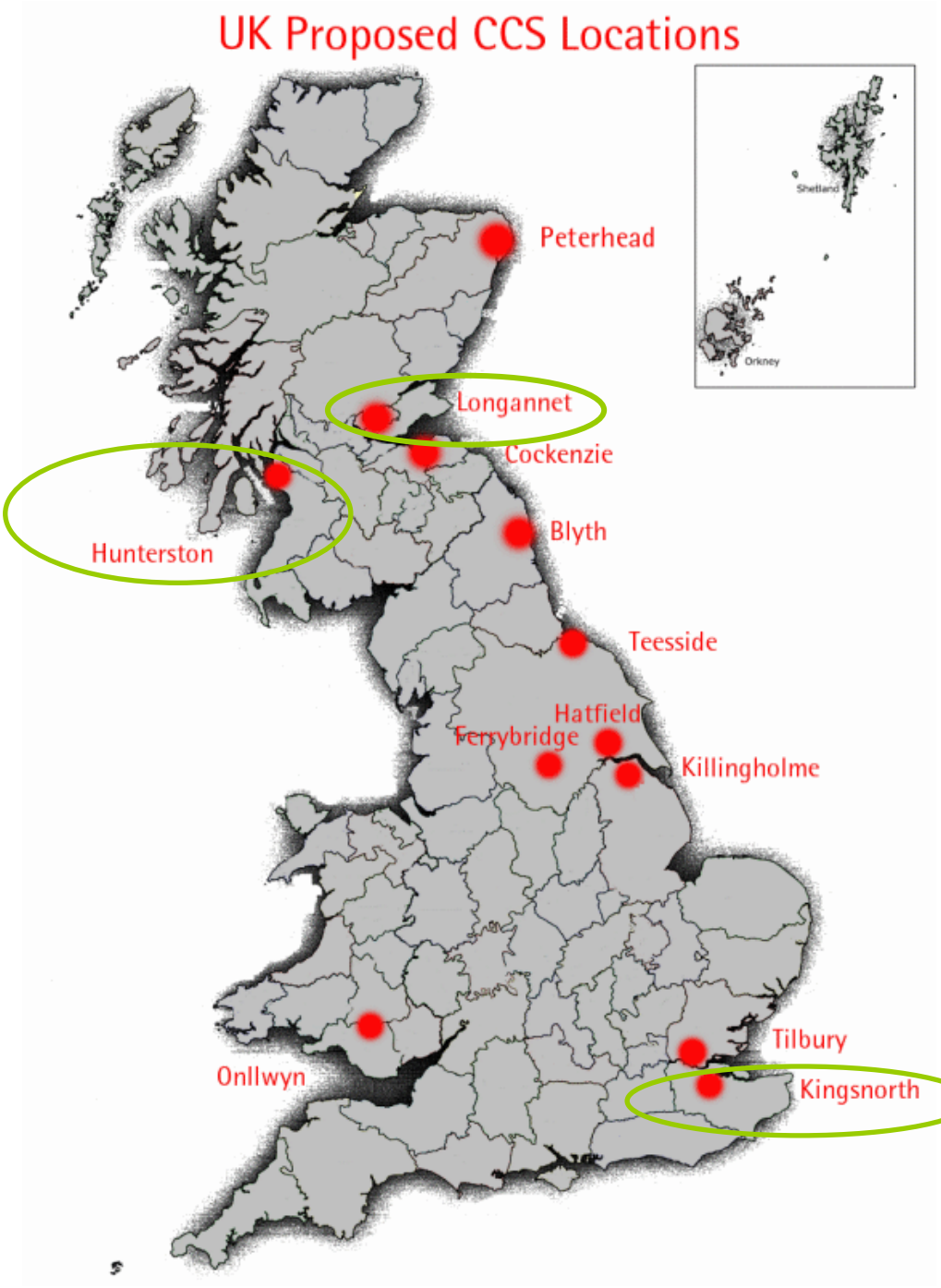


Figure 10: CCS projects in UK[174]

In the following there is a description of the projects that have been identified as having CCS potential in the short- to medium-term.

[174] Source; CCSa, http://www.ccsassociation.org.uk/ccs_projects/uk_projects.html

RWE npower – Blyth post-combustion project

This is a feasibility study by RWE npower to build a 2400 MW supercritical clean coal power station on the site of the former Blyth Power Station. The new station would save over 3 million tones of carbon dioxide per year with facilities to burn carbon neutral fuels such as biomass at a later date. The power station would also be built carbon capture ready (post-combustion).

In an environmental "scoping document" submitted to DTI (now DECC) the company outlined proposals for a new power station consisting of three 800 MW, high-efficiency supercritical coal-fired units. The proposed station would be extremely efficient, reducing CO2 emissions by over 22% per unit of electricity generated compared to existing power stations of same size. The unit could be operational in 2014 and would provide electricity for up to 3.5 million homes.

Figure 11: Artistic impression of the new Blyth power station

The units would be developed to include facilities for burning up to 10% biomass to further reduced emissions.[175]

Scottish Power - Cockenzie and Longannet post-combustion project[176]

Scottish Power is planning to convert the Longannet and Cockenzie power plants to clean coal technology by fitting supercritical turbines and boilers. The plants would incorporate post-combustion carbon capture technology on the combined generation capacity of 3390MW, and the new plants could reduce carbon emissions by 20%. The Longannet plant is in the run-up for the Government funding competition.

Partners are Aker Clean Carbon for the capture technology, Marathon Oil for the transportation via existing North Sea pipes, and Edinburgh University for the identification of long-term storage in sub-sea rocks. Alstom Power and Doosan Babcock will provide the design input for the 'supercritical' turbines and boilers. Aker Clean Carbon opened its 1 MW sized mobile test unit at Longannet in May this year. It is the first time that CCS technology is in use on an operational coal-fired power station in the UK.

The new 'supercritical' turbines and boilers, which will burn coal at ultra-high temperatures and pressure, may be built within the existing power station buildings.

[175] www.rwe.com
[176] www.scottishpower.com

Figure 12: Cockenzie Power Station

The phased 19-month development foresees both stations continuing to operate at a reduced capacity while the new facility is constructed. If the proposal proceeds, construction could start in 2009 with operations beginning in 2012.

Progressive Energy – Teesside pre-combustion project[177]

This is a project by Progressive Energy to potentially develop a 800 MW clean coal project with pre-combustion carbon capture and storage. Two new companies have been set up; Coastal Energy which will own the power station, and COOTS Ltd, which will own the CO2 pipeline assets. Centrica previously participated with 50% ownership but pulled out in May this year, ostensibly to concentrate on less risky technologies.

The original budget for the project was 7.2 million GBP. In addition to providing approximately 6 TWh of low carbon electricity per year, the project has the potential to provide the basis for a wider infrastructure letting other projects also dispose CO2 through the same system.

If it goes ahead, the project would be the first to combine integrated gasification combined cycle (IGCC) and carbon capture and storage (CCS) capabilities, and would lead to the development of a 'clean coal' power station to supply electricity for British Gas customers, together with a pipeline and storage project to capture over 80% of the CO2 emissions.

SSE – Ferrybridge post-combustion project[178]

The Scottish and Southern Energy Ferrybridge Power Station in West Yorkshire will be developed as a 500 MW clean coal power station, and will be built capture ready to incorporate post-combustion carbon capture and storage at a later date. Once built, the power station will save 500,000 tonnes of carbon dioxide per year and a further 1.7 million tonnes when the carbon capture technology is added.

SSE announced in June 2006 the entry into a partnership with Mitsui Babcock, Siemens and UK Coal with a view to installing cleaner coal' technology at Ferrybridge Power Station. This partnership comprises a 500 MW Supercritical[179] Boiler, with a thermal efficiency of over 45% and the subsequent deployment of post-combustion carbon capture equipment. The first task was to undertake the front end engineering. Currently, Ferrybridge is a 1995 MW combined coal and biofuel power plant.

[177] www.progressive-energy.com

[178] www.scottish-southern.co.uk

[179] Supercritical plant operates at greater than 'supercritical pressure' (typically 300 bar) with 600^0C steam conditions. By raising the pressure and temperature of the generated steam to supercritical conditions, power plant efficiency is increased, making more electricity from less coal and reducing CO_2 emissions compared to a conventional plant. Supercritical plant can be 'retrofitted' to existing coal plants, using the existing infrastructure at the site

Figure 13: Ferrybridge combined coal and biofuel Power plant

The development of the plant would involve the 'retrofit' of a 500 MW Supercritical Boiler and turbine which would be the first of its kind in the UK. It would be made 'capture ready' to facilitate the subsequent deployment of post-combustion CO2 capture equipment. High-level engineering feasibility studies into the project have already been completed. The partners are now carrying out further detailed front-end engineering design work with the aim of confirming the viability of the scheme. Installation of the supercritical plant is estimated to require an investment by SSE of around 250 million GBP and the post-combustion CO2 capture equipment is estimated to require a further investment by SSE of around 100 million GBP. SSE would own and operate the supercritical plant and the carbon capture equipment, if deployed.

E.ON – Killingholme pre-combustion project[180]

This 450 MW IGCC coal-fired power station is being considered by E.ON UK, to be built next to the existing Killingholme gas-fired station. The project would be built in separate phases, with pre-combustion carbon capture and storage fitted as a second phase for storage in depleted gas fields under the North Sea.

As a part of E.ON's 4 billion GBP investment plan in the UK they are also launching a feasibility study into a 450 MWe world-leading clean coal (IGCC) power station at Killingholme in Lincolnshire. The 1 billion GBP clean-coal plant close to E.ON's gas plants will include CO2 capture and storage[181]. Little details are available on the CCS part of this proposal.

[180] www.eon-uk.com

[181] "The Killingholme fields: E.ON plans 'clean coal' power plant", Independent on Sunday, May 14, 2006.

Figure 14: Artistic view of the Killingholme Fasilty

E.ON – Kingsnorth post-combustion project[182]

Plans to build two new supercritical units of 800 MW at the Kingsnorth coal-fired power station in Kent have been announced by E.ON UK. The units would be built next to the existing power station, reducing carbon emissions by 2 million tonnes per year. The units would be designed as capture ready, to be fitted with post-combustion carbon capture and storage at a later stage. The Kingsnorth plant is one of three finalists in the Government funding competition.

The partners supporting E.On on Kingsnorth are:

- Arup for project management,
- EPRI for international technology dissemination,
- MHI (Mitsubishi Heavy Industries) as carbon capture technology supplier
- Penspen for pipeline transportaion, and
- Tullow Oil for CO2 storage

Note that MHI and Foster Wheeler Energy Ltd. have been chosen to carry out the FEED study

E.ON UK is planning to replace the four existing coal-fired 485 MW units at Kingsnorth Power Station with two new cleaner coal units rated at 800 MWe each. The 1 billion GBP investment is planned to use state-of-the-art technology to produce power from coal far more efficiently and far more cleanly than ever before in the UK. The carbon emissions are expected to drop with 20% or two million ton a year from 2012.

The new units, which would operate at an efficiency of 45% and above compared to existing units' 36%, would be built next to the existing four 485 MWe coal-fired units, which will cease operation and be demolished once the new units are fully operational and proven. The current plan is to phase out the old units by end of 2015 under the strictures of the EU's Large Combustion Plant Directive.

If approved, these would be the UK's first supercritical coal-fired units, and they would produce enough electricity to supply around 1.5m homes. If built these units would be the first new coal build in the UK for over 20 years and could set a new benchmark for cleaner coal-fired generation in the UK. E.ON has announced that it will not build Kingsnorth if it does not win the competition, given the new requirement of CCS on all coal new-builds. Instead, E.ON would consider building a gas-fired power plant[183].

[182] www.eon-uk.com

[183] The Guardian, June 18th 2009

Figure 15: An illustration of E.ON's supercritical coal power plant at Kingsnorth in Kent. The new units are located to the right while the old units to be removed, are located close to the waterfront to the left.

E.ON UK says it is considering making the new units capable of burning biomass with coal.

RWE npower – Tilbury post-combustion project[184]

RWE npower has announced a feasibility study into the construction of a 1000 MW supercritical coal power station at Tilbury, Essex. The plant would incorporate post-combustion carbon capture and storage and could be operational by 2016, saving up to 90% of the plants carbon dioxide emissions per year. The Tilbury plant was originally part of the Government funding competition but did not pre-qualify.

RWE npower's Tilbury Power Station is located on the north bank of the Thames Estuary, in Essex. The 1428 MW coal fired power station began producing electricity in 1956 and can power 1.4 million homes, playing an essential role in providing secure energy supplies for the UK.

Originally an oil-fired station, today Tilbury burns 'biomass' fuels alongside low-sulphur coal. Co-firing biomass like sawdust and palm kernel extract at Tilbury generates enough 'carbon neutral' electricity to supply approximately 50,000 homes per year, and reduces the need for an equivalent amount of coal generation.

Figure 16: The 50 year old Tilbury Power station today - a combined biofuel and coal fired power station.

RWE entered into a partnership with the Shaw Group to carry out the feasibility study and the cost estimate was in excess of 1 billion GBP. The study looks into supercritical plant technology that will improve the efficiency of the combustion process together with 'carbon capture' systems. The announcement followed proposals outlined 30 March 2006 by parent company RWE to investigate the building of a 1 billion EURO CO2 free plant in Germany, subject to the necessary political framework conditions and authorisations.

The Tilbury study looks at the end-to-end process from planning and consent to transport and storage options. RWE npower also uses its testing facilities at Didcot in Oxfordshire to examine ways to improve combustion efficiency and develop the chemical processes for stripping out and capturing the CO2.

[184] www.rwe.com

RWE npower – Aberthaw post-combustion Project[185]

This plant is a 3 MW pilot plant[186], scaling up to 100 MW demonstration plant at Tilbury (see previous project). RWE's team included[187] BOC (a Linde Group company), Cansolv Technologies Inc., I.M Skaugen SE, The Shaw Group Inc., and Tullow Oil. I.M.

RWE npower has announced plans to design and build a carbon capture pilot plant at a UK coal power station. The first phase is to be located at Aberthaw Power Station in South Wales. An initial £8.4 million investment will focus on a 3 MW capture plant, with further investment planned to support a capture and storage demonstrator plant of at least 25 MW. The larger capture and storage demonstrator plant would form part of one of the new 'supercritical' power stations which are currently under feasibility and planning at npower's existing sites in Tilbury, Essex and at Blyth, Northumberland. The pilot plant is expected to be operational in 2010 and the costs are expected to be about £8.4 million

Figure 17: Aberthaw Power Station

RWE npower - Hunterston post-combustion project[188]

RWE npower has taken a 75% stake in Peel Energy CCS Ltd, which was formerly jointly owned by Peel Energy and Danish company DONG Energy. The restructured joint venture, with RWE npower's involvement, has pre-qualified for the Government's CCS Demonstration competition.

Peel Power is a subsidiary of the property and transport company Peel Holdings. Other partners include Senergy and Mott McDonald. The plant is a new coal (and biomass)- fired 1.6 GW plant in Hunterston, Scotland[189]. The project will, should it be qualified, comprise a capture facility of up to 400MW which would form part of a new cleaner supercritical coal fired power station. It is proposed that the CO2 would then be transported to disused gas fields in the North Sea where it would be permanently stored. The project could be up and running by 2014..

BP – Peterhead pre-combustion project[190]

A joint venture by BP and Scottish and Southern Energy, this was a hydrogen power project at Peterhead, Scotland, which would convert natural gas into hydrogen to fuel a 350 MW power station, whilst using carbon capture and storage to reduce carbon dioxide emissions by 1.2 million tonnes per year.

The Peterhead project has been abandoned for now, but a short summary is nevertheless provided here. The same technology will be used at Hydrogen Energy (Rio Tinto and BP's joint venture)'s plants in Abu Dhabi and Carson (USA)

The project consists of 3 main parts: a pre-combustion CO2-removal unit, conversion of a 350 MW gas-fired power station to run on hydrogen; and transport, injection and storage of the captured CO2 in the Miller field. The partners were originally ConocoPhillips, BP, Scottish & Southern Power and Shell, but since then ConocoPhillips and Shell have withdrawn from the project. The CO2 capture plant would be built close the existing Peterhead power

[185] www.ccs-association.org/docs/2007/CCSA%20News%20Dec%202007.pdf
[186] Scale-up from 1MW to 3MW was announced earlier this year (source:E&Y CCS country attractiveness index, Q1 2009)
[187] www.npowermediacentre.co.uk/Content/Detail.asp?ReleaseID=1864&NewsAreaID=2
[188] www.npowermediacentre.com/Content/Detail.asp?ReleaseID=2325&NewsAreaID=2
[189] www.business7.co.uk/business-news/latest-business-news/2008/11/21/new-plant-to-fire-up-nation-97298-20912014/
[190] www.bp.com

station and the CO2 has to be transported 240 km to be injected into Miller. After a 30-36 months construction phase, the project was originally planned to start up at YE 2009,

The total project cost was estimated to be around US$ 600 million or GBP 350 million. The project's profitability was not sufficient to satisfy the owners and thus BP applied for governmental support to realise the project. Several sources claim the application was at least 100 mill. GBP.

BP decided on May 23 2007[191] to pull out of the project because the timescales for a CCS competition announced by the government in its Energy White Paper was too long for BP.

Powerfuel - Hatfield Colliery pre-combustion Project[192]

In March 2006, Powerfuel formed a partnership with Kuzbassrazrezugol (KRU) for development of Hatfield Colliery

KRU, one of Russia's largest coal producers, signed the agreement with Powerfuel to acquire a 51% shareholding in the Company and inject fresh capital to refurbish Hatfield Colliery with the aim of recommencing coal mining in 2007. There is expected to be up to 100 million ton of Britsk coal in the Hatfield colliery which is expected to produce 2 million tonnes of coal per annum by 2009. Total capital costs of the project are expected to be in the region of 110 million GBP.

Powerfuel and KRU have obtained conditional section 36 consent for the development of a 900 MWe IGCC clean coal power generation plant on the Hatfield site. The power plant project is at the feasibility study stage and, depending upon the design capacity of the power plant, total construction costs associated with this project could amount to up to 800 million GBP. The plant is designed with the capability to produce both hydrogen for transport use and syngas for possible pipeline export to other local power generation stations.

Powerfuel expects to be able to raise 1 billion GBP in project financing.

The plant will be fitted with full carbon capture and storage facilities, with a CO2 pipeline running along the railway line to the North Sea. Powerfuel aims to use the CO2 for EOR and to store in the Brent oilfield. That will have the advantage of delaying the shutdown of Brent, perhaps by up to 15 years, and by using the CO2 for enhanced oil recovery will generate substantial revenues.

Valleys Energy (Progressive Energy, BGS, BRGM (France) and TNO (Netherlands)) - Onllwyn [193]

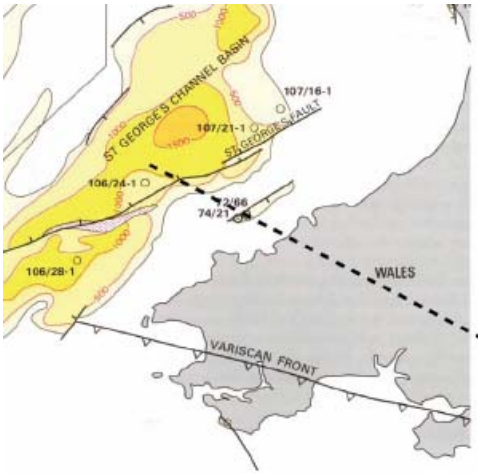


Figure 18: Artists Impression of the Onllsyn plant (courtesy of Valleys Energy Ltd.)

Under the umbrella of EU's CO2 STORE project, Valleys Energy Ltd (a partnership that includes Progressive Energy) has developed a proposal to construct a new 450 MW IGCC plant with CCS at Onllwyn, near Drym in Wales. Approximately 85% of total CO2 emissions would be captured, which equates to about 2.4 million tonnes per year.

The British Geological Survey and Valleys Energy Ltd investigated a number of potential CO2 storage sites for the proposed facility and identified the St George's Channel Basin off the coast of Pembrokeshire as the most suitable.

[191] www.platts.com/Content/Electric%20Power/Newsletters%20&%20Reports/EU%20Energy/See%20A%20Sample/index.pdf
[192] www.coalpro.co.uk/17th%20March%202006.pdf
[193] www.berr.gov.uk/files/file30690.pdf

THE CCS INDUSTRY IN UK

There are no companies in UK actively working with development of CCS capture technology. However, there exist a number of suppliers, engineering companies and consulting firms with an interest in CCS. They include:

- Doosan Babcock: Doosan Babcock is a multi-specialist energy services company operating in the thermal power, nuclear, petrochemical, oil & gas and pharmaceutical industries. Doosan Babcock is one of the global leaders in the design of boilers. It is a very active member of various government and private CCS consortia and initiatives.
- Schlumberger: Schlumberger is a leading oilfield services provider.
- AMEC: a leading engineering company
- RPS: RPS is an international consultancy currently advising clients on the practical considerations for CO2 storage in depleted oil and gas reservoirs
- Powerfuel: Powerfuel operates the Hatfield mine and has obtained consent for building a 900 MW "clean coal" plant alongside the mine[194].
- M.W. Kellogg[195] is a British-based company which has been engaged in process projects from the 1930's. Over the last 40 years the company has delivered multiple refinery and petrochemical projects worldwide, and is most renowned in Norway for delivering the original plant FEED and the major extension projects at the Kårstø gas receiving and processing terminal. MWKL was involved in the In Salah project in Algeria in 1995 in a joint EPC contract with KBR & JGC a central feature of which was CO2 Compression and Geological storage.

CCS Research and Development

CCS research in the UK receive relatively little funding compared to countries like the US and Norway. According to the Guardian, UK research received just over £6 million in the past decade, compared to £40 million annually in Norway[196].

Scottish Centre for Carbon Storage[197]

The Scottish Centre for Carbon Storage (SCCS), established in 2005 with funding from The Scottish Funding Council, is a partnership between the British Geological Survey, Herriot Watt University and The University of Edinburgh, and is the UK's largest grouping of CO_2 Storage researchers. The centre combines expertise based on petroleum and hydrocarbon geoscience in 3D regional and field scale geological modelling, geophysics, geo-engineering and subsurface fluid flow. The Centre also has expertise across the full Carbon Capture & Storage chain, and frequently provides media assistance (print, radio, and TV), advice to UK and Scottish Government, and Policy advice and opinion.

Ten Industry Partners have joined the SCCS research consortium, contributing over £550,000 towards PhD studentships. Each industry partner subscribes to fund a single project and the research outcome from each project is shared. Although each project is specific in nature the combined research will represent key elements of the entire CCS supply chain. Participants include; ARUP; BG Group; BP; CO2 DeepStore; E-On; Schlumberger; Scottish and Southern Energy; Scottish Enterprise; Scottish Power; and Shell.

Existing projects are focused on the geological storage and monitoring of CO2. New projects are being developed on CO2 Regulation, CCS deployment, and CO2 capture, and Learning rates (to predict future costs) of CCS power plants.

SCCS is the first institution of higher learning in the world to offer a focused Master's programme in CCS:

"Opportunities for CO2 storage around Scotland"- This one-year study was recently completed The study evaluated sources, hydrocarbon reservoir and saline aquifer sinks, volumes of potential storage sites and timing of availability, potential for Enhanced Oil Recovery, the options for CO2 transport and economic models for CO2 storage. Nine multinational commercial organisations with operational interests in Scotland, and the Scottish Government fundedthe project. It identified the UK's largest storage sites beneath the North Sea – totalling between 4,600 and 46,000 million tonnes CO2. This storage capacity is likely to be much larger than the storage needs of the UK, and comparable to that of Norway.

[194] www.powerfuel.plc.uk/

[195] Interviewed 26th February 2007 in a meeting with 8 CCS experts lead by Commercial VP Mike Cleaver

[196] Source: Guardian, April 24 2009

[197] See http://www.geos.ed.ac.uk/sccs and http://www.geos.ed.ac.uk/sccs/SCCS_update.pdf

UK Carbon Capture and Storage Consortium[198]

This is a consortium of engineering, technological, natural, environmental, social and economic scientists. The consortium is a way to rapidly expand a UK research capacity in the area of carbon capture and storage, commensurate with the large potential contributions to national energy targets. They aim to deliver viable large-scale Carbon Capture & Storage options for the UK.

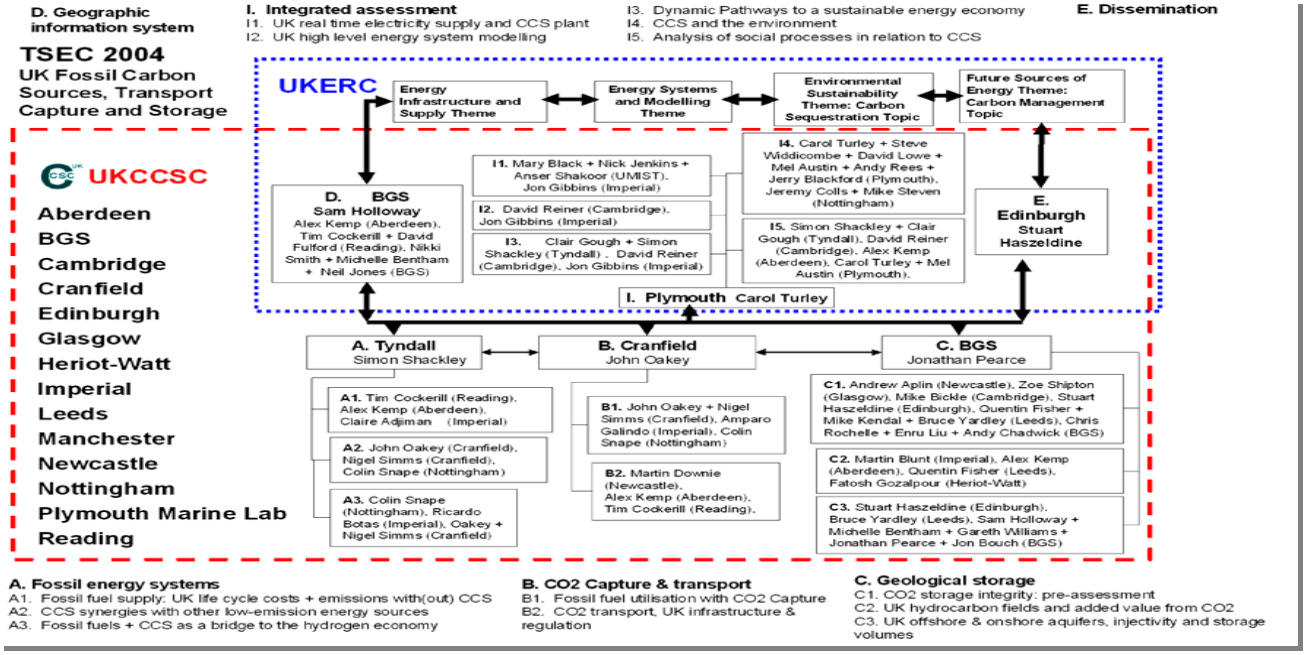


Figure 19: Members of the UKCCSC Consortium and its relationship to the UK Energy Research Centre (UKERC).

Technology Strategy Board

The TSB funds CCS projects through:

- CO2 Aquifer Storage Evaluation and Monitoring (CASSEM), which ia a £2.5 Million project, funded by EPSRC and industry, that develops methodologies, workflows and insights for the identification and evaluation of CO2 storage sites in offshore saline aquifers. The project will go on until 2011 and lead research centre is Edinburgh University.
- June 2009 Competition Funding: This funding programme is open to CCS.[199]

E.ON and EPSRC Partnership

E.ON UK and the Engineering and Physical Sciences Research Council (EPSRC) announced in May 2009 that they will award $10 million to university-led projects. They are:

- University of Nottingham and Partners: CO2 absorption
- Newcastle University and Partners: large-scale transportation
- Leeds University and Partners: oxyfuel combustion

RWE npower's Combustion Testing Facility at Didcot

RWE npower's Combustion Test Facility (CTF) was completed in September 2008, at Didcot Power Station. The test facility looks at the technical, operational and commercial issues associated with CCS. In the autumn of 2008 a post-combustion CO2 capture plant was completed, where CO2 was separated under flue-gas conditions – a feat RWE is the first of its kind in the UK. RWE npower is planning to carry out both oxyfuel and post-combustion research at the plant[200]

[198] www.geos.ed.ac.uk/ccs/UKCCSC

[199] www.innovateuk.org/_assets/pdf/competition%20carbon%20abatement%20technologies%20technology%20strategy%20board.pdf

[200] Source: Company press release, March 2009.

Energy Technology Institute (ETI)

The ETI wishes to commission a project to assess the technology development needs for CCS mineralisation, especially technologies which will allow CO2 to be captured directly from flue gases without a separate capture step.

CCS by mineralisation (or mineral carbonation) has been identified by the Intergovernmental Panel on Climate Change (IPCC) as a promising additional technology in the CCS portfolio. Although the UK appears to be well-served with potential sites for geological storage of CO2, the risk remains that these may turn out to be insufficient, uneconomic or impractical. Mineralisation is therefore could therefore represent an important risk mitigation strategy for the UK's CCS activities.

Imperial College Centre for Carbon Capture and Storage (IC4S) [201]

Researchers at Imperial College recently announced the launch of the Imperial College Centre for Carbon Capture and Storage (IC4S. The college-wide virtual Centre, a part of the Energy Futures Laboratory and supported by the Grantham Institute for Climate Change, will act as a focal point for work at Imperial on all aspects of CCS.

Carbon Mitigation Initiative [202]

Princeton University is in a joint project with BP and Ford Motor Company to find solutions to the greenhouse and global warming problem. Together their researchers are developing strategies to reduce global CO2 emissions that will be safe, effective, and affordable. The program started in 2000 and will run for 10 years. BP is the main sponsor with US$ 15 million while Ford paid US$ 5 million.

Oxycoal UK

Oxycoal UK is a research project developing oxyfuel technology, lead by Doosan Babcock. The project will run until November 2009 with two years possible extension. Vattenfall joined in December 2008

USEFUL UK REFERENCES

- Ernst&Young, CCS Country Attractiveness Index (available on-line)
- *"Our energy future - creating a low carbon economy".* The DTI/DEFRA Energy White Paper published in February 2003.[203]
- "*The Energy Challenge*". The Energy Review report issued in July 2006[204].
- "*Meeting the Ewnergy Challenge – A White Paper on Energy*" DTI May 2007
- 'I*ndustrial CO2 emissions and CO2 storage potential in the UK*', British Geological Survey, 2006. (not found in public domain)
- "*The Re-Use of Offshore Oil and Gas Pipelines. Report and recommendations relating to the UKCS Pipeline System*" - published in January 2006[205]. (282-EEEGR_UKCS-PRP_Final_Report_03-01-06.pdf)
- '*The Infrastructure, Availability and Costs for the CO2 Transportation and Storage Offshore in the North Sea*', East of England Energy Group, 2006. (not found in public domain)
- DTI commissioned the research to develop a detailed understanding of the potential costs of Carbon Capture and Storage (CCS) technologies in the UK and to construct supply curves for the future. The report "*Analysis of carbon capture and storage cost-supply curves for the UK*" was completed by Pöyry Energy Consulting[206] in January 2007[207].

[201] www.imperial.ac.uk/ccs

[202] www.princeton.edu/~cmi/

[203] http://www.dti.gov.uk/files/file10719.pdf

[204] http://www.dti.gov.uk/files/file31890.pdf

[205] http://www.eeegr.com/filemaster/t_indreport_template.php?category=Industry+Reports~Decommissioning~The+Re-Use+of+Offshore+Oil+and+Gas+Pipelines&ind=&search=

[206] Author(s): Barry Ladbrook and Phil Hare. Pöyry Energy Consulting, King Charles House, Park End Street, Oxford, OX1 1JD, UK. Tel: +44 (0)1865 722660 Fax: +44 (0)1865 722988, www.ilexenergy.com. E-mail: consulting.energy.uk@poyry.com

[207] http://www.dti.gov.uk/energy/sources/sustainable/carbon-abatement-tech/page19502.html

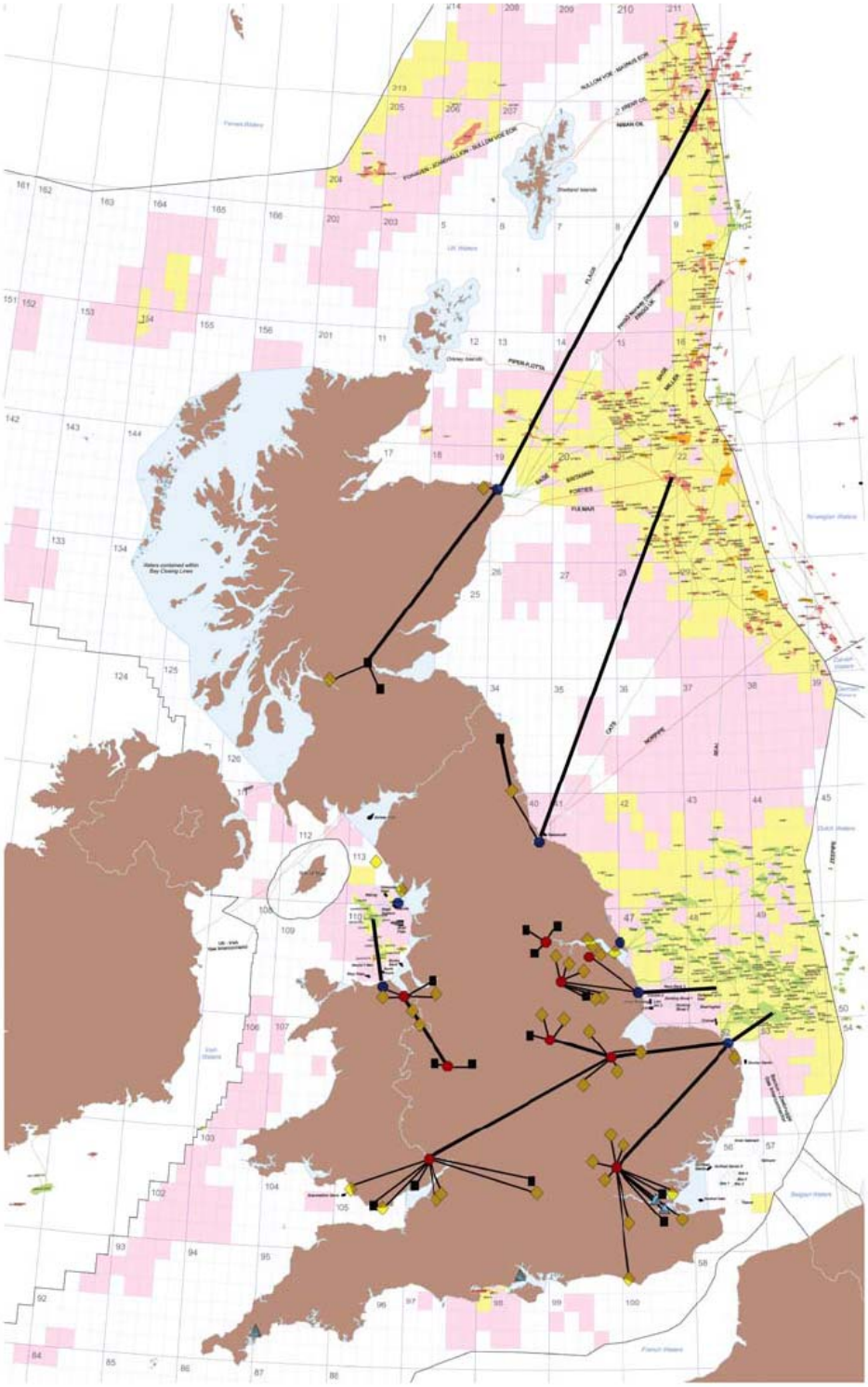


Figure 20: An illustration of the base case transport network used in Pöyry Energy Consulting 2006 study: Analysis of carbon capture and storage cost-supply curves for the UK.[208]

[208] www.dti.gov.uk/files/file36782.pdf

France

GOVERNMENTAL PROGRAMS AND STRATEGIES

The French Agency for the Environment and Energy Management (ADEME)[209], has earmarked CO2 capture and storage as one of its research priorities. In this context, it takes part in federating and structuring national efforts in the field, with the creation in 2002 of Club CO2. ADEME supports large numbers of projects and initiatives concerning all aspects of the capture/transport/storage technological stream, and devotes special attention to socio-economic and environmental impacts in a sustainable development perspective. Within the Club CO2 there are two thematic foci; CO2 capture and transport, and on geological storage.

Club CO2[210]

Club CO2 was set up in 2002 at the initiative of the ADEME to act as an umbrella organization for French research on CO2 capture and geological storage. It brings together industrial players (Total, Air Liquide, ARCELOR, Lafarge, Alstom Technologie, Electricité de France, Gaz de France, etc.) and public research bodies and institutions (ADEME, BRGM[211], CNRS[212] and IFP).

Club CO2 has set itself three main tasks:

to identify directions and strategies for French scientific programs;

to defend the French position and technology offering in European and international bodies;

to initiate and coordinate joint work by public-sector and corporate research teams.

CURRENT CCS PROJECTS IN FRANCE

Total's project in Lacq[213].

Total announced[214] Feb. 8, 2007 the launch of a pilot CO2 capture and sequestration project in the Lacq basin in southwestern France. The project calls for up to 150,000 metric tons of CO2 to be injected into a depleted natural gas field in Rousse (Pyrenees) over a period of two years as from end-2008.

The source of the CO2 is from oxy-fuel combustion at Lacq's steam production unit at the gas processing plant. The purified CO2 will be compressed and conveyed via pipeline to the depleted Rousse field, 27 kilometres from Lacq, where it will be injected through an existing well into a rock formation 4,500 metres under ground.

The demonstrator unit is scheduled to start up in late 2008, after two years of studies and preparation. The project has three key objectives:

- to improve mastery of the oxyfuel combustion process, particularly with a view to applications in the production of extra-heavy oils,
- to halve the cost of carbon capture compared to existing processes,
- to develop monitoring methods and instruments to demonstrate on a larger scale the reliability and sustainability of long-term CO2 storage technology.

The pilot will also contribute to the goal CO2 emissions-free power generation (Zero Emission Fossil Fuel Power Plant) defined by the European Technology Platform, in which Total is a partner.

The project, which will cost nearly €60 million, will be carried out in partnership with Air Liquide and in cooperation with the French Petroleum Institute (IFP), the French Bureau of Geological and Mining Research (BRGM) and others.

[209] www.ademe.fr
[210] www.clubco2.net
[211] www.brgm.fr
[212] www.cnrs.fr
[213] www.scandoil.com/moxie-bm2/carbon/technology_carbon/total-launches-the-first-integrated-co2-capture-an-2.shtml
[214] www.total.com/en/press/press_releases/pr_2007/070208-co2-capture-sequestration_11400.htm

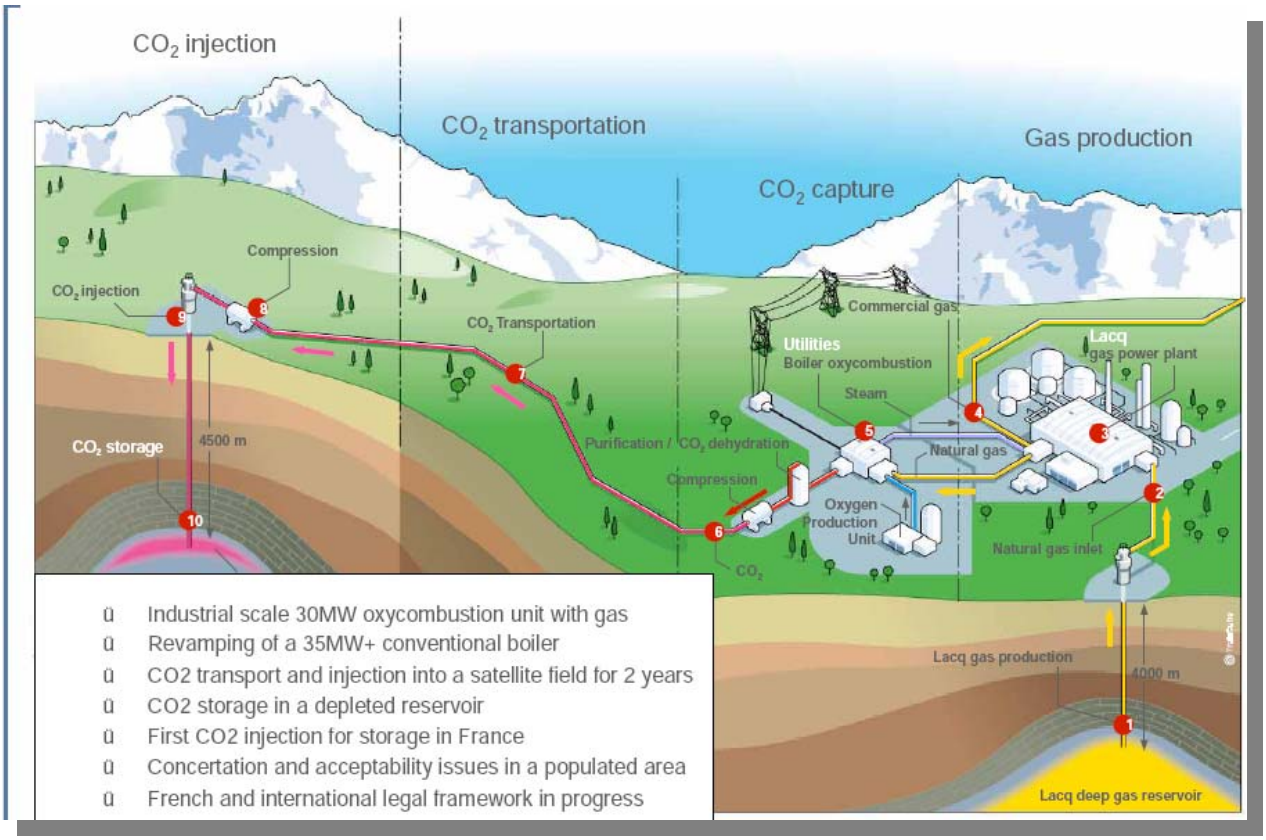


Figure 21: Total's Lacq project. Source Total[215].

Over the past ten years, Total has participated in several CO2 sequestration projects, notably in saline aquifers at North Sea oil production sites.

Veolia Environnement CCS project[216]

Veolia Environnement[217] began in 2005 a research program on CCS from waste treatment plants. They announced in March 2008 treatment plant in Claye Souilly, near Paris, to study the installation of an industrial-scale pilot unit for the capture and geological storage of CO2. With an annual treatment capacity of 200,000 metric tons per year of CO2, the site will be the biggest of its kind in France to date.

The CO2 will be produced by the existing biogas-to-energy units and will be injected under supervision into a saline aquifer, located at a depth of more than 1,500 meters.

Cost, financing and timeframe of the project was not disclosed.

Project PICOREF (completed)[218]

PICOREF is a R&D programme dedicated to the storage of CO2 in permeable reservoirs. It is supported by the French Ministry of Industry and by a consortium of French companies, research institutions and academic laboratories. The two-year project started 2005, with a budget of 3,75MEURO for 2005.

PICOREF follows a four-year study of the geological storage of CO_2, supported by the RTPG (Réseau des Technologies Pétrolières et Gazières - network of oil and gas technologies), industry and French research organizations. These studies were aimed in particular at taking stock of available knowledge and tools in a field that is new to the oil extraction and underground storage industries. The year 2005 is a year of transition between this fundamental research and its application to industrial projects.

This project PICOREF continued in 2006-2007 within the French National Research Agency (ANR). The preliminary inventory done within the European GETSCO project will be completed by a new French project funded by ADEME (French Agency for Environment). METSTOR (Methodology for CO2 Storage) began in 2006 for site selection in France.

[215] www.olf.no/getfile.php/Dokumenter/Presentasjoner/Murmansk%202008/Minsaas.Johansen.pdf
[216] www.veolia.no/internett/cms36no_ON.nsf/($All)/8845195F2CF263B6C1256DC700732766
[217] www.veolia.com
[218] http://www.igu.org/html/wgc2006/pdf/paper/add11170.pdf

CCS TECHNOLOGY COMPANIES IN FRANCE

Company/association	Web site	Relevant business/technology
Air Liquide	www.airliquide.com	Development of oxycombustion solutions for industrial boilers and power plants. Innovative processes for pre- and post-combustion separation and purification of CO2, (adsorption, cryogenics and membranes). Engaged inr European programmes such as Encap, Ulcos or Dynamis or American projects, e.g. with Department of Energy (DoE). Air Liquide is taking part in several R&D pilot projects on CO2 storage in France (Picoref project), Europe (Recopol pilot on CO2 injection into coal seams) and North America (regional partnerships with the DoE, in Canada).
Alstom	www.alstom.com	Engineering firm specializing in energy industry. Technology for e.g. CO2 capture and handling.
Arcelor Mittal	www.arcelormittal.com	The world's largest steel company. Engaged in various technology development projects; and in some CDM projects.
Bureau de recherches géologiques et minières (BRGM) – the national geologic survey agency in France.	www.brgm.fr	Research addressing CO2 storage in geological formations. Between 1993 and 1995, it took part in the first European research project on the feasibility of the concept, the Joule II project, i.e. "The underground disposal of CO2." Involved in e.g. SACS, Gestco, Nascent, Weyburn, CCP Samcards, Picor, Castor, InCA-CO2, Ulcos and Picoref. Management of the CO2GeoNet European network of excellence, an active member of the thematic CO2Net European networks, and is secretary of the French Club CO2.
Centre national de la recherche scientifique (CNRS)	www.cnrs.fr	Government-funded research organization, under the administrative authority of France's Ministry of Research. Focus on environmental impacts of climate change and CO2 sequestration in ocean etc.
Electricite de France (EDF)	www.edf.com	EDF is working in partnership with ADEME, universities and industry in a project addressing storage of massive amounts of CO2.
Gaz de France (GDF)	www.gazdefrance.com/en	GDF is collaborating in a numbero f CO2-seqiestration projects [219]; e.g. European CO2-NET2 network; RECOPOL project on injecting CO2 into coal seams in Poland; CASTOR project; and GESTCO project set up to list CO2 storage sites in Europe. In France, the GdF Group is conducting several studies on CO2 transport and storage, in partnership with ADEME and RTPG. GDF Production Nederland B.V. has been conducting a pilot operation since May 2004 to inject CO2 into a depleted gas deposit in the Dutch North Sea zone. A similar injection operation is being planned as part of the development of the Snøhvit deposit in the Barents Sea, in collaboration with Statoil.
Géostock,	www.geostockgroup.com	GEOSTOCK group offers a comprehensive range of services anywhere in the world on all types of underground storages. Involved in Picoref project.
Frech Gas Institute (IFP)	www.ifp.fr	IFP is coordinating a number of projects including Castor (a European project aiming to cut the cost of CO2 capture by half and to validate the concept of geological storage), InCA-CO_2 (International Cooperation Actions on CO_2 capture and storage, a European project that seeks to promote European know-how in the field on the international scene) and Picoref (Capturing CO_2 in reservoirs in France).
L'Institut National de l'environnement industriel (Ineris)	www.ineris.fr	French public research body of an industrial and commercial character with focus on environmental safety.
SARP Industrie	www.sarpindustries.fr	Company specializing on treatment on hazardous waste and recycling services. Engaged in CCS projects.
Schlumberger	www.slb.com	Engaged in CCS projects through subsurface characterization, modeling, simulation and prediction, well completion, and CO_2 monitoring both during injection and long-term storage. Participant in the following projects: GCEP (US) , IPGP (France) CO2CRC (Australia) CO2ReMoVe (EU) COSMOS-1 (France-Germany) COSMOS-2 (France-Germany)

[219] www.igu.org/html/wgc2006/pdf/paper/add11170.pdf

		RECOPOL-2 (EU) Batelle (US-DOE) Frio (US-Texas) Otway (Australia) , Sleipner (Norway) In-Salah (Algeria) Weyburn (Canada) Gorgon (Australia) Paertner in international forums and trade association EU Zero Emission Fossil Fuel Power Plant Carbon Sequestration Leadership Forum IEA Greenhouse Gas R&D Program EU Communications & Public Perception Committee CO2 Capture and Storage Association (CCSA-UK) CO2 Club (France), CO2Net (EU)
Total	www.total.com	The leading French oil company is taking part in several main CCS projects; including the Sleipner and Picoref projects. Furthermore leading the Lacq project – see above.
Veolia Environnement	www.veolia.com	Veolia Environnement is a global company providing environmental services in the water, environmental services, energy and transportation fields.

Italy

GOVERNMENTAL PROGRAMS AND STRATEGIES

The Italian government recognises the huge challenge of meeting Italy's Kyoto Protocol commitments (existing gap 97 Mt CO2/yr) while satisfying an ever-increasing energy demand. To address this, the Italian energy policy foresees a number of measures, including CCS.

A number of National projects and programmes will be supported by National Government, Ministry of Economic Development, Ministry of Research and Regional Governments[220]. Thel 3-year Energy R&D National Programmes with a funding of 150 Meuro includes funding for 2 CO2 Separation & Capture programmes; "quantifying existing potential capacity to storage CO2 over time" and "ECBM Site-Tests in Sardina (Sulcis Area)".

The Ministry of Economic Development has set up in 2003 a National Committee in order to coordinate the Italian participation to all the international initiatives on Zero Emissions.

Italy is furthermore active in various international for a, such as Carbon Sequestration Leadership Forum (CSLF); European Technology Platform on ZEFFPP; IEA (CERT & WPFF) and International Partnership on Hydrogen Economy. In addition to participation in various EU FP6 and FPG projects.

CCS TECHNOLOGY COMPANIES AND INSTITUTES IN ITALY

Company/association	Web site	Relevant business/technology
ENEA - National Agency for New Technologies, Energy and the Environment	www.enea.it/com/ingl/default.htm	The Department of Technologies for Energy, Renewable Sources and Energy Conservation focuses its operations on two areas: increasing energy efficiency and achieving a low-carbon economy. See below.
ENEL	www.enel.it	The largest power company in Italy is engaged in several projects related to CCS; including the Zero Emission Power and oxy-coal combustion demo.
ENI	www.eni.it	Eni is the leading Italian oil and gas company. Their engagement in CCS is mainly through their participation on the CO2 Capture Project (CCP)[221] together with 7 other leading energy companies world wide (BP, ChevronTexaco, Hydro, EnCana, Shell, Statoil and Suncor), plus US DOE and EU.
CNR - The National Research Council	www.cnr.it	Research relevant to CCS mainly on biological and environmental impact of storage.
CESI RICERCA	www.cesiricerca.it/default_e.asp	Public research Company in the electro-energy sector. Owned 51% by ENEL.
ANSALDO	www.ansaldoenergia.it	Ansaldo is an Italian manufacturing company specializing in power plants. Their focus on CCS technology is towards development of low fuel gas turbines and use of fuel cells in an CCS combines system. With Sotacarbo [222] research centre, Ansaldo has proposed the COHYGEN project, which is sulcis coal syngas production with CO2 and H2 separation.
SOTACARBO	www.sotacarbo.it	Sotacarbo is a limited company established in 1987 which aims to develop new and advanced clean coal technologies. It has represented Italy in the international organization IEA The Clean Coal Centre.
INGV	www.ingv.it	National Institute for Geophysic and Vulcanology.
CARBOSULCIS		Public mining company in Sardinia, doing study of underground storage. Carbosulcis is working at a

[220] Marcello Capra, Ministry of Economic Development: Presentation at "Clean coal technologies" at the British Embassy in Rome, Dec. 13, 2006

[221] www.co2captureproject.org

[222] www.sotacarbo.it

		project for CCS by Enhanced Coal Bed Methane (ECBM) Technology. Partner with Sotacarbo and INGV.

CCS INITIATIVES IN ITALY

Enel[223] projects

Enel – the largest power company in Italy, is engaged in two projects related to CCS;

Enel CCS1 (post-combustion) [224]

This objective of this project is To retrofit one 660 MWe coal fired unit in Brindisi with CO2 capture equipment and start CO2 underground storage by 2012. The pilot capture plant is under construction in 2008 and planned in operation from 2009.

The pilot plant will capture 2,25 ton CO2/hr using MEA absorption post-combustion.

Phase 3 in the project is to select a suitable storage site in Italy. A 2 year storage feasibility studies are conducted in collaboration with the National Institute of Geology and Vulcanology (INGV).

Phase 4 is based on experience gained with the pilot project. Enel will then build a demo plant of this technology at the USC pulverized coal power station, currently under construction. About 600,000 Nm3/h of flue gases from one unit will be processed and the concentrated CO2 flow transported and stored in an underground reservoir. The demo plant is expected to be ready by 2012.

The capture rate will be in the order of 1 to 1,5 million ton CO2/year.

Enel CCS2 (oxy-fuel)

The project goal is to build by 2012 a small (35-70 MWe) zero emission coal fired power plant based on a pressurized oxy-combustion technology already proved at pilot scale.

Enel has signed a cooperation agreement on oxy-combustion technology with ENEA and ITEA. ITEA has patented an innovative process called ISOTHERM that has already been tested on a pilot scale for over 4000 hours. The partners will finish a feasibility study for a coal-fired power plant in 2007, with a 50 MWth plant planned for 2009. A small demo plant (35-70 MWe) should be ready by 2012.

Italian National Agency for New Technologies, Energy and the Environment (ENEA)[225]

ENEA has a wide range of research programmes related to energy and environment; including CCS activites such as "Clean coal/Zero emission Coal Technologies" and the proposed ZECOMIX test platform.

ZECOMIX [226] [227]is proposing a project for coal gasification for H2 and power generation with CO2 separation. It consist of three main components:

- H2 production by advanced coal gasification process (ZEC)
- Power production through high efficiency H2-O2 cycle with gas turbine (ZECOTECH)
- CO2 capture and storage.

L'Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)[228]

OGS operates as national reference for coordinating the Italian participation in entities, projects and international research initiatives in the fields of oceanography and experimental geophysics, including studies, applied research and technological development in the field of exploration, exploitation and storage of geo-energy and energy residues, as CO_2, on land and at sea, in Italy and abroad.

[223] www.enel.it
[224] www.zero-emissionplatform.eu/website/docs/GA2/conti%20barbucci.pdf
[225] www.enea.it
[226] www.iea-coal.org.uk/publishor/system/component_view.asp?LogDocId=81293&PhyDocId=5682
[227] www.aidic.it/H2www/webpapers/30%20Calabro'.doc
[228] www.ogs.trieste.it

OGS is partially funded by the Italian Government according to a Three-Years Plan of Activity. In the actual one, the following researches, related to the geological confinement of CO_2, are funded:

numerical 3D modeling for the CO_2 confinement and its implementation on massive parallel computers;

theory and modeling of seismic waves propagations, with application to the geologic confinement of CO_2;

evaluation of content and stability of CO_2 hydrates in geologic formations in the offshore;

tomographic evaluation of Q factor and anisotropy parameters, with application to the monitoring of re-injected CO2 fate.

OGS is the co-ordinator of the Italian Project "Geological sequestration of CO_2 and development of the related technologies" , involving OGS, ENEA, ENI-Agip, Aquater, CNR, URS and other 13 universities.

CO2 GeoNet

Universita di Roma "La Sapienza" and OGS partcipates in the European Networks of Excellence CO_2GeoNet[229] together with 11 other institutes to study underground CO_2 storage.

[229] www.co2geonet.com/home.aspx

The Netherlands

In order to reduce emissions and secure energy supply, the Netherland government has identified CCS as one of 10 areas where the government would like to show more leadership. [230] CCS is an interesting mid term option for the government for a transition towards a sustainable energy-production system, but may not jeopardise the development and stimulation of sustainable energy-production and energy efficiency activities. The Netherlands shows great potential for CCS, due to the amount of (small) depleted gas fields.

The CATO programme[231]

The CATO programme represents a high-level knowledge network in the fi eld of CO2 capture and storage in the Netherlands*. The aim of the CATO programme is to identify whether and how CO2 capture and storage (CCS) can contribute to a sustainable energy system in the Netherlands. From economical, technical, social and ecological points of view it is analysed under which conditions this option could be implemented in the energy system. CATO is implemented by a strong and unique consortium of Dutch companies, research institutions, universities and environmental organisations, led by the Utrecht Centre for Energy research.

Given its size, over 25 million Euro, the CATO programme can be regarded as the Dutch national research programme on CO2 capture and storage. The Dutch government supports CATO with 12.7 million Euro, half of the costs. The programme runs from 2004 until the end of 2008.

CCS PROJECTS IN THE NETHERLANDS

The CRUST project : Storage[232]

The CRUST project is a CO2 geological storage demonstration project, and was launced by the Dutch government in 2002. CRUST aims to make an inventory of possible sequestration sites, to study legal and environmental aspects and the possibilities for CO2 re-use.

Gaz de France Production Nederland B.V. (GPN) currently produces natural gas from various gas production installations on the Dutch continental shelf of the North Sea. At one of it's platforms – K12-B about 100km offshore – CO2 has been separated from natural gas. The separation unit is activated MDEA process licensed from BASF. The extracted CO2 was vented to the atmosphere.

Since May 2004 the vented CO2 gas is compressed and injected into the same gas reservoir. Until now the CO2 is injected in a part of the reservoir that is not producing anymore, in this way interference with the gas producing wells is prevented. Since the start-up the injection project is running very well, no major problems were encountered.

The pilot test injection amount is restricted to 20,000 ton CO2/year. In a later stage the injection amount can be scaled up to 480,000 ton/year.

The project is 90% financed by the government and 10% by Gaz de France. This project is important in order to prove that long term storage in depleted gas reservoirs is possible.

The Enecogen project: Post-combustion[233]

The Enegogen project is post-combustion cryogenic CO2 capture from flue gas of Eneco[234] gas fired CHP power plant. The initial capture capacity is 10,000 ton CO2 /yr, with ambitions of expanding to 2 million ton CO2 in full scale project. The full scale project entails capture of flue gas from a 850 MW gas power plant.

About 50% of the cooling needed for the cryogenic separation comes from the nearby Liongas's LNG terminal[235]. The captured CO2 will be transported to CO2 'infrastructure' of Rijnmond, linked to horticulture, storage sites, and perhaps North Sea.

The initial investment is EURO 37 million, of which EURO 10 million is subsidies from Ministry of Finance.

[230] www.cslforum.org/documents/NetherlandsCCS.pdf
[231] www.co2-cato.nl
[232] www.co2captureandstorage.info/project_specific.php?project_id=131
[233] www.enecogen.com/CO2.html
[234] www.eneco.nl
[235] www.liongas.nl/en/

Project development 2006-2008, design 2009 and operation of from 2011. The timing of full-scale gas-plant and LNG terminal uncertain.

The Nuon 'CO2 Catch Up' Project: Pre-combustion[236]

Nuon is undertaking a R&D project for capturing CO2 from the multi-fuel (coal and biomass) Willem Alexander coal gasification plant in Buggenum. The project is in cooperation with Delft University, ECN, TNO, and KEMA. The test installation is a simplified version of the CO2 capture design that has been prepared for Nuon Magnum. The CCS project investment is EURO 40 million, of which EURO 10 million in subsidies from Ministry of Finance. If everything runs according to plan, the test programme in Buggenum can commence in the second quarter of 2010

The plan is to extend CO2 capture to the planned NUON Magnum[237]: a 1,200 multi-fuel (biomass, coal, gas) power plant in Eemsmond. Nuon already uses the gasification technology in its power plant in Buggenum, in the province of Limburg. Nuon expects the power plant to be commissioned in 2011. In March 2008, it was announced that Mitsubishi Heavy Industry won the contract to build the ga-fired part of Nuon Magnum.[238]

The SEQ 'Zero Emission Power Plant' Project[239]: Oxy-fuel

The zero emission power plant (ZEPP) is an innovative concept for oxyfuel combustion of 170 MWth (50MWe) power plant in Drachten/Akkrum. It is expected a capture rate of 250,000 ton CO2 annualy, with transport and storage into gas fields for EGR, resulting in a yield of natural gas of about 40 million cubic metres.

The ZEPP project involves the collaboration of SEQ Nederland BV, ENECO Milieu BV, Delft University of Technology (TU Delft) and the Stichting Energy Valley initiative.

The project cost is cost €60 million of which €10 million is subsidy from Ministry of Finance.

The project is expected to leads towards development of large scale oxyfuel power plants, rising efficiencies with new turbine technologies with 'flexible concept' repeatable on many locations, perhaps driven by storage or oxygen availability.

[236] www.nuon.com/about-nuon/Innovative-projects/nuon-magnum/clean-coal.jsp
[237] www.nuon.com/about-nuon/Innovative-projects/nuon-magnum/index.jsp
[238] www.nuon.com/Images/Nuon%20Magnum%20Nieuwsbrief%20nr5%20feb2008_tcm185-74943.pdf
[239] www.seq.nl

Japan

GOVERNMENTAL PROGRAMS AND STRATEGIES

General policy

Japan ratified in June 2002 the "Kyoto Protocol" with a goal of reducing their Green House Gas (GHG) emissions to 6% below the 1990 levels. In June 2009, the government announced it's middle-term 2020 target to 15% reduction from the 2005 baseline, while the long-term target is 70% reduction by 2050[240]. This target is excluding external carbon credit purchases. The forecast for 2010 is 5.9% above the the 1990 level, indicating a total reduction of 12% GHG emission from today's level[241]. This amounts to about 150 million ton CO2 equivalents.

The Kyoto Target Achievement Plan[242] as of April 2005 stipulates that this reduction target should be met through reduction in domestic emission (50%), CO2 sinks – including CCS (30%), and the rest by procuring emission credits, e.g. the Kyoto Mechanisms. METI (Ministry of Economy, Trade and Industry) suggest that the Japanese industry can reduce emission by 7% within 2010 through new technology[243].

For the domestic reduction strategy, there are currently two prevailing approaches:

- Keidanren [244], supported by METI [245], is proposing a "Voluntary Action Plan", where various industry/commercial segments are setting (or being imposed) a sector-wise reduction target. The proposed plan covers about 80% of the industrial and energy conversion sectors. The "enforcement" and follow-up will be conducted by the METI/ANRE in the Industrial Structure Council.
- The Ministry of the Environment proposes more mandatory CO2 Tax schemes.

Regarding the emission credit procurement scheme, NEDO – New Energy and Industrial Technology Development Organization[246] – is responsible for the implementation of Japans procurement program. Japan has pledged to buy offsets of 100 million tons in CO2 equivalent in the 2008-2012 Kyoto period. In the two years through March 2008 NEDO bought the equivalent of 23.1 million metric tons. It has so far bought offsets under Kyoto's Clean Development Mechanism (CDM) scheme only, which allows rich-nation polluters to fund emission cut projects in developing countries and in exchange receive offsets called CERs. However, within December 2008 Japan will buy greenhouse gas emission rights from east European nations.[247]

Japan did early take a lead in combating global warming through both the Kyoto protocol, and through significant investment in research funding. Japan has been leading the research on ocean sequestration, on capture technologies and to some extent in sub-terrain sequestration.

The Ministry of Environment announced recently[248] a report that that adoption of energy-saving technologies could reduce the country's CO2 output by 70 percent by 2050. However, details and budgets for such an achievement are not readily available.

As of November 2007, the Japanese government will allow its factories and power plants to capture and store CO2 under the seabed as part of its efforts to curb global warming. This is in response to the revision of the November 2006 revision to the Convention on the Prevention of Maritime Pollution by Dumping of Wastes and Other Matter, or the London Convention which added CO2 to the list of substances that can be disposed of in the oceans under certain conditions. Japan is focusing on sub-sea storage, and scientists believe that water-bearing layers surrounding the Japanese archipelago could retain up to 150 billion tons of CO2, equivalent to more than 100 years of CO2 emissions by Japanese plants.

The new prime minister Fukuda announced at the World Economic Forum in Davos January 2008 a follow-up of the Cool Earth 50 named "Cool Earth Promotion Program"[249], with the following key elements:

- Japan will utilize it's G8 presidency in 2008 to drive the Bali-process further

[240] Presentation by environment minister Tetsuo Saito at the Foreign Correspondents Club in Japan, June 24, 2009.
[241] search.japantimes.co.jp/cgi-bin/nn20070810a5.html
[242] www.kantei.jp/foreign/policy/ondanka/index_e.html
[243] search.japantimes.co.jp/cgi-bin/nn19970926a6.html
[244] The Japanese Business Association www.keidanren.or.jp
[245] Ministry of Economy, Trade and Industry www.meti.go.jp/english
[246] www.nedo.go.jp/english/index.html
[247] planetark.org/wen/50782
[248] www.yomiuri.co.jp/dy/features/science/20070218TDY03004.htm
[249] www.mx.emb-japan.go.jp/sp/Davos.ppt

- From 2008, Japan will provide approximately US $10 billion in aggregate over the subsequent five years as assistance for adaptation and access to clean energy ($2 billion) and mitigation ($8 billion) in developing countries.
- Japan will invest US $30 billion over the next 5 years to develop new, innovative technology on a range of areas, including CCS on coal fired power plants. However, much of these funds are already in existing R&D plans.

Carbon Capture and Storage

Japan did early take a lead in combating global warming through both the Kyoto protocol, and through significant investment in research funding. Japan has been leading the research on ocean sequestration, on capture technologies and to some extent in sub-terrain sequestration.

The government has in their "Cool Earth-Innovative Energy Technology Program" of March 2008 identified CCS as one of 21 basic technologies to reduce CO2 emission domestically. The main challenges are high capture costs and insufficient storage capacity on Japanese territory.

However, although the capture part can be addressed domestically, the storage capacity in Japan is limited and not easily accessible. The Japanese government is currently performing thorough seismic survey of the sub sea storage capacity of Japan. The government's target is to be able to store 100 Mton annually.

Private sector engagement

The Japanese energy utility industry is heavily dependent on import of fossil fuel for their goal/oil and gas power plants, and is engaged in R&D related to energy efficiency and new combustion technologies. They are, however, very cautious on heavy investment in CCS technologies due to undecided policies regarding CO2 regulations and emission reduction targets. However, when new power plants (including coal) are commissioned, CCS will be an important issue.

In 1990, the Kansai Electric Power Co., Inc. became the first electric power company to start research on CO2 separation and capturing techniques, and in the following year, built a pilot plant for capturing CO2 at the Nanko Power Plant in Osaka City, and conducted R&D on the world's most efficient CO2 absorber.

Utilities, technology companies and trading companies are opportunistically engaged in CDM projects around globally in expectation of a Japanese emission trading market. The manufacturing industry if furthermore engaged in several demonstration projects for oxy-fuel, post-combustion removal and recently in IGCC. Agency for Natural Resources and Energy (ANRE)[250] regulates the energy utilities, and is cautious in regulations and initiatives that may negatively influence the energy industry.

Japan's roadmap to CO2 reduction and associated technologies are illustrated below:

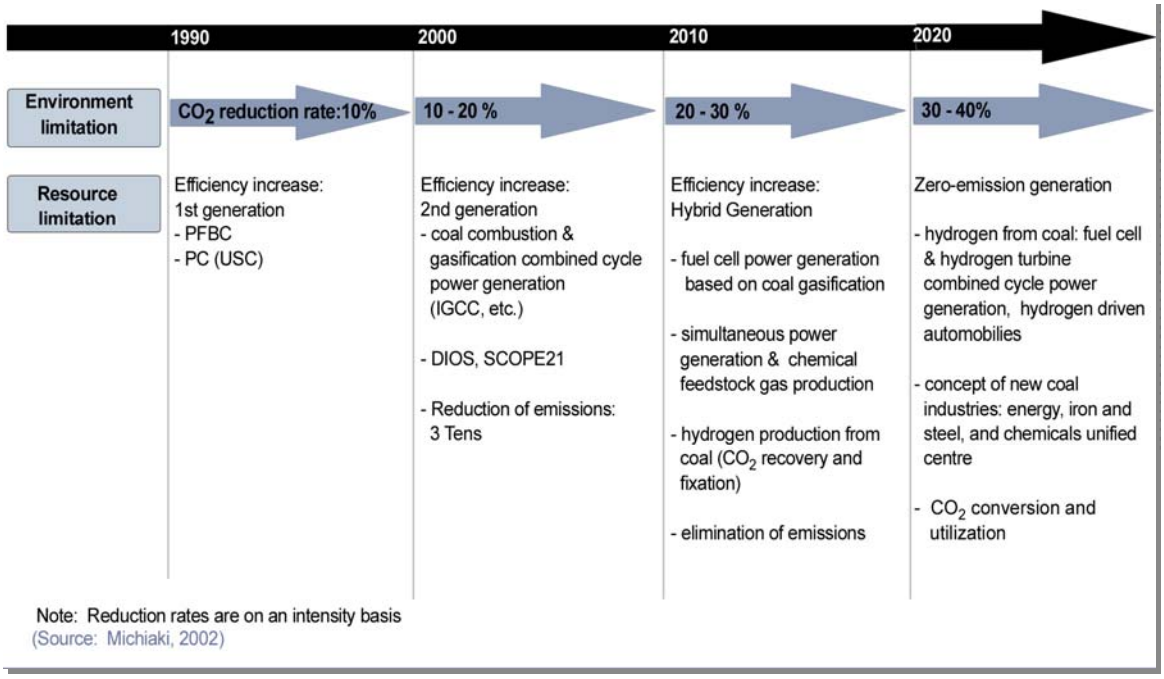


Figure 22: Japanese CO2 management strategy.

[250] www.enecho.meti.go.jp/english/index.htm

Public CCS funding initiatives and partnerships

A majority of public funding to CCS activities originates from Ministry of Economy, Trade and Industry (METI[3]), Ministry of Science and Education (MEXT[251]), Ministry of Environment (MoE[252]) and the Prime Minster Cabinet Office [1].

METI's Office of Environmental Affairs[253] R&D budget for FY 2006 was 5.66 billion Yen (~50M$) and request for FY 2007 is 4.3 billion Yen (~37M$), with main focus on two areas; ocean/aquifer sequestration and on clean coal technologies[254].

MoE has a large project for "Global warming countermeasures" with an FY2007 budget of 3,3 billion Yen (~30M$) but that includes bio fuel and development of new energy. It is not clear how much is earmarked for CCS.

NEDO (New Energy and Industrial Technology Development Organization)[255] is focusing on clean coal technologies projects, and supports currently 64 Energy and Environment Technology Development projects[256]. A budget of ~10M$ is allotted for International Coal Utilization Projects with e.g. China, Indonesia, Vietnam etc.

Finally, NEDO has a Kyoto Mechanisms Credit Acquisition Programme for 2007-2013 with annual budget for procuring CDM credits of at least 50M$/year. 3 Kyoto Mechanisms Promotion Programs have a total budget for 2006 on ~162M$.

The private sector in Japan, including the utilities, are highly competitive, but are also traditionally closely connected with the government. The competition is often concentrated in an east-west axis (Kansai/Osaka region versus Tokyo). So also in the history of CCS research and development in Japan since beginning of 1990s[257]:

In the east, Tokyo Electric Power Company (TEPCO)[258] were initially engaged in ocean deposition research, but quite soon gave it up for the benefit of the parallel research at Central Research Institute of Power Industry (CRIEPI). This research was initially supported by NEDO, but has diminished compared to similar research activity RITE.

In the west - Kansai Electric Power Company (KEPCO) and Kansai Industry Federation, supported by KEPCOs main technology providers Sumitomo initially, and later Mitsubishi Heavy Industry (MHI) focused on development of post-combustion capture technology – mainly amine-absorption. This consortium opted for establishment of an "western version of NEDO", and in 1990 Research Institute for Innovative Technologies for the Earth (RITE) was established. RITE took later the lead the ocean/aquifer research.

The figure below is an illustration of the relationship between the government (METI), the private companies engaged in CCS research and the national research organization RITE.

[251] Ministry of Education, Culture, Sports, Science and Technology www.mext.go.jp/english
[252] Ministry of the Environment www.env.go.jp/en
[253] www.meti.go.jp/english/other/sitemap/index.html
[254] Conversation with Kentaro Endo, Director Environmental Affairs, METI.
[255] www.nedo.go.jp/english/
[256] www.nedo.go.jp/kankobutsu/pamphlets/kouhou/2007gaiyo_e/87_140.pdf
[257] Conversation with Dr. Takashi Ohsumi, Chief Researcher, RITE
[258] www.tepco.co.jp

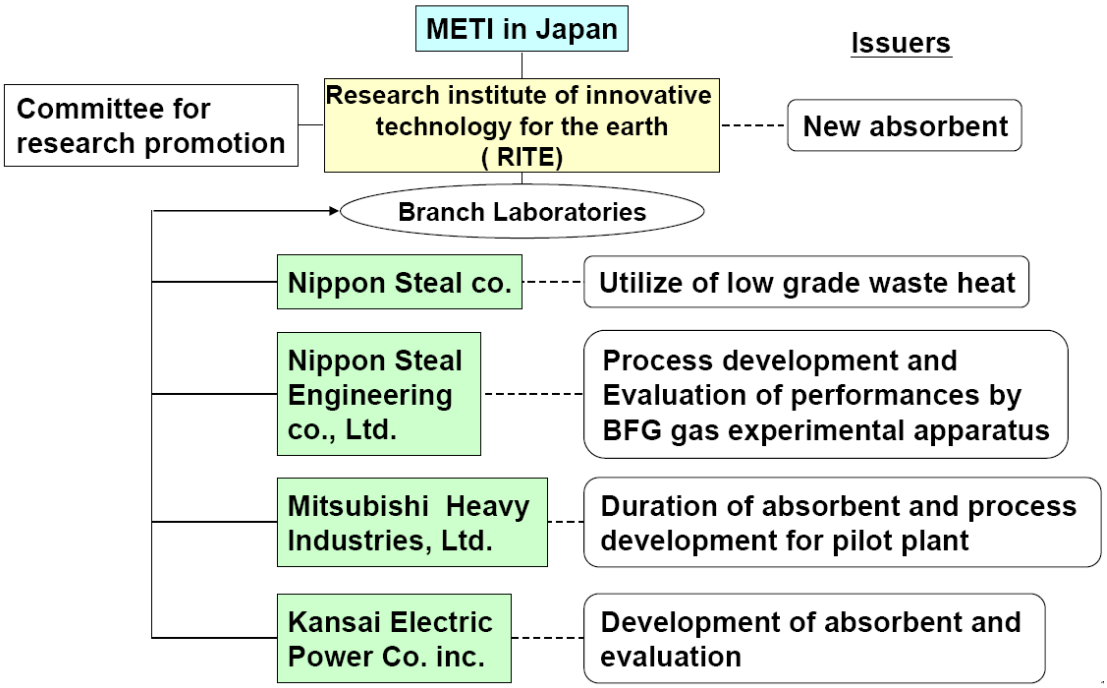


Figure 23: Source RITE[259]

Japan CCS Co.

The Japanese CCS Company, Ltd. was launched in May 2008[260] by 29 major Japanese power and energy-related companies to jointly develop carbon capture and storage technologies.

The 29 companies, who will each invest 3 million yen in the new firm, include power companies (11), petroleum companies (5), engineering businesses (4), petroleum resource development companies (2), steel company (1) and a chemical company, all with expertise in specialized areas needed for CCS.

Japan CCS aims to *conduct feasibility studies* for the government in FY 2008r in an attempt toward realizing Japan's goal to capture and store 100 million ton of CO_2 per year from 2020. Japan CCS aims to combine the CCS technologies of the participating companies to overcome technological difficulties for commercialization. It also said it aims to launch large-scale experiments as early as possible.

The Japanese government is targeting an annual reduction of 100 million tons in CO2 emissions through CCS technologies by 2020.

Japan CCS Co. is currently engaged in two projects in Japan:

- *Feasibility Study on a Total System from Electric Power Generation to CO2 Storage*, as a part of the "Innovative Zero Emission Coal Gasification Electric Power Project"[261] funded by NEDO. In this project, CO2 is captured at the Nakoso IGCC demonstration plant, transported 70 km to the Iwaki-oki Gas Field and stored in depleted gas reservoirs in the field. Term: July 2008 –2010
- Development of Assessment Technologies for a Deep Aquifer appropriate for Demonstration as a part of Research and Development of Underground Storage Technology for CO2, funded by METI. The purpose of the project is to develop assessing techniques of deep saline aquifers appropriate for CCS demonstrations

METI has announced funding for a new demonstration project for *offshore* aquifer injection in Japan in the order of 100,000 ton CO2/yr[262]. The operator/host for the project will be JAPEX (Japan Petroleum Exploration Co)[263]. Although invited, the industry is so far reluctant to contribute to the project since there is no clear integrated domestic CCS policy or plan in Japan.

METI and JOGMEC have over the last 3 years evaluated a large number of injection sites, and currently there is a list of 20 feasible candidates. Mr. Akio Ito from RITE estimates the total aquifer storage potential in Japan to be in the order of 150 billion ton CO2. METI announced in 2006 a long-term plan for storage of 200 million ton CO2

[259] CCS workshop Feb. 15, 2007. Y. Fujioka – RITE. www.rite.or.jp/English/E-home-frame.html
[260] www.shimbun.denki.or.jp/english/article/2008090902.shtml
[261] www.nedo.go.jp/kankobutsu/pamphlets/kankyo/gaiyoue_2008.pdf
[262] Conversation with Toshihiro Mitsuhashi, Director at Office for technology for Climate Change, METI.
[263] www.japex.co.jp

domestically, and the target is to develop technology that reduces the cost of storage to less than $ 25 per ton. According to RITE, the current cost of CCS in Japan is in the range of 66 $/ton, including 21 $ for the storage part and 38 $ for capture and compression.

Battelle Energy Technology[264], the commercial energy science and technology arm of Battelle, the world's largest non-profit independent research and development organization, announced in July 2008[265] it will consult with Japan CCS, using its knowledge base of CCS projects and technology.

RITE has signed MoU for technical partnership with Japan CCS Co. Ltd.

Figure 24: Shareholders in Japan CCS Co. Ltd. Source: RITE.

CURRENT CCS PROJECTS IN JAPAN

Despite the Japanese governments visions of becoming a global leader in combating climate change, there are no larger-scale CCS projects inside Japan, and none has been announced. The focus from the government has been on sequestration, while the industry has driven capture development. It seems now that the Japanese government and also the industry is focusing on financing and development of projects abroad, with China as the nearest target.

Storage Projects

Nagaoka CO2 injection project (completed)[266]

The project started 2000, and was inspired by the Sleipner project. This is an on-shore, underground injection of CO2 into saline aquifer at 1000m depths.

The project was funded by METI with a total of 59M$ from 2000-2007. During the period 2000-2005 about 10,000 ton CO2 was injected. The period 2005-2007 was for monitoring purposes. The project is now completed.

The following outcomes from the project are reported[267]:

[264] www.battelle.org/solutions/default.aspx?Nav_Area=Solution&Nav_SectionID=5&Nav_CatID=5_Carbon%20Management
[265] www.battelle.org/SPOTLIGHT/07-16-08carboncapture.aspx
[266] www.rite.or.jp/English/lab/geological/geological.html

10,400 tons CO2 was successfully injected into a saline aquifer at 1100 meter depth.

Despite the 6.6 magnitude Niigata earthquake in July 2007 with epicentre close to the injection point, no CO2 leakage has been observed.

Simulations calibrated towards observed data indicates long-term CO2 storage reliability of more than 1000 years.

The project has significantly enhanced basic knowledge of aquifer storage in Japan.

The JCOP project (completed)[268]

JCOP, Japan CO2 Geo-sequestration in Coal Seams Project, representing Japan's first CO2-ECBM (Enhanced Coal-Bed Methane) field trial has been designed to evaluate technical and economical feasibility of extracting methane gas while storing CO2 in Japanese coal seams. The main objective of the project is to reduce GHG emissions by subsurface injection of CO2 into deep coal beds in Yubari, Hokkaido having 6-8m thick under nearly 900m from the surface. At the same time, the project is expected to indicate that injection of CO2 into coal will enhance the coal bed methane (CBM) recovery.

The project is headed by General Environmental Technos Co. Ltd.(KANSO) – a 100% owned subsidiary of KEPCO. Laboratory tests have been conducted at RITE and several universities (Hokkaido, Akita, Waseda, Kyoto). The pilot test by JCOAL and technology for capture is provided by by Mitsubishi Heavy Industry and KEPCO.

Project started FY2002 and phase 1 was planned for 3 years, but extended 2 years due to low injectivity and well troubles. The project is now under commissioning, and further activity in this topic will be channelled to the FutureGen project.

CO2 injection: average 2-3 ton/day for 42 days (115 ton for 2005).

CH4 production: 24,000 m3 for 2005.

The project was fully financed by METI with an overall cost of approx. 30M$.

Ocean sequestration projects[269] [270]

The CO2 ocean sequestration project in Japan was established as a 3 stage national project in 1997. The project is financed by METI and conducted by RITE[271].

- Stage 1 (1997-2002): feasibility and analysis
- Stage 2 (2002-2007): 1) Technological & Economical Assessment of CO2 Ocean Sequestration Capability, 2) Development of Environmental Impact Assessment Technology, and 3) Development of the CO2 Dilution Technology. Budget 3-4 M$/year
- Stage 3 (2007-2012): despite controversy of deposition of CO2 in the ocean, the government seems determined to continue to project by offering funding of 0.5M$/year for another 5 year. It is, however, not determined that RITE will continue to conduct the research. One alternative candidate for this project is Prof. Toru Sato at Tokyo University.[272]

Capture Projects

Clean Coal Technology (CCT) projects in Japan

In Japan, coal consumption has rapidly increased since 1998, with gross thermal power generation efficiency increasing from approximately 38% to 41% over the past dozen or so years. In addition, emissions of CO2, SOx and NOx per generated power unit from thermal power plants are far below the level of other industrialized countries. This is due to ever advancing Clean Coal Technologies (CCT), of which Japan claims superiority.

The R, D & D on CCT is mainly driven from NEDO and JCOAL, with power utility companies and gas, oil and coal companies engaged.

The report "Clean Coal Technologies in Japan – JCOAL – January 2007" gives a comprehensive and up-to-date overview of the status of CCS technology and projects in Japan.[273]

---

[267] Presentation by Akio Ito, RITE, Feb. 25, 2008.
[268] www.kanso.co.jp/kankyo_j/k_kenkyu/co2_eng.html
[269] www.rite.or.jp/English/welcome/Project/ocean.html
[270] Proceedings from "International Symposium on CO2 Storage", Organized by National Maritime Research Institute, Tokyo March 5, 2007.
[271] www.co2captureandstorage.info/project_specific.php?project_id=47
[272] Conversation with Dr. Ohsumi, RITE
[273] www.brain-c-jcoal.info/cctinjapan-files/english/cct_english.pdf

Nanko Natural Gas Pilot Plant

KEPCO and MHI has collaborated on small scale CO2 capture from KEPCO's Nanko power plant[274] in Osaka since 1991. The CO2 capture capacity is only 2 ton/day, but the project has been invaluable development of new solvents, such as MHI's patented and commercial KS1 solvent.

Kurosaki Chemical Plant[275]

KEPCO and MHI further also collaborate on a chemical plant in Kurosaki with a CO2 capture capacity of nominal 283 ton/day and maximum 330 ton/day. The feed gas is flue gas from natural gas or heavy oil boilers. The start-up of this project was in October 2005.

Mihara 400 MW Power Plant

MHI is constructing a 400 MW t Mihara with a capacity of treating 1,2 million Nm3 gas per hour.

Matsushima Coal Power plant[276]

MHI has installed CO2 capture facility on J-Power's coal-fired Matsushima Power Station in Nagasaki. The capture is limited at 10 tons/day, but the focus has been on understanding the long-term effects of impurities on the amine scrubber process. The project has been operating more than 4000 hours since July 2006.

Sumitomo Chemicals Plant, Chiba[277]

The Sumitomo plant features a Fluor Econamine FG CO2 scrubber system for the treatment of flue gases generated from on-site gas boilers and coal/oil boilers. The scrubber produces around 150-165 t/d food-grade CO2. The scrubber plant was licensed by Fluor and has been operating since 1994. It was engineered and constructed by Mitsubishi Heavy Industries on a turn-key basis under the Fluor license and supervision. The maximum flue gas volume is ~36,500 Nm3/h.

Nippon Steel CO2 capture project

Nippon Steel, in collaboration with RITE, MHI and KEPCO on a CO2 capture project from Nippon Steel's facilities in Kimitsu Works. CO2 is separated in an absorption process from a discharge gas containing 22% CO2 and reused in the process. The capacity is 20ton/day and the objective is to develop and test e.g. absorbents to reduce the capture cost to almost half.

The project started in 2004 and is planned to continue until 2008.

EAGLE – Coal Energy Application for Gas Liquid & Electricity[278] [279]

J-Power launched a 3-year program (fiscal 2007-2009) to develop a technology for separating and capturing CO_2 from the coal gasification process, in collaboration with the New Energy and Industrial Technology Development Organization (NEDO). This development will be conducted at J-Power's Wakamatsu Research Institute in Kitakyushu, Fukuoka Prefecture.

J-Power and NEDO have worked on a project named "Coal Energy Application for Gas, Liquid and Electricity" (EAGLE) since 1995 to establish a coal gasification technology that produces synthetic gas efficiently and economically. When developed, the new CO2 separation and capture system will be installed in the EAGLE pilot plant with a coal processing capacity of **150 tons per day**. The plan is located on the site of the Wakamatsu Research Institute.

The research objective of the program is to develop:

1. the most advanced oxygen-blown, single-chamber, two-stage entrained-flow gasifier that can efficiently produce synthetic gas (CO+H2), and
2. technology for advanced purification of synthetic gas for fuel cells, through the removal of particulate matter, hydrogen sulfides, halogen compounds, and other impurities, and 3) technology for CO2 separation and collection from coal-gasification gas.

[274] www.kepco.co.jp/english/rd/topics/topics_2.html
[275] www.mhi.co.jp/mcec/product/recov_co2/experience/japan.html
[276] www.mhi.co.jp/mcec/product/recov_co2/experience/demo.html
[277] www.sumitomocorp.co.jp/english/environmental_e/img/env2005e.pdf
[278] www.jpower.co.jp/english/ir/pdf/2007-06.pdf
[279] www.nedo.go.jp/kankobutsu/pamphlets/kankyo/gaiyoue_2008.pdf Page 8

Setting the CO2 recovery rate at around 90 percent in consideration of costs, the company aims to increase the CO2 purity to 99 percent or more.

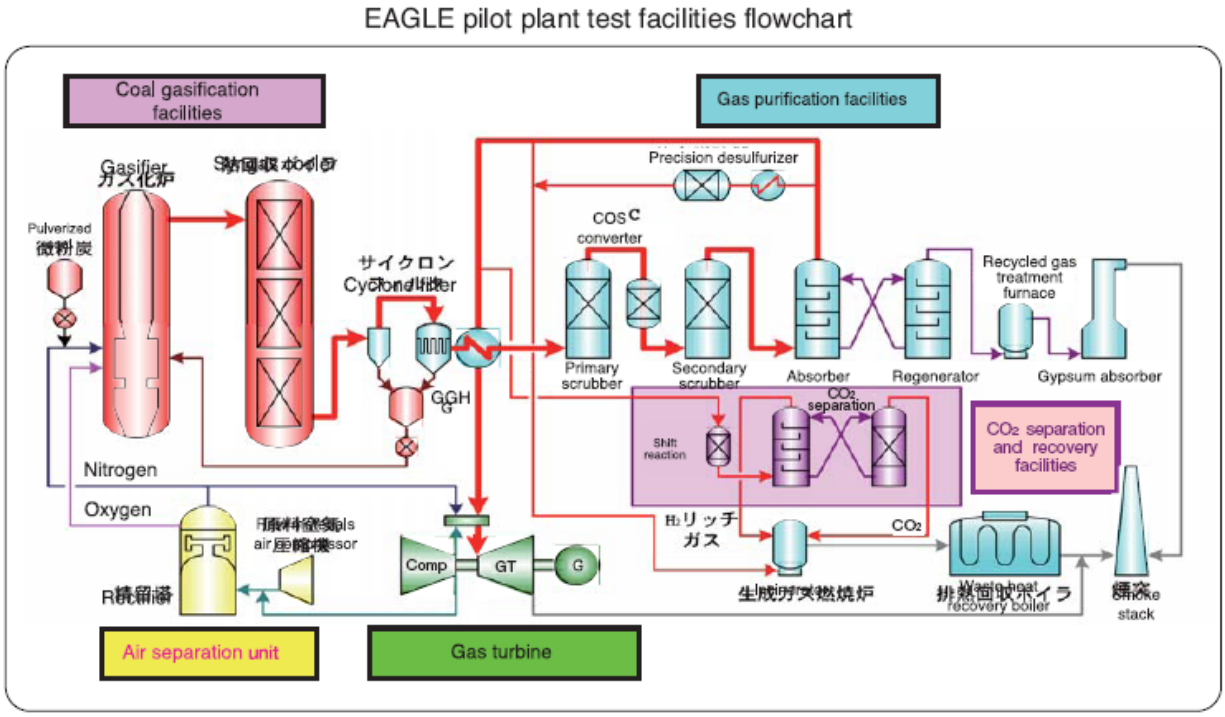


Figure 25: Outline of the Eagle plant. Source NEDO[280]

Mikawa CO2 capture pilot plant by Toshiba[281]

Toshiba Corporation announced in December 2008 that it will install a post combustion capture pilot plant at Sigma Power Ariake Co. Ltd.'s Mikawa Power Plant, in Omuta City, Fukuoka, Japan. Construction of the plant is scheduled to start in spring 2009, and the commissioning and validation testing is expected to begin in August.

The Mikawa pilot plant is designed to capture 10 tons of CO2 a day from the boiler flue gas of the 47,5 MW coal fired thermal power plant.

Beyond proving system performance, plant verification will encompass a wide range of tests aimed to accumulate knowhow required for the design of utility-scale power plant application, says Toshiba. These include the effects of the thermal power plant flue gas contents, such as SOx, on the operation of the system when integrated with other power plant equipment, such as turbines and boilers.

International CCS Projects with Japanese participation

Japan-China EOR project

The governments of Japan and China have agreed on May 7th, 2008, to cooperate in carrying out a project to inject CO_2 emitted from a thermal power plant in China into an oil field. [282]

According to the project plan, from 1 to 3 million tons of CO2 will be captured annually from the Harbin Thermal Power Plant in Heilungkiang Province and potentially other plants elsewhere. It will then be transported by pipeline about 100 km to China's largest oil field – the Daqing Oilfield, and injected and stored into the oilfield.

CCS alone will be unprofitable, but the two countries have determined that it makes financial sense if CCS is combined with an oil-exploitation (EOR) project. More than 40 million tons of oil is produced from the said oilfield annually. The project is expected to increase this figure by 1.5 to 2 million tons. It reportedly will also become possible to keep more than 150 million tons of CO_2 into storage in the future.

[280] www.nedo.go.jp/kankobutsu/pamphlets/kankyo/gaiyoue_2008.pdf
[281] www.toshiba.co.jp/about/press/2008_12/pr0301.htm
[282] Nikkei financial news, May 3, 2008

Under the plan, more than one million tons of CO2 annually from will be transferred to the Daqing Oilfield, about 100 km from the plant, and will be injected and stored in the oilfield. The viscosity of crude oil there is thick but will be decreased by injecting CO_2, making it easier to exploit the oil.

From Japan, the METI-affiliated Research Institute of Innovative Technology for the Earth (RITE) and other organizations plan to take part in the project, in addition to Toyota Motor Company and JGC Corp. From China, China National Petroleum Corporation and other organizations will participate. The two sides will begin negotiations on cost-sharing.

The project will cost 20 to 30 billion yen and is intended to start in 2009.

According to the Ministry of Economy, Trade, and Industry (METI), if realized, it will be the first case of injecting CO2 from a thermal power plant into an oil field.

Yantai IGCC

The Yantai 400 MW Integrated Gasification Combined Cycle (IGCC) project in Yantai, Shandong Province, has been included in China's 10th 5-year plan as a key element in developing and deploying clean coal technologies. Feasability studies were conducted since 1995, and the project is now under construction. The European Commission regards this project as a great opportunity to promote European technology in China and several international subcontractors are involved. Japan, trough Mitsubishi Heavy Industry, is also engaged in the project[283].

The State Power Grid Company, Shandong Electric Power Group, Shandong International Investment and Trust Co., and Yantai Power Development Company form a Special Purpose Company to build, operate and manage the Yantai IGCC plant.

The total project cost is estimated to be about $ 420 million, of which 20% will be financed by equity, 75% by a domestic loan and (China has requested) the balance by a $ 15-18 million GEF grant. The Chinese Government has decided bear the bulk of the $ 120 million cost difference between constructing a comparable PC plant (the least cost option) and the IGCC plant[284].

White Tiger CCS project in Vietnam[285]

The planned White Tiger CCS project was the first CDM proposal based on CCS (registered Sept. 2005) and also the first commercial CCS project in Asia. The project includes capture of CO2 from a Combined Cycle Gas Turbine (CCGT) plant and injecting into the White Tiger oil field in Vietnam. This is a join project between Mitsubishi Heavy Industry and Marubeni with Vietsovpetro as local partner..

The annual capture is up to 4.6 million ton CO2/year and injection is planned across 144 km pipeline into an oil well at 4000m depth into the active oil/gas reservoir.

The project start is planned for 2010. If so, further expansion may be 7.4 million to CO2/year from 2014 to 2016. It should be noted that the proposed methodology is not yet approved by UNFCCC as eligible CDM.

Bintulu CCS project in Malaysia[286]

This project is also a CDM proposal, submitted January 2006, and includes capture of CO2 from natural gas (containing 3-6% CO2) from an LNG plant in Bintulu, Malaysia. The project is a join project between Mitsubishi Heavy Industry, JGC and Petronas.

The annual capture is 3 million ton CO2/year and injection though 120 km pipeline into an sub-sea saline aquifer at 1,400 meter depth.

The project is planned to start up in 2011. It should be noted that the proposed methodology is not yet approved by UNFCCC as eligible CDM.

The CS Energy Oxy-Fuel Project ("Callide Project")[287]

The Callide Oxy-fuel project is described in the Australia chapter.

The project is headed by CS Energy Ltd (CSE), and Japanese partners include IHI Corporation, J-Power and Mitsui & Co., plus Schlumberger and Xstrata Coal. Of a total project cost of U$206, the Japanese partners contribute at least $30 million.

[283] www.berr.gov.uk/files/file20018.pdf

[284] http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2003/08/19/000094946_0308190402026/Rendered/PDF/multi0page.pdf

[285] cdm.unfccc.int/UserManagement/FileStorage/AM6CJE7R0VH1DPTZ79LW4QQ26ZTQ04

[286] cdm.unfccc.int/UserManagement/FileStorage/VK1I5G0CSRZYB8JCSMF1420747JTS7

[287] www.csenergy.com.au/research_and_development/oxy_fuel.aspx

Construction at Callide A Power Station started November 2008, and will be followed by electricity generation from the oxy-fuel process in 2010 and geo-sequestration in 2011. The demonstration project will continue for up to five years, during which time the project team will assess the potential commercial applications of oxy-firing technology to other plant.

The project has been labelled a project of significance by the Asia-Pacific Partnership on Clean Development and Climate.

JODCO (UEA)

Mitsubishi Heavy Industries is involved in the JODCO EOR Project in Abu Dhabi with JODCO Japan Oil Development Co., Ltd. (JODCO)[288]

JODCO plans to recover the CO2 from existing power plants for injection in the Upper Zakum Field, thereby minimising its emission. It was reported[289] that JODCO was planning to utilise this CO2 injection technique on the Upper Zakum Field in 2004-05. This is not confirmed.

If it proves to be successful, the technology will be replicated and applied to other fields. The present project will be the first time that CO2 capture from power plants, followed by application in an enhanced oil recovery operation, will have been used in a commercial situation. If applied to all oil fields in the UAE, 15 million ton CO2/year could be sequestered in this way, equating to 15% of the overall CO2 reduction required for Japan under the Kyoto Protocol.

CCS TECHNOLOGY COMPANIES IN JAPAN

The following list contains the most active technology manufacturer and technology user companies in Japan. It should be noted that other power companies and gas/oil and chemical industries are carefully monitoring governmental policies for CO2 reduction. They are positioning themselves with respect to applying technologies and trading schemes for meeting expected tougher emission reduction requirements. However, for the time being, few are actively developing or doing R&D on CCS technologies apart from the companies listed.

Mitsubishi Heavy Industries (MHI)[290]

MHI is the leading technology provider in Japan with respect to port-combustion carbon capture technologies, with a number of demonstration plants ranging back to early 1990s. The current technology for amine absorption is based on using commercial technologies based on their developed absorbent KS-1.

MHI is involved in most of the commercial CO2 capture projects and installations in Japan; including the Nanko Test facility; the Mihara 400 MW Test Facility; the Matsushima Coald Fired Demonstrating Plant and the Chemical plant in Kurosaki.

MHI active participation in CCS projects spans the following regions:

- Asia: MHI has delivered CO2 capture technologies for chemical plants and power stations in Malaysia (200 ton/day) and India (three sites each of 450 ton/day)
- Middle East: The following Middle East countries are actively working for the feasibility study of CO2 capture and EOR; Saudi Arabia, Abu Dhabi, Dubai, Oman, Qatar. Some of then are already established the organization to proceed with the CO2 capture and EOR projects and these projects are near the implementation stage.
- North Sea: MHI received Front End Engineering and Design (FEED) order for the Norwegian Kårstø CO2 capture facility August 2008[291].
- MHI signed in February 2009 a license agreement for its carbon dioxide (CO2) recovery technology with Samsung Engineering Co., Ltd., a major engineering company in Korea. Samsung Engineering will use MHI's proprietary "KM-CDR Process" technology in the CO2 recovery system which Samsung will construct at the Phu My Fertilizer Plant of PetroVietnam Fertilizer and Chemicals Corporation (PVFCCo), a petrochemical company in Vietnam.
- On June 22, 2009, Mitsubishi Heavy Industries (MHI) and Mitsubishi Corporation (MC) announced that they will provide the feasibility study for ZeroGen project in Australia, and to provide the technologies for both the IGCC and the CCS units.

[288] jodco.co.jp
[289] www.co2captureandstorage.info/project_specific.php?project_id=36
[290] www.mhi.co.jp/mcec/product/recov_co2/experience/index.html
[291] www.mhi.co.jp/en/news/story/0808201251.html

- In June 2009, MHI was selected as technology provider of carbon dioxide (CO2) capture technology by E.ON UK for its application to the UK Government's CCS demonstration competition. MHI, in consortium with Foster Wheeler Energy Limited in the UK, has received an order from E.ON UK plc, a leading UK energy company, to carry out the pre-front-end engineering design (pre-FEED) of a CO2 capture plant planned for a coal-fired power station[292].
- MHI and E.ON Energie AG will jointly test technology for recovering carbon dioxide (CO2) from flue-gas emissions from a coal-fired power generation plant in Germany. The CO2 recovery test plant to be added to E.ON Energie's existing plant will adopt MHI's technology for absorbing and desorbing CO2 from flue gas using its proprietary KS-1 solvent, and will be capable of capturing 100 metric tons of CO2 per day (flue-gas flow rate: 20,000 cubic meters per hour). The recovery plant operation will commence early in 2010[293].

IHI – previously Ishikawajima-Harima Heavy Industries[294]

IHI is manufacturing consortium covering a range of products including energy related equipments such as boilers, coal gasification, total environmental protecting facilities, renewable energy, fuel cells, nuclear power station, etc.

Most relevant for CCS are large capacity coal fired boilers with ultra high efficiency ("ultra super critical") and steam temperature up to 620 degree Celsius. These USC boilers have low CO2 emission, but additional CCS is required for "near zero emission fossil fuel power station". IHI is introducing oxyfuel boiler technology applicable for newly built and existing boilers.

IHI is heavily involved in the Japan-Australia Callide Oxyfuel Project cooperating with CS Energy of Australia and JCOAL, JPOWER of Japan. This project is to realize world first near zero CO2 power station with geo-sequestration. Governmental funds from both Japan and Australia have already decided, and project will start officially in the mid of 2007. Modified boiler for oxyfuel will start to operate in 2009. Operation with geo-sequestration for four years is scheduled during 2011-2014. IHI expects to be the first company in the world to generate electrical power from a near zero CO2 unit.

In the future, IHI expect that needs of CO2 geo-sequestration will increase much, and they consider that EOR is the easier case to apply on commercial bases, but CDM will be also considered by IHI. [295]

JGC[296]

JGC is a Japanese engineering company specializing on oil and gas field development and utility business. They have about 2,000 employees, serving a number of offerings including consulting, planning, basic and detailed design, materials and equipment procurement, construction, commissioning, operation and maintenance services for various plant and facilities.

JGC has been very active in the Middle East region (Japan's major source for oil and gas), and are among others participating in the Al Salah project with project engineering, procurement and construction.

JGC has been promoting activities in a wide range of areas in order to attain clean energy development and green power generation, with the clear aim of contributing to conservation of the global environment. In the field of natural gas, JGC is implementing activities to construct a DME (Dimethyl Ether) plant. In the oil area, JGC had constructed the IGCC (Integrated Gasification Combined Cycle) power plant that gasifies residual oil and reforms it into a clean power generation fuel to generate power by combined cycle. Further, JGC produces liquid fuel from crude oil to be used for the high temperature combustion gas turbine, and GEFINERY, the combined power generation system, has been attracting attention as a new technology meeting the needs for a highly efficient power generation system. In the power generation field, JGC has constructed the large-scale combined cycle power generation plants and to demonstrate the new clean fuel for power generation. Additionally, JGC is emphasizing Biomass Slurry Fuel (BSF) as a clean power generation fuel, reformed from wood biomass for practical application and contributing to promoting the wide use of green power.[297]

CCS related activities and future plans of JGC[298]:

Engineering, Procurement and Construction (EPC) of CCS related plants

JGC participated in the project development of the In Salah project in Algeria including EPC of the gas processing plant. Approximately 1.2 M t-CO2/y has been injected and stored through this CCS project since 2004. In 2005, a joint venture including JGC and KBR has been awarded the Front-End Engineering Design (FEED) and an option for

[292] www.mhi.co.jp/en/news/story/0906181297.html
[293] www.mhi.co.jp/en/news/story/0807031245.html
[294] www.ihi.co.jp
[295] Keiji Makino, Executive Chief Engineer, Energy & Plant Operations, IHI. Email conversation Feb. 20, 2007.
[296] www.jgc.co.jp
[297] www.jgc.co.jp/en/02bisdmn/05cleanenergy_power/index.html
[298] Tsukasa Kumagai, Group leader, Industrial Project Division, JGC Corporation. Email conversation March 2, 2007.

the Engineering, Procurement and Construction Management (EPCM) Contract for the "Greater Gorgon Downstream Liquefied Natural Gas (LNG) Project", which will be constructed at Barrow Island in Western Australia and install CCS facilities to inject and store CO2 separated from the natural gas.

Development of CCS projects

JGC has been conducting a feasibility study of 3 M-tCO2/y CCS project in Malaysia in cooperation with Petronas for 3 years. The CO2 source is the PETRONAS LNG complex located at Bintulu in Malaysia. Based on the feasibility study, JGC has submitted a new CDM methodology for CCS to the CDM executive board, together with Mitsubishi Research Institute. We will continue improving and revising this methodology to meet requirements coming from discussions being conducted internationally. As well as development of this CCS-CDM methodology, to promote the project design, JGC has been carrying out a research and development program supported by METI including development of technologies for site characterization, safety assessment, and monitoring and verification since 2006.

Development of CCS technologies

JGC is developing a new technology related to CO2 capture, specifically the High Pressure Acid Gas Capture Technology (HiPACT), as a member of an international consortium with BASF of Germany. This technology will save CCS cost by 20%. Also there are wide varieties of application, which is not only natural gas but also heavy hydrocarbon and coal gasification to obtain clean fuels from the gasification plant such as hydrogen, GTL, Methanol and DME including IGCC. That means HiPACT has a large potential for the CCS project. JGC are now ready for demonstration and our target to commercialisation is the end of 2012.

Japan Coal Energy Center (J-Coal)[299]

JCOAL is the non-profit organization, and is supervised by METI. JCOAL (Japan Coal Energy Center) and CCUJ (Center for Coal Utilization, Japan) were integrated on April 1st, 2005, and started the activities as JCOAL, the new and the only non-profit organization in Japan which covers consistently all fields from the coal mining to the field of coal utilization. The main activities of JCOAL are subsidized by METI and NEDO and supported financially and technically by more than 100 private companies and organizations concerning on coal, such as electric power companies, iron and steel manufacturers, general trading companies, coal producers, engineering companies, heavy industrial manufacturers and so on.

With respect to CCS, JCOAL is engaged in three areas; Hydrogen from Coal with CO2 Separation[300]; Oxy-fuel Combustion and CO2 Geosequestration in Coal Seams. JCOAL was lead in the JCOP project described elsewhere in this report[301].

Tokyo Electric Power Company (TEPCO)[302]

TEPCO was early involved in both ocean sequestration, and in CO2 adsorption research (Pressure Temperature Swing Adsorption technique project started in 1997), but both these projects were terminated some years ago[303]. Apparently, very little research relate to CCS is ongoing directly under TEPCO. TEPCO is engaged in several CDM projects.

Japan Petroleum Exploration Company (JAPEX)[304]

JAPEX is an important Japanese oil and gas exploration and production company with about 5,400 employees. JAPEX took part of the early exploitation of the very few Japanese offshore petroleum resources, and later moved on to Asian and Russian fields.

JAPEX is a supporter for development, demonstration and testing of CCS technologies, especially related to underground storage. JAPEX was been involved in the Nagaoka CO2 Injection Pilot Project to develop technologies for monitoring the behaviour of injected CO2 using a time-lapse 3D (or 4D) seismic method. JAPEX is also participating in R&D projects for CO2 injection site selections, well planning, reservoir simulations, stratigraphic analyses, rock physics experiments, etc. to comprehensively develop the technologies relevant to CCS.

J-Power – previouslt EPDC[305]

J-Power, earlier known as EPDC (Electric Power Development Corporation) is mainly a wholesale producer of electricity in Japan. Since 1990, J-Power has aggressively pursued business opportunities aboard related to power

[299] http://www.jcoal.or.jp/index-en.html
[300] http://www.jcoal.or.jp/cctinjapan_en/cctinjapan_en.html
[301] http://www.jcoal.or.jp/overview_en/kankyou.html
[302] www.tepco.co.jp
[303] Private conversation with Mr. Kentaro Endo, METI
[304] www.japex.co.jp/en
[305] www.jpower.co.jp/english

generation projects, and the last decade also in projects for renewable energy, forestation and other projects with CO2 emission credit opportunities.

J-Power is partner in the Nagaoka CO2 injection project in Japana, and is also leading the technology development on IGFC (Integrated Coal Gasification Fuel Cell Combined Cycle). IGFC involves triple combined cycle power generation using three power generation systems; fuel cells, gas turbines, and steam turbines driven by fuel gas made by a coal gasification process. If this extremely advanced coal utilization system is realized, it will enable a power generation efficiency rate of about 60%, and CO2 reduction would be down to about two-thirds of conventional levels.[306]

J-Power is also an integral part of the project management aspect of the Callide Oxyfuel Project in Australia, bringing more that 50 years of experience in electricity generation and that knowledge of R&D activities for clean coal technologies from Japan.

Japan Oil Development Company (JODCO)[307]

JODCO was established in 1973 between 9 international major oil companies to develop oil fields in middle east (Abu Dhabi).

JODCO, in collaboration with by Mitsubishi Heavy Industries, has developed what is claimed to be a novel technique based on CO2 injection for boosting oil production from wells characterized by diminishing output. This is to be tried for the first time by JODCO as part of its operations on the Upper Zakum Field in the United Arab Emirates.

The reported project was to be started 2004-05, but no further information about project status has been found.

Toshiba Corporation[308]

On October 1 2008, Toshiba established a new CCS development and promotion organization, and will seek to accelerate development of its carbon capture technology by installing a pilot plant at Sigma Power Ariake Co. Ltd.'s Mikawa Power Plant, in Omuta City, Fukuoka Prefecture. Construction of the plant is scheduled to start in spring 2009, and the commissioning and validation testing is expected to begin in August.[309]

Mitsui & Co. Ltd.

Mitsui taps an expanding global network to access strategic information and harness business engineering capabilities. Main businesses include sales, manufacture, export / import, international trade and services in the following fields: metal products & minerals, machinery, electronics & information, chemicals, energy, consumer products & services and logistics & financial markets. Mitsui is also diversifying services, exploring for and developing natural resources, making commercial investments, developing technologies in new businesses and much more.

Mitsui is primarily a trading company, but has been engaged in several power plant projects in Japan and aboard. They are a partner in the Callide Oxyfuel project in Australia.

CCS RESEARCH AND DEVELOPMENT

Much of the public R&D on global warming countermeasures is conducted through RITE – Research Institute for Innovative Technologies for the Earth. In addition, substantial research is done by the private/publicly owned energy utilities - specifically by CRIEPI (Central Research Institute of Electricity Power Industry), and the large industry conglomerates such as Mitsubishi Heavy Industry, Ishikawajima Heavy Industries etc.

NEDO and METI are the main public contributors to R, D &D funding for CCS technologies; through various projects.

Research Institute for Innovative Technologies for the Earth (RITE)[310]

RITE was established in 1990 for the purpose of developing technologies mitigating global warming. At present about a hundred and sixty members are working in the following research areas:

[306] www.jpower.co.jp/english/company_info/about/kaisya/pdf/e2006.pdf
[307] www.jodco.co.jp/
[308] www3.toshiba.co.jp/power/index3.htm
[309] www.toshiba.co.jp/about/press/2008_12/pr0301.htm
[310] www.rite.or.jp

The *System Analysis group* makes analysis and software models to analyse and qualify emission reduction measures around the world. Their computer model DNE21+ is used to find minimum cost measures to meet emission reduction targets for a simulation period up to 2050.

The *Chemical Research Group* is researching on and developing chemical technologies for CCS; including capture technologies in form of membrane (polymer, inorganic and hybrid) and chemical absorption. There is also research on chemical fixation of CO2 in form of carbonates.

The *CO2 Sequestration Research* group is developing aquifer storage technologies for CO2 through laboratory experiments and simulations; and on-site projects such as the Nagaoka projects and others. This group has also been world leader on ocean deposition research.

The *Plant Research Group* is working on forestation and agriculture countermeasures against global warming, with extensive collaboration with Australia.

With respect to CCS research, RITE is probably the leading institute in Japan, and they have established an extensive global network, including with Norway. NTNU and RITE signed in 2006 a MoU for general collaboration on CO2 capture technologies. Collaboration on amine absorption has been suggested, but is tricky due to competitive interests; while collaboration on membranes (Prof. May-Britt Hagg and Dr. Kazama) is very promising.

For the future, RITE is signalling a continued strong focus on aquifer storage, but may phase out off ocean sequestration, although there is continued governmental funding on this area.

Central Research Institute of Electric Power Industry (CRIEPI)[311]

CRIEPI is the research institute for the 10 large electric utilities in Japan, and was from late 1980's engaged in CO2 handling research and policy issues. CRIEPI was initially the leading driver for ocean sequestration research before RITE took over mid 1990's. CRIEPI today is mainly engaged in socio-economic analysis and policy assessment for CO2 issues, including emission trading, and has little direct R&D on CCS technologies[312].

Other research institutes and Universities

Various other universities and research institutes in Japan are working on aspects of CCS technologies; mainly as partners to the leading technology companies or with RITE. These include Hokkaido University, Waseda University (Tokyo), Akita University and Kyoto University on aquifer deposition and ECBM. Several universities are collaborating with e.g. MHI and IHI on technologies for oxy-fuel/pre-combustion technologies and on capture technologies.

Private sector R&D

The 10 Japanese electricity utilities, led by TEPCO and KEPCO, have conducted significant R&D in the areas of CO2 capture technologies over the last two decades. This R&D has mainly been focusing on adsorption, absorption and membrane technologies, and recently (last 5-7 years) also on pre-combustion methods such as oxy-fuel and fuel reforming.

Examples include:

- TEPCO's CO2 capture from COM (Coal-Oil-Mixture) fired flue gas using chemical solvents, and also PTSA (pressure and temperature swing adsorption) with a zeolite adsorbent. 1000 m3 N/hr of the flue gas was treated.
- Tohoku Electric Power Company test of CO2 capture from coal-fired flue gas using the PSA technique with a zeolite adsorbent. 1,700 m3 N /h of the flue gas from 1000 MW coal-fired power plant was treated.
- KEPCO's test of amine absorption, treating 600 m3 N/hr of flue gas from 600 MW LNG-fired power plant at the Nanko power station. At the beginning of the test Fluor Daniel's Econamine FG □solvent was used but later KS□ solvents were used. The KS□ solvents were developed by KEPCO and Mitsubishi Heavy Industry.
- Hokuriku Electric test plant treating 50 m3 N/hr of flue gas from a coal-fired power plant at the Toyama-Shinko power station. The pressure swing adsorption technique with a zeolite on moving bed was used.
- TEPCO and Tohoku EPC collaborated on a laboratory-scale test for R&D on adsorbent with higher performance and lower pressure loss using a test facility treating 5-10 m3 N/hr of flue gas.

[311] criepi.denken.or.jp/en/

[312] Conversation with Dr. Ohsumi, RITE and with Dr. Sugiyama, Leader - climate policy project, CRIEPI.

- Various tests on oxyfuel combustion, the Benfield process, hybrid processes combining cryogenic separation and pressure swing adsorption or membrane separation had been studied by other electric power companies.
- Furthermore, R&D on CO2 fixation and utilization, with approaches ranging from biological processes to catalytic hydrogenation reactions, has been conducted.

A good reference to detailed results and conclusions from these experiments is given in a paper by Takahiso Yokohama from CRIEPI – the research institute for the Japanese electricity utilities.[313]

[313] services.bepress.com/eci/separations_technology_vi/7/

Australia

GOVERNMENTAL PROGRAMS AND STRATEGIES

General policy

Australia currently is responsible for only about 1.5% of the world's total fossil fuelled-based carbon emissions (ranking it 14th in the world), but its reliance on its coal resource for power generation has resulted in a very high per-capita energy-related carbon emission for the country.

In a major shift of policy in late 2007, the Labour Government led by PM Kevin Rudd government ratified the Kyoto protocol on March 11th 2008[314], and issued their Initial Report under the Kyoto Protocol[315] one year ahead of the deadline set by UN. The government thus demonstrated its strong will and ability to address domestic and international climate change challenges. In May 2009, the government announced that The Carbon Pollution Reduction Scheme (CPRS), a cap and trade system, will be phased in from 1 July 2011, delayed by one year 'to manage the impacts of the global recession.' A one year fixed price period will be introduced, with permits costing $10 per tonne of carbon in 2011-12, with the transition to full market trading from 1 July 2012.

Australia's Kyoto target is 108% of 1990 levels by 2008 to 2012[316]. The former government's confidence in meeting that target was initially not shared with the current. However, the report *Tracking to the Kyoto Target*[317], shows that Australia's greenhouse gas emissions are projected to reach 599 million ton annually (Mt CO2-e) over 2008-12, which is 108% of the 1990 level. Australia has also committed to reduce carbon pollution by 25 per cent of 2000 levels by 2020 if the world agrees to an ambitious global deal to stabilize levels of CO2 equivalent in the atmosphere at 450 parts per million or less by 2050.

Australia is entering international agreements to meet its reduction targets through emission allowance trading, such as the recent agreement (March 2008) with Papua New-Guinea on a Forest Carbon Partnership[318]. The Rudd government is pushing for a national Emission Trading Scheme[319] within 2010, and is considering how to integrate this system in an international context.

On May 20th 2008, the Australian Government has released draft legislation for consultation which will establish the world's first framework for CO2 capture and geological storage (CCS). The CCS legislation establishes access and property rights for the injection and storage of greenhouse gases into sub sea reservoirs in Commonwealth waters (more than three nautical miles offshore).

On 21st November 2008 the Australian Federal Parliament approved the Offshore Petroleum Amendment (Greenhouse Gas Storage) Act 2008[320]. The legislation applies to waters between the 3 mile nautical limit and outer limit of continental shelf.

Private sector engagement.

Aside from self-interest in meeting shareholder expectations, or pursuing energy efficiency, industry accepts there will be a carbon constrained future (of some form or another) and therefore takes theses types of schemes very seriously. In the current debate on carbon trading it has been raised that uncertainty about future carbon policy may be limiting such investment, but this is different to saying there is currently no incentive. As an example, all the Low Emission Technology Demonstration Fund (LETDF) projects are predominantly financed by the private sector (roughly 2/3rd private to 1/3rd public), and the private sector has already matched the ~A$265 million with at least double that amount.

Furthermore, the Coal21 Program and the active participation in the Cooperative Research Centre (CRC) partnerships indicated a strong commitment from the private sector in contributing to solve the CCS challenges.

[314] www.theage.com.au/news/national/rudd-ratifies-kyoto/2007/12/03/1196530553722.html
[315] www.climatechange.gov.au/projections/pubs/tracking2007.pdf
[316] www.climatechange.gov.au/inventory/publications/pubs/unfccc-report.pdf
[317] www.greenhouse.gov.au/projections/index.html
[318] carbonfinance.org/Router.cfm?Page=FCPF&ft=About
[319] www.greenhouse.gov.au/emissionstrading/about.html
[320] www.comlaw.gov.au/comlaw/Legislation/Act1.nsf/0/EB22EF0E7299CDDBCA25750B0077109C?OpenDocument

Australian Coal Association Low Emission Technologies Ltd (ACALET)[321]

Australian Coal Association – an association of private industry - commenced in 2003 its 1 billion A$ Coal21 Programme[322], which is a partnership between the coal and electricity industries, unions, federal and state governments and the research community to develop clean coal strategy – including gasification and oxy-fuel and other CCS related technologies. The main activity is to develop a National Action Plan, to identify CCS technologies and to assess the potential abatement that could be achieved and describes the actions that need to be taken if they are to be deployed commercially in Australia.

The associated Coal21 Fund[323] is a voluntary levy on its members. The original levy of A$ 300 million is now increased to A$1 billion to develop CCT technologies including CCS over the next 10 years.

As of July 2009, the COAL21 Fund has made major commitments to the following active and in-development carbon capture and storage research projects:

- up to A$300 million for a Queensland Integrated Gasification Combined Cycle (IGCC) project, including $26 million for a feasibility study for the ZeroGen Project
- A$68 million to the Callide Oxyfuel Project in Queensland
- A$50 million for a post combustion capture project in New South Wales, starting with the Munmorah PCC Project project
- A$20 million for Queensland geosequestration initiatives

The COAL21 Fund has also given in-principle funding of A$75 million to the research and development program of the National Low Emissions Coal Council, matching the A$75 million commitment of the Commonwealth government.

The Australian Construction, Forestry, Mining and Energy Union has called for a target of 5 per cent of electricity to be generated from low emission coal technology by 2020, in order to protect the coal power station industry and coal miners' jobs. The Union suggests that the coal industry increases its levy for new technologies from A$0.20 per ton of coal now to A$1 per ton.

Public CCS funding initiatives and partnerships

The Global CCS Initiative (GCCSI)[324]

The Australian initiative the *Global CCS Institute (GCCSI)* was formally launched[325] April 16, 2009 to speed up the development of carbon capture and storage technology. The Institute is headquartered in Australia, and provides international policy and management oversight to the goal of delivering at least 20 commercial scale CCS plants around the world by 2020. The Australian Government will contribute up to $100 million per annum towards its operation.

The Institute will aim to accelerate carbon projects through facilitating demonstration projects and identifying and supporting necessary research - including regulatory settings and regulatory frameworks.

The objectives of the initiative are:

- The Global CCS Institute will draw together information, knowledge and expertise to build a much-needed central base.
- It will play a pivotal role in facilitating the development and deployment of safe, economic and environmentally sustainable commercial-scale CCS projects.
- The Global CCS Institute will advise on the technologies that will capture, transport and store emissions, and provide expert insight on the costs and benefits of carbon solutions and the operational and legislative requirements needed to achieve success.
- It will work collaboratively with governments, non-government bodies and the private sector to build confidence in CCS and help drive the international momentum needed to provide a solution to the urgent problem of climate change.

The Global CCS Institute has received unprecedented international support, with more than 20 national governments and over 80 leading corporations, non-government bodies and research organizations signing on as foundation members or collaborating participants. The list of founding members is found here[326].

[321] www.newgencoal.com.au
[322] www.coal21.com.au
[323] www.coal21.com.au/Media/COAL21%20Fund%20Announcement.pdf
[324] www.globalccsinstitute.com
[325] www.pm.gov.au/media/Release/2009/media_release_0913.cfm
[326] www.globalccsinstitute.com/downloads/The_Global_CCS_Institute_Founding_Members.pdf

It has appointed Mr Nick Otter as interim CEO and recently appointed Mr James D. Wolfensohn to the position of Chair of the International Advisory Panel of the Global Carbon Capture and Storage Institute.

Low Emission Technology Demonstration Fund[327]

The Australian Government provided in 2005 funding through the Low Emissions Technology Demonstration Fund (LETDF) to help Australian firms commercialize world-leading low emissions technologies. The objective of the $500 million LETDF was to demonstrate the commercial potential of new energy technologies or processes or the application of overseas technologies or processes to Australian circumstances to deliver long-term large-scale greenhouse gas emission reductions, through:

- the demonstration of the commercial potential of new energy technologies or processes,
- the application of overseas technologies or processes to Australian circumstances.

The LETDF is managed by the Department of Resources, Energy and Tourism. The Fund aims to combat climate change whilst ensuring Australian companies remain competitive in the development of innovative energy technologies.

Round One of the LETDF closed on 31 March 2006, no further funding rounds will be held.

5 projects have been granted a total of A$330 million, triggering projects with total accumulated investments of **just over A$3 billion**. The current projects are:

- Chevron's Gorgon CO2 Injection Project. Public funding is A$60 million of a total project cost of A$841.3 million.
- CS Energy: Oxy-firing demonstration and carbon sequestration project. Public funding is A$50 million of a total project cost of A$188 million.
- HRL Limited: 400 MW Integrated Drying Gasification Combined Cycle (IDCC) Clean Coal Demonstration Project. Public funding is A$150 million of a total project cost of A$750 million.
- International Power: Hazelwood 2030 (Lignite Drying with Post Combustion Capture). Public funding is A$80 million of a total project cost of A$369 million.
- *Solar Systems Generation Pty Ltd: Large Scale Solar Concentrator Power Project. This is not a CCS project, but included here for completeness. Total project cost is A$420 million, with public funding of A$125 million.*

Asia-Pacific Partnership on Clean Development and Climate[328,329]

"Asia-Pacific Partnership on Clean Development and Climate" (AP6) was inaugurated January 12, 2006, and consist of Australia, India, Japan, China, Korea and US. Australia has taken a leading role in chairing the partnership and is the main financial contributor (India, China and Korea are receivers so far). The partnership includes 8 action plans, of which the Action plan on Cleaner Fossil Energy[330] is mostly relevant in this context. The Task Force identified a range of key advanced coal and gas technologies that can significantly reduce greenhouse gas emissions, air-borne pollutants and other environmental impacts, including Integrated Gasification Combined Cycle (IGCC), producing hydrogen from coal, and Ultra-Supercritical Pulverized Coal.

The Cleaner Fossil Energy action plan identifies 13 project proposals, of which a majority is on capacity building and assessing knowledge; including workshop and seminars, policy and guidelines etc. The CS Energy Oxy-fuel demonstration project, signed in March 28, 2008 by the Australian Government and the project partners, is the first project in the world to demonstrate the application of oxyfuel technologies in an existing coal power station and is recognized as an APP Flagship project.

Australia has committed a total funding of A$200 million over 5 years (A$ 70 million already allocated) to the AP6 projects; including:

- A$8 million for assessing post-combustion capture for coal-fired power stations in AP6 countries
- A$5 million for CO2 enhanced coal-bed methane
- A$3 million for CO2 capture and storage programs
- A$2 million for ultra-clean coal

---

327 www.ret.gov.au/energy/energy%20programs/low_emissions_technology_demonstration_fund/Pages/LowEmissionsTechnologyDemonstrationFund.aspx

328 www.dfat.gov.au/environment/climate/ap6

329 www.asiapacificpartnership.org

330 www.dfat.gov.au/environment/climate/ap6/action-plans/cleaner-fossil-energy.pdf

- A$500,000 for oxy-fuel combustion technology road-mapping and demonstration programs

Clean Coal Victoria[331]

Premier John Brumby of the State of Victoria in Australia announced May 8 a $110 million fund to establish new large-scale, pre-commercial CCS demonstration projects. The Premier also committed $12.2 million to create Clean Coal Victoria in the Latrobe Valley, an organization which aims to maximize the value of Victoria's brown coal resources. A further $5.2 million will go towards investigating carbon storage sites in the Gippsland basin to better understand carbon storage potential through research and modeling of the region's geology.

The CCS demonstration project is part of the Brumby Government's second generation Energy Technology Innovation Strategy (ETIS) and will take the Government's total clean coal investment to over $244 million since 2002. The aim of these investments is to assist power stations such as Loy Yang at Traralgon to reduce and ultimately eliminate their greenhouse gas emissions.

GeoScience Australia[332]

GeoScience Australia (GA) is a national agency for geoscience research and geospatial information, provides much of the primary national geoscience data, along with the State Geological Surveys, that is a crucial part of the information required for the determination of the storage prospects of Australia. GA is a major contributor to a number of the CO2 storage projects undertaken within CO2CRC. In addition, GA provides technical advice to DITR in relation to the regulation of CCS.

The GEODISC Project[333]

The A$12 million GEODISC Project (1999-2003) conducted within the Australian Petroleum Cooperative Research Centre (APCRC) examined over 100 sites as potential geological storage sites, and identified an ultimate storage capacity in excess of 1600 years of Australia's total current emissions. It also developed a methodology to enable the potential of sites to be compared taking into account a range of factors including storage volume, security and proximity to CO2 sources.

National Clean Coal Initiative[334]

The National Clean Coal Initiative supports the development and deployment of clean coal technologies that Australia will need to achieve substantial reductions in greenhouse gas emissions from future coal use.

Direct beneficiaries of funding provided under the National Clean Coal Fund will include the research community and technology developers, operators of demonstration projects and developers of CO2 storage sites and associated infrastructure. Industry stakeholders including coal producers and power producers will contribute an additional $1 billion in funding for the Initiative (including through Coal21) and will benefit in the long term through the enhanced sustainability of coal as a major energy source. The National Clean Coal Fund also includes A$ 75 million – including A$25 million for CSIRO – to be invested in clean coal research.

The National Clean Coal Initiative will commence from 1 July 2008 and support deployment strategies for low emission technologies out to 2030. The National Clean Coal Fund will support the National Clean Coal Initiative for its first seven years from 1 July 2008 to 30 June 2015.

Clean Energy Initiative[335]

The Australian Government announced on May 12, 2009 that it will invest A$4.5 billion to support the growth of clean energy generation and new technologies, and to reduce carbon emissions and stimulate economic activity.

The Clean Energy Initiative will support clean technologies and industries and assist Australia's transition to a lower emissions path.

The Government will invest:

- A$2.4 billion in low emissions coal technologies, including new funding of $2 billion in industrial-scale CCS projects under the Carbon Capture and Storage Flagships program;
- A$1.6 billion in solar technologies, including new funding of $1.365 billion in a Solar Flagships program - helping position Australia as a world leader in this vital energy technology for the future; and

[331] www.climatechange.vic.gov.au
[332] www.ga.gov.au
[333] www.apcrc.com.au/Programs/geodisc_res.html
[334] www.ret.gov.au/Pages/FederalBudget200809.aspx
[335] www.environment.gov.au/minister/garrett/2009/budmr20090512i.html

- A$465 million to establish Renewables Australia to support leading-edge technology research and bring it to market, including new funding of $100 million. The new body will advise governments and the community on the implementation of renewable energy technologies, and support growth in skills and capacity for domestic and international markets.

This represents an investment of $3.5 billion in new money by the Rudd Government in clean energy in this Budget. The CCS Flagships program supports the demonstration of large industrial scale projects in Australia, and may include a carbon dioxide storage hub. The two strategic technology priorities of CCS and solar will be underpinned by supporting specialised research, development and demonstration programs.

Other funds

Other relevant announced funding schemes include

- the Queensland Government's A$300 million Clean Coal Technologies Fund[336]
- the A$300 million Australian coal industry's COAL21 Fund
- Commonwealth funding to develop CCS Legislation at A$18 million, including A$9 million to the Department of Industry, Tourism and Resources, and A$9 million to Geoscience Australia.
- Western Australia Low Emission Energy Development Fund at A$36,5 million.
- The New South Wales Clean Energy Fund at A$100 is still under development, but will include new coal initiatives at A$22 million with A$20 million for geo-sequestration projects.

CURRENT CCS PROJECTS IN AUSTRALIA

The locations of the current major CCS projects in Australia are illustrated below:

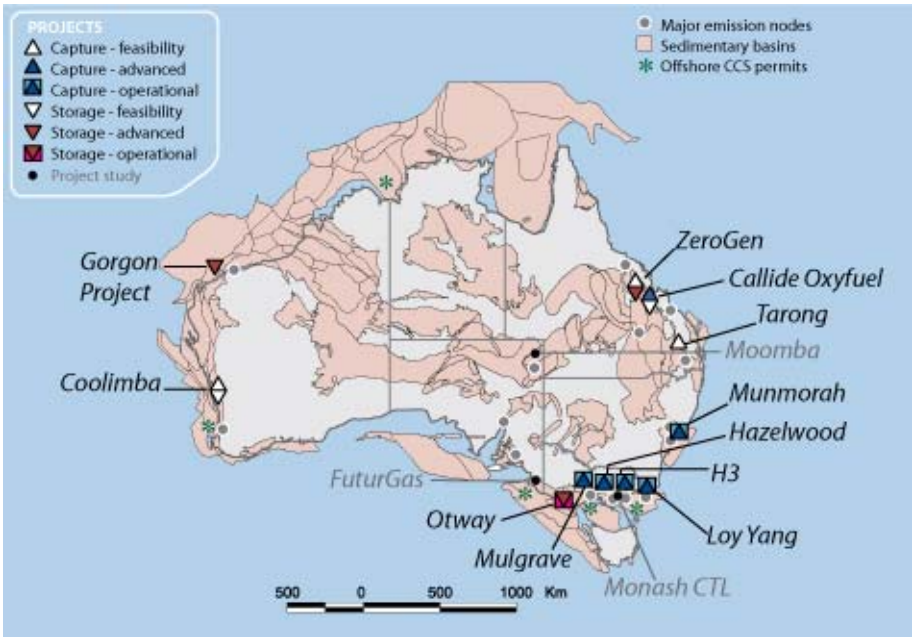


Figure 26: Current projects and potential projects in Australia involving CCS. Courtesy of CO2CRC.

Capture only projects:

The Mulgrave IDGCC project, Victoria[337]

This Integrated Drying Gasification Combined-Cycle (IDGCC) project at Loy Yang in Victoria is pressurized drying and gasification of a 400 MW brown coal-fired power plant, with the

[336] www.energy.qld.gov.au

[337] www.hrl.com.au/www/45/1001127/displayarticle/1001182.html

objective to reduce CO_2 emissions by 40%. Pre-combustion CO2 capture will be employed at a 10 MW pilot scale initially[338].

The project partners are HRL Developments, Harbin Power Engineering Ltd (HPE) and CO2CRC. The project, estimated at A$ 750 million, is supported with A$100 million from LETDF and A$50 million from ETIS (Energy Technology Innovation Strategy).

The project is scheduled to commence construction of the power station in 2007 with completion after 2009. The Victorian Government has granted an exploration licence over sufficient coal for 40 years operation of that power station. HRL will build a 100 MW intermediate scale brown coal IDGCC plant in the Latrobe Valley in the next four years as the first commercial demonstration of this patented technology.

Successful development of IDGCC technology opens the way for oxygen-blown brown coal IGCC suitable for CCS in the period 2010 – 2020 and will bridge to the hydrogen economy. Oxygen-blown brown coal gasification has already been tested by HRL in its pilot scale gasifier in Mulgrave.

CO2CRC / HRL Mulgrave Capture Project[339]

The CO2CRC/HRL Mulgrave Capture Project will look at three technologies – solvent, membrane and absorbent – for capturing CO2 from the next generation of high-efficiency power stations. To test the new technologies, three CO2 capture rigs have been commissioned at HRL's gasifier research facility at Mulgrave in Melbourne

The A$4.1 million Pre-Combustion Carbon Capture project is a joint collaboration between industry, research partners and the Victorian Government, with just over A$2 million coming from the Brumby Government's Energy Technology Innovation Strategy (ETIS) Brown Coal R&D program..

The Hazelwood Carbon Capture Project, Victoria[340]

The Hazelwood CO2CRC PCC Project is a brown coal drying and a post-combustion CO_2 capture and storage project at the International Power's Hazelwood facility. The project aims to initially cut CO_2 emissions by 30 per cent at a retrofitted 200 MW brown coal unit at Hazelwood.

The CO_2 capture in the order of 10,000 ton per year will be based on ammonia absorption technology. CO_2 will be utilized for ash water treatment (neutralizing alkaline) and be sequestered into calcium carbonate. Excess CO_2 will be processed for industrial gas markets. CO2CRC will use the plant to test a range of solvent and process changes and using two other rigs, will test adsorbent and membrane post-combustion techniques.

The solvent capture plant began operation in 2009 at a nominal capture rate at 10,000 ton/year.

Project partners are International Power, Loy Yang Power, CO2CRC, CSIRO and the Process Group.

The total project cost is A$ 369 million. The Australian Government is contributing A$50 million through the LETDF and the Victorian Government an additional A$30 million.

The Loy Yang Post-Combustion Capture project, Victoria[341].

CSIRO announced in August 2008 that Australia's first post-combustion CO_2 capture (PPC) pilot was performed at Loy Yang Power Station in Victoria's Latrobe Valley.

The 10.5 meter-high pilot plant is designed to capture up to 1000 ton of CO_2 per annum from the power station's exhaust-gas flues. Future trials will involve the use of a range of different CO_2 -capture liquids.

The project is part of the Latrobe Valley Post Combustion Capture Project – a joint collaboration between Loy Yang Power, International Power Hazelwood, government and researchers from CSIRO's Energy Transformed Flagship and the CO2CRC (including Monash and Melbourne Universities). The Loy Yang component of the project is supported by the Victorian Government for A$ 2.5 million through the Energy Technology Innovation Strategy. The overall cost is around A$ 5 million.

Figure 27: The PCC pilot rig at Loy Yang Power Station. Source CSIRO.

[338] www.aie.org.au/melb/material/destinationrenewables/IDGCC.doc
[339] www.co2crc.com.au/dls/brochures/CO2CRC_Mulgrave_brochure.pdf
[340] www.greenhouse.gov.au/demonstrationfund
[341] www.csiro.au/news/CarbonDioxideCapture.html

The Munmorah Post-Combustion Capture project, New South Wales[342]

The Munmorah pilot program aims to investigate the potential to adapt post carbon capture ammonia absorption processes to Australian conditions. Delta Electricity and CSIRO are jointly developing a A$ 5 million research scale pilot facility at Munmorah Power Station on the NSW Central Coast to capture (and release) up to 3,000 ton per year of CO_2.

The pilot phase began in February 2009 and will continue until June 2010.

Transport ad storage is currently not included in the project, but the State government is looking into four possible carbon storage sites in the state.

It should lead to a larger A$ 150 million CO_2 capture project; increasing to 100,000 ton per year in the demonstration phase starting around 2011. This demonstration project would include CO_2 capture, transport to and injection into a suitable geo-sequestration site and could be operational by 2013.

This project is part of the Asia Pacific Partnership on Clean Development and Climate (AP6).

Tarong Energy Post Combustion Capture project, Queensland[343]

CSIRO and Tarong Energy announced in September 2008 a A$5 million joint pilot project of a post-combustion capture (PCC) pilot plant at coal fired Tarong Power Station, 45km south of Kingaroy.

The pilot plant is designed to capture 1,500 ton per annum of CO_2 from the power station and is part of a broader research program to identify ways to reduce greenhouse gas emissions from the energy sector.

The two-year project will start September 2009, with the pilot plant expected to be operational in the first half of 2009 and the research activities associated with the technology completed in 2011.

The Tarong trial will focus on assessing the performance of an amine-based PCC pilot plant that will be integrated into the existing coal-fired power stations. CSIRO and Tarong Energy will each contribute A$ 2.5 million to the project.

The PCC pilot plant at Tarong is an integral part of the Asia Pacific Partnership on Clean Development and Climate (APP) program's PCC Flagship Project.

CO2CRC H3 Capture Project (new)[344]

This project, led by CO2CRC, is based at International Power's Hazelwood plant and overlaps with the Hazelwood Capture Project. CO2CRC is testing a range of solvents and different process configurations using the solvent post-combustion capture plant. In addition, post-combustion techniques using adsorbent and membrane technologies are being developed using two purpose-built rigs.

The project is using the 30 metre high solvent capture plant installed by International Power as part of the Hazelwood Carbon Capture Project to test and evaluate new and improved solvents, compare equipment performance, investigate impurities removal and optimise solvent capture processes.

The project will use purpose-built research modules to evaluate two new technologies for CO2 capture; membranes and adsorbents.

The project is part of the Latrobe Valley Post-Combustion Capture Project and is supported by the Victorian Government, through their Energy Technology Innovation Strategy (ETIS) Brown Coal R&D funding, and by the Federal Government, through the CRC Program.

Latrobe Valley Post Combustion Capture Project (LVPCC)[345]

The ETIS Brown Coal R&D program is one a several components to the overall ETIS program which includes support for renewables, large scale demonstration of low emissions technologies and enabling R&D. The LVPCC is a collaboration by Loy Yang Power, International Power, CSIRO and CO2CRC to create a multisite, multi-technology post combustion capture (PCC) hub to identify CCS options for the Victorian brown coal generators.

The broad aims of the project are:

---

342 www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/223832/Delta-Electricity-NSW-clean-coal-summit.pdf

343 www.csiro.au/news/NewJointPCCProject.html

344 www.co2crc.com.au/research/demo_postcombustion.html

345 http://www.legislation.vic.gov.au/domino/Web_Notes/newmedia.nsf/955cbeae7df9460dca256c8c00152d2b/faae119e5faffe9dca2574820002d659!OpenDocument

- Identification of cost-effective options for reduction of CO2-emissions in Victorian brown coal fired power stations, both retrofit and new build
- Focus on post-combustion capture of CO2
- Determine effects of CO2-concentration, moisture content, SOx, NOx and fly-ash on sorbent systems and novel separation technologies
- Technical and economical assessment based on results from pilots and laboratory research

The project is based at two generation sites, Loy Yang A, operated by Loy Yang Power and Hazelwood operated by International Power and continues till June 2010. This project comprises the Hazelwood Carbon Capture Project and Loy Yang Post-Combustion project described above.

Capture and storage projects:

The Callide Oxy-Fuel Project[346] - Queensland

This world-first, fully integrated demonstration of oxy-fuel pulverized coal technology includes retrofitting of a 30 MW unit at CS Energy Ltd.'s Callide A in Biloela in Central Queensland.

The first stage the project will include CO_2 capture, while stage 2 includes transport, injection and storage of the captured and liquefied CO_2 in deep geological formations. The project team is assessing potential geo-sequestration sites to the west of Biloela and plans to select the final location in 2009. The gas volumes are up to 60,000 ton CO_2 over a 5 year period.

The project is headed by CS Energy Ltd (CSE) in partnership with IHI Corporation (Japan), J-Power (Japan), Mitsui & Co. (Japan), Schlumberger Oilfields Australia, and Xstrata Coal. Supporting parties are the Australian Coal Association and the Australian and Queensland Governments. JCoal (Japan) is providing man management support to the project.

The total estimated total project expenditure: approx A$ 206 million, including A$ 50 million from LETDF.

The contract for the project was signed on March 28, 2008 between Martin Ferguson, Minister for Resources and Energy and CS Energy[347]. Construction at Callide A Power Station commenced in November 2008, to be followed by electricity generation from the oxy-fuel process and geo-sequestration in 2011. The demonstration project will continue for up to five years, during which time the project team will assess the potential commercial applications of oxy-firing technology to other plant.

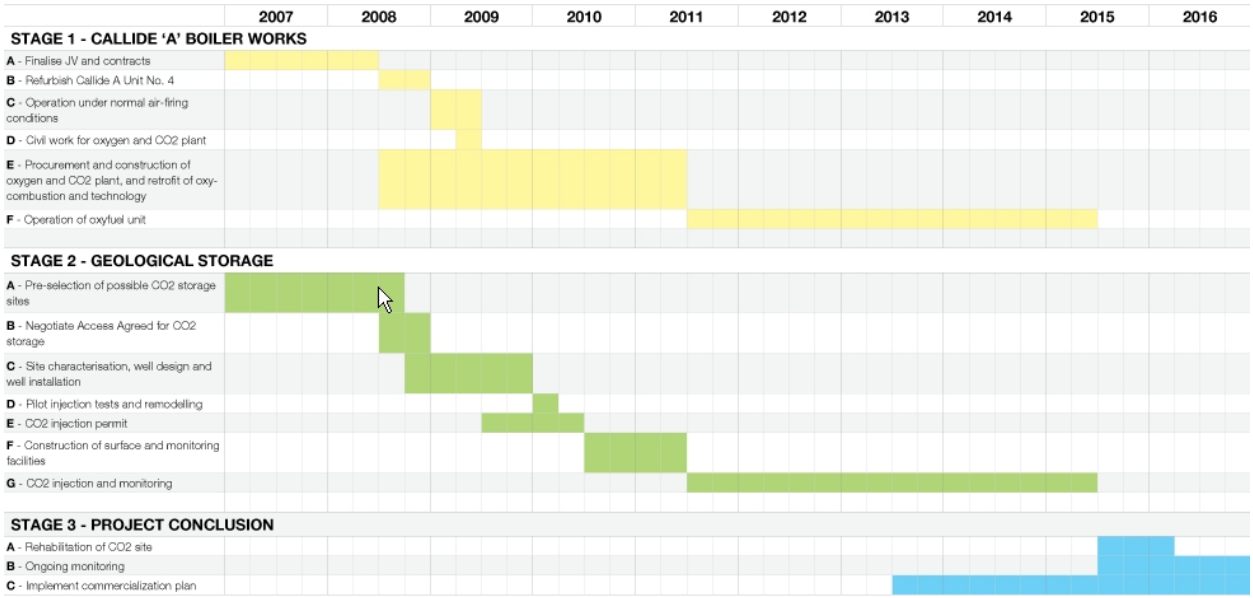


Figure 28: Timeline of the Callide oxyfuel and storage project. Source: www.callideoxyfuel.com

[346] www.**callide**oxyfuel.com

[347] www.csenergy.com.au/_CMSImages/csenergy/pdfs/080330%20oxyfuel%20JV%20signing.pdf

The ZeroGen, Queensland[348]

The ZeroGen project is Queensland Government's demonstration project of Integrated Coal Gasification Open Cycle project combined with CCS. The project will be the world's first commercial-scale IGCC power plant with CCS capability, producing 530 megawatts of electricity starting operation in 2015.

ZeroGen had originally planned to first build a demonstration plant, however following discussions with project stakeholders a new opportunity emerged to proceed directly to commercial-scale.

On June 22, 2009, Mitsubishi Heavy Industries (MHI) and Mitsubishi Corporation (MC) announced that they will provide the feasibility study for the project[349], and to provide the technologies for both the IGCC and the CCS units.

Royal Dutch Shell continues to support ZeroGen's CO2 injection testing program as part of its global efforts to develop and deploy CCS technology. As part of the feasibility study undertaken for the original demonstration project, drilling investigation of geological sites began in June 2006 in the Northern Denison Trough located in the Springsure/Emerald region in Central Queensland. The goal of the drilling program is to carry out the necessary scientific procedures to understand the local geology of the Northern Denison Trough and confirm its ability to safely and securely store carbon dioxide (CO2).

In mid 2007, ZeroGen announced positive results from the first stage of its drilling program and confirmed the geology was suitable to safely store CO2. The program is currently in the second stage of its drilling program and is aiming to identify specific reservoirs with sufficient capacity to store CO2. ZeroGen will carry out a test injection of CO2 into the reservoirs to allow it to conduct a series of further studies which will include CO2 monitoring and verification techniques, and injection optimization.

The project partners the Queensland Government, Australian Coal Association's COAL21 Fund (ACALET), Shell Development (Australia), ZeroGen Pty Ltd, in addition to the Japanese technology providers MHI and MC. The project has been endorsed by a number of leading national and international entities including the Queensland Government, Australian Coal Association, WWF-Australia, CFMEU, World Coal Institute and Electric Power Research Institute.

While the costs of the ZeroGen project to date have been met by the Queensland Government, the Australian Coal Association, through the COAL21 Fund is providing $26 million to cover additional costs in the revised feasibility study for Stage One.

The Coolimba Oxy-Fuel Project, Western Australia[350]

Aviva Corp.[351] announced the development of a 2x200 MV base load "oxy-fuel ready" power station in the Mid West region of Western Australia. The Coolimba Project will be built from the outset as a coal fired boiler that will be capable of rapid conversion to capture the CO2 produced during the combustion of coal. A 30 MW demonstration project is currently being built in Queensland, and will enter service in the second half of 2009. The Coolimba project aims to build on the experiences of this project to become the first commercial scale oxy ready project in Australia.

Converting the boiler to oxy firing is only one step in the process of capturing and sequestering CO_2. Suitable locations will need to be found for the long term storage of C02. Hence, Aviva will work with the CRC for CO_2 capture and storage, based in WA at Curtin University, to support the necessary research and development work to allow the C02 to be sequestered immediately after the oxy firing conversion is completed at Coolimba.

Coolimba Power commissioned the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) in February 2008 to undertake a study to assess the potential for the underground storage of CO2 in WA's Mid West region. The A$ 250,000 study is a major step toward low-emission power generation in WA and will position Coolimba among the first commercial projects to adopt this technology in the world. Sequestration sites are currently being sought by CO2CRC and ARC Energy with capacity for 2.9 million ton CO_2 per year for up to 30 years.

The project cost is in the order of A$ 1 billion.

[348] www.zerogen.com.au
[349] www.mhi.co.jp/en/news/story/090622english.html
[350] www.coolimbapower.com.au/oxyready.html
[351] www.avivacorp.com.au

Storage only projects:

The Gorgon CO2 Injection Project, Western Australia[352]

As part of the Gorgon LNG Project[353], Chevron Australia (operator), Shell and Exxon are planning a sub-project for CO_2 sequestration. The Gorgon gas field is one of the world's premier hydrocarbon resources and situated 130 km off the northwest coast of Western Australia.

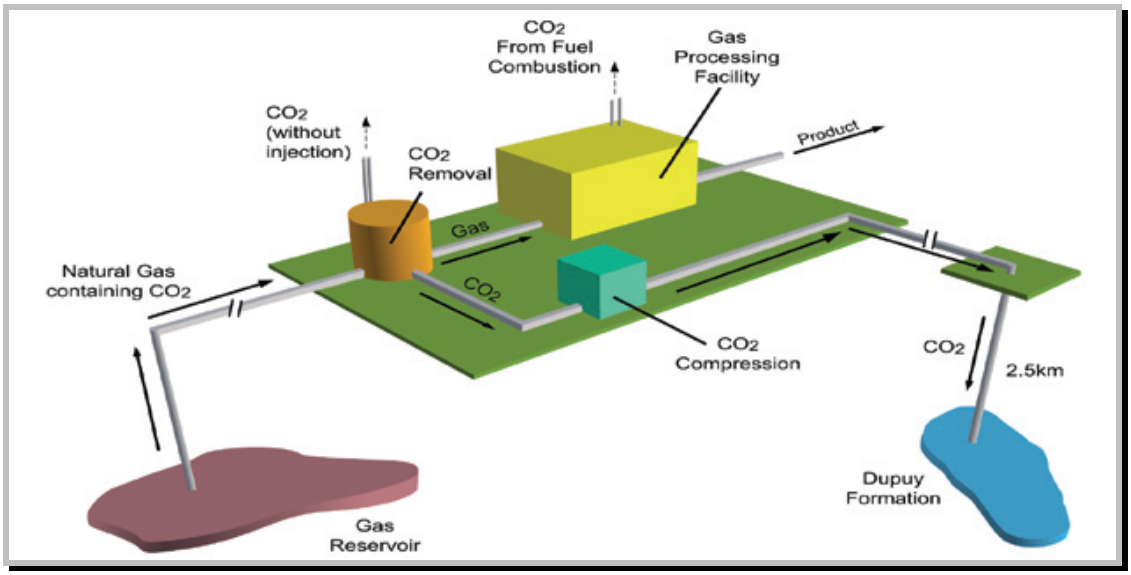


Figure 29: Overview of the Gorgon project. Source www.gorgon.com.au.

The CO_2 sequestration project is world's largest CO_2 capture and storage project with a potential to capture 3.3 million ton CO_2 annually from separation of CO_2 from the natural gas.

The project is a commercial-scale demonstration project involving three components:

- Capture of CO_2 from reservoir natural gas; compressing, drying and liquefying the CO_2 and transportation by pipeline to the injection site.
- Injecting the CO_2 2.3 km underground into the Dupuy saline aquifer formation under the Barrow Island.
- Long-term monitoring of the stored CO_2 to ensure its safety. The project aims to store a total of 125 million ton of CO_2 over its 40 years lifetime.

Chevron is operator of the Project with a 50% interest, with ExxonMobil and Shell each holding 25%.

The overall Gorgon LNG project costs are in the order of A$ 15-20 billion, of which the storage component is in the order of A$ 1 billion. The Australian Government announced in Nov. 2006[354] that it provides A$ 60 million from the Low Emissions Technology Demonstration Fund to support the sequestration project.

The overall project is expected to commence late 2009, and CO_2 reinjection is expected to start in 2012-13. Data wells have been drilled and a major study of the subsurface is underway.

The CO2CRC Otway storage Project, Victoria[355]

The CO2CRC Otway Project is the most advanced storage project in Australia and the world's largest research and geo-sequestration demonstration project. The project includes:

- Injection of 50,000 - 100,000 ton of CO_2 over 2 years. The injection started in April 2008 with a rate of 150 ton per day. The injected gas is a mixture of 80% CO_2 and 20% methane) from the Buttress production, and is stored in the depleted natural gas field Waarre C Formation at approximately 2100m below the surface.
- A major monitoring and verification program, which international and national scientists believe to be the most comprehensive of its type in the world. A wide range of monitoring and verification technologies are

[352] www.gorgon.com.au/03moe_greenhouse.html
[353] www.gorgon.com.au
[354] www.environment.gov.au/minister/env/2006/mr23nov06.html
[355] www.co2crc.com.au/otway/

being installed including down-hole geochemical and geophysical techniques for monitoring the CO_2 migrating plume via the existing observation Naylor-1 well. Drilling of the injection well (CRC-1) was completed in March 2007 and the injection of a mixture of CO_2 and methane into a deep geological formation is scheduled before the end of this year.

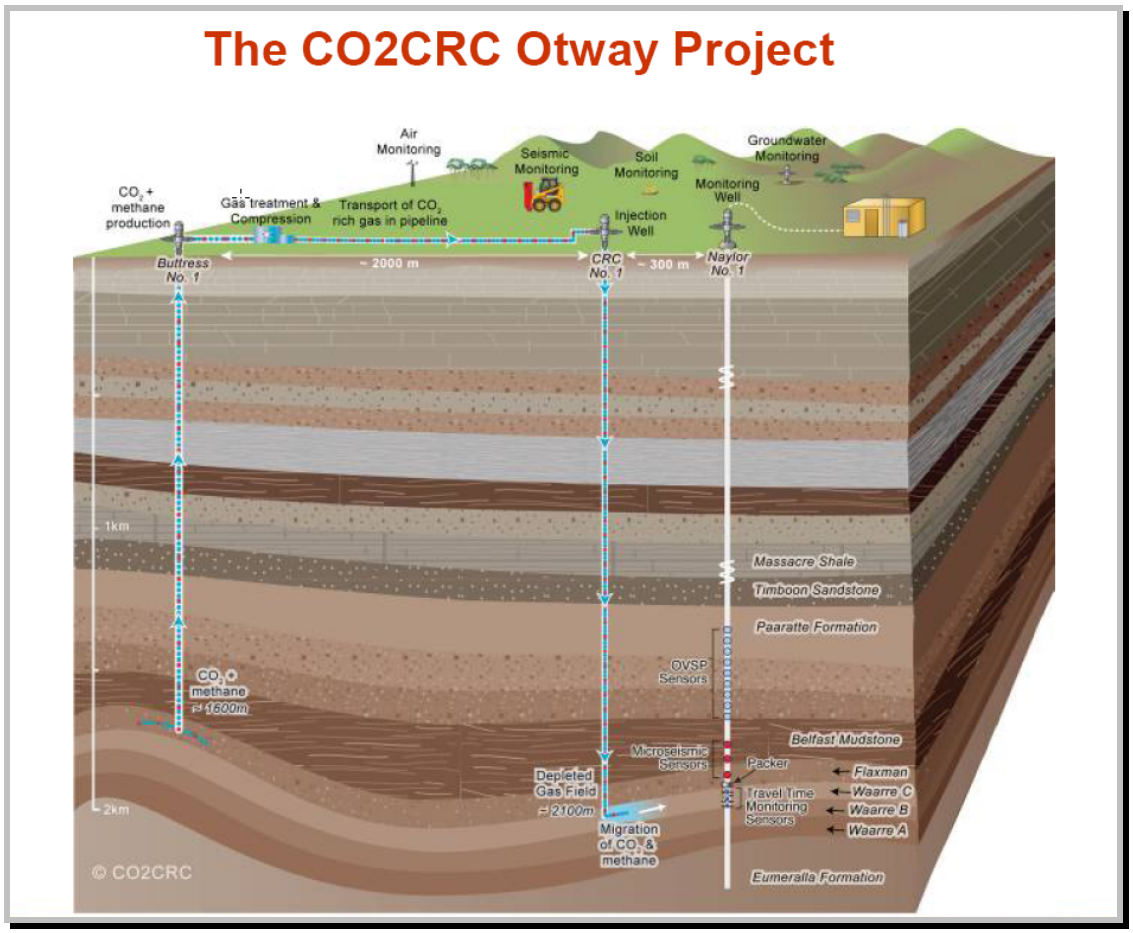


Figure 30: Illustration of the CO2CRC Otway Project. Courtesy of CO2CRC.

The project is supported by the Federal Government through the Cooperative Research Centres Programme, the Australian Greenhouse Office, and AusIndustry, as well as by the Victorian Government, and the industry. The CO2CRC has also established a new company, CO2CRC Pilot Project Ltd[356], the first CO2 capture and geological sequestration company in the world established specifically to carry out the operations of the project.

The budget is A$40 million and funded through the Australian Federal Government through the Australian Greenhouse Office and AusIndustry; The Victorian Government and US Department of Energy. The project is supported by 15 companies and 7 governmental agencies, and involving involves researchers from Australia, New Zealand, Canada, Korea and the USA. CO2CRC Pilot Project Ltd, the operating company, includes AngloCoal, BHP Billiton, BP, Chevron, Schlumberger, Shell, RioTinto Solid Energy, Woodside and Xstrata.

An extension of the Otway Project (Stage 2) will build on knowledge and facilities established for Stage 1. The main outcome is to validate CO_2 storage capability in a saline aquifer by injecting and storing CO_2 in the Paaratte Formation. Beyond this, the general objective is to better characterize low permeability systems by studying few targeted formations. Stage 2 will use many of the operational facilities already established for Stage 1. Stage 2 of the project will include separation of the CO_2 from the methane before injection of highly concentrated CO_2. 90-97% CO_2 will be injected via the CRC-1 injection well developed in Stage 1. Additional monitoring activities will also be put in place to enhance the capability and optimize monitoring of a saline aquifer.

CO2CRC was successfully in getting A$ 6.145 million from the Cooperative Research Centre Programme at the Minister for Education, Science and Training and an additional A$2 million from the Victorian Government to undertake Stage 2.

[356] www.co2crc.com.au/about/cppl.html

Cancelled and suspended projects

The Kwinana Hydrogen Project Project[357]

The Kwinana Project, proposed by Hydrogen Energy, is a 500 MW hydrogen power project based on sub-bituminous coal. The plant will be fully equipped with CCS. The plant is planned next to BP's Kwinana refinery in Western Australia.

About 4 million ton of CO2 each year would be captured and transported by pipeline some 35 km offshore and injected about 2 km below the seabed into a saline formation for permanent geological storage.

Extensive testing of the integrity and suitability of the offshore saline formation was planned for 2007-2010. Subject to successful studies of technical viability, and providing government policy is in place to make the project commercially viable, a final investment decision to develop the plant would be expected in 2011. It was anticipated that the plant would be in operation by 2014. CCS would be started in 2021.

The project partners were Hydrogen Energy, BP and Rio Tinto. The project would require total capital investment of over A$2 billion.

The project was cancelled in May 2008, after BP admitted that the geological formations off Perth contain gas "chimneys" that mean it is next to impossible to establish a seal in the strata that could contain the CO2[358].

The Fairview project (Zero Carbon Power from Coal Seams)[359]

The Zero Carbon Power from Coal Seams project involves extracting methane from coal seams that are too far underground to be mined. The methane will be burnt in a 100 MW power station and the CO2 emissions will be captured and injected back into the coal seam, closing the loop and reducing greenhouse gas emissions.

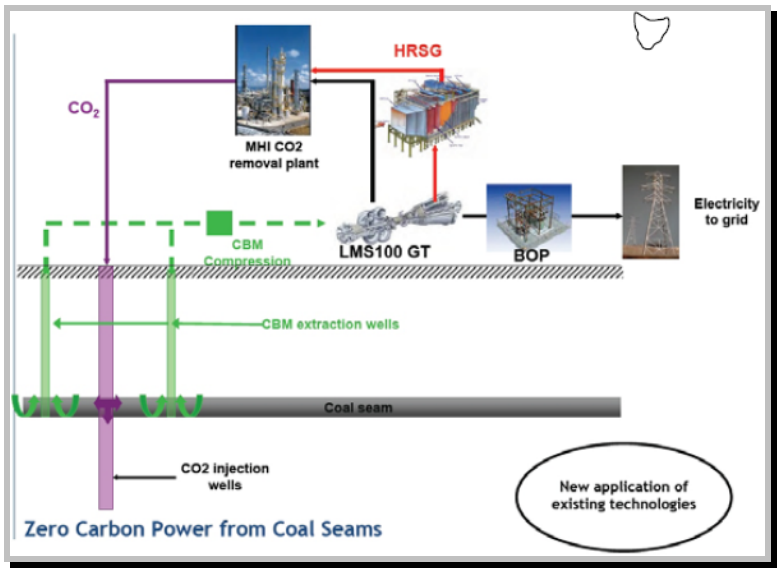


Figure 31: Source: R. Gillespie, AIE National Conference 2006.

The project will capture one-third of the CO2 emissions from the power station on a post-combustions manner. Over 100,000 ton of CO2 will be captured and stored each year. The project will demonstrate the use of coal beds as a source of fuel for power generation and as a storage site for the CO2 emitted from the power station.

The total life cycle cost of this project was A$445 million of which the Australian Government was to contribute $75 million through the LETDF. The project partners were Santos, BHP-B, Lucas, GE, ICTPL and CSIRO.

The project was cancelled in autumn 2008.

[357] www.hydrogenenergy.com/MediaArticle.aspx?m=29&amid=498
[358] www.theaustralian.news.com.au/story/0,25197,23672893-5005200,00.html
[359] www.co2crc.com.au/MEDIA/06/LETDF_oct30_2006.doc

The Moomba Carbon Storage Project, South Australia[360]

Santos' Moomba Carbon Storage (MCS) Project in the Cooper Basin in South Australia is a new project currently in the feasibility stage. The objective is to establish an Enhanced Oil Recovery solution, and on longer time span establish a huge CO_2 storage hub in the Cooper Basin. The initial injection, commencing from 2010, is one million ton CO_2 per year, but Santos' vision is that the project could be scaled up to 20 million ton per year. The site has potential of 400 million ton CO_2 storage.

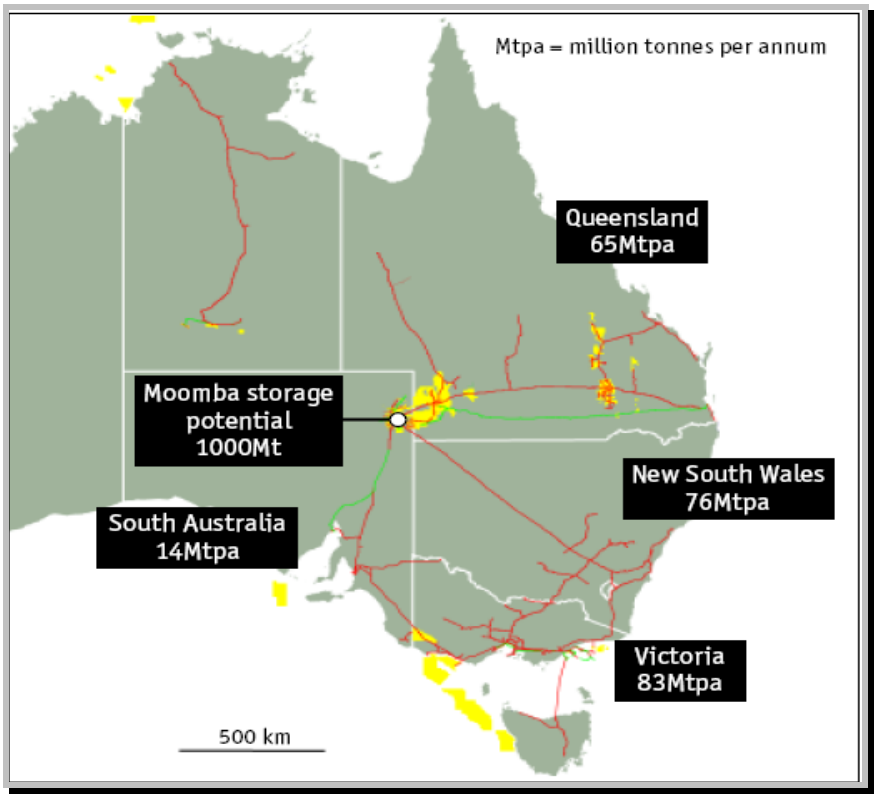


Figure 32: Storage potentials and pipeline structures in eastern Australia. Source Santos Limited.

The project thus has three phases:

- The first phase is to demonstrate the technical and economic feasibility of storing CO_2 in depleted oil and gas fields in the Cooper Basin, in central Australia. It involves the capture of all CO2 separated as part of the gas processing operations at Moomba, transporting that CO_2 to a designated site and injecting the CO_2 stream into partially depleted oil reservoirs. A significant EOR benefit is expected. To be commenced within 2010.
- The second phase focuses on building capacity and confidence in the technology as increasing volumes of CO_2 are moved towards Moomba. MCS would link to the development of a clean coal power generation project in eastern Queensland or/and New South Wales' Hunter Valley. CO2 captured from that project would be transported towards Moomba utilizing existing infrastructure wherever possible.
- Phase 3 will deliver Australia's first common-user carbon storage hub at Moomba. Significant quantities of CO_2 would be captured from key point sources in New South Wales, Queensland and South Australia. Dedicated CO_2 pipelines would be built to connect these emitters to the Moomba carbon storage hub. The CO_2 would be distributed to designated sites and stored in depleted oil and gas reservoirs or deep aquifers.

The Moomba Carbon Storage project is being developed by Santos as the operator of the Cooper Basin Joint Venture. The other parties involved are Beach Petroleum and Origin Energy. This team has decades of oil and gas exploration and production experience coupled with a proven track record in major project management.

The initial announcement in 2007 indicates a cost of A$ 700 million[361]. Santos was seeking government support of A$ 275 million for the initial demonstration project, but received A$ 10 million for support in Front End Engineering (FED) in December 2007 from Australian coalition government.

The partners announced a suspention of the project in March 2009.

[360] www.santos.com/library/Santos_Moomba_Carbon_Storage.pdf
[361] www.santos.com.au/Archive/NewsDetail.aspx?p=121&np=78&id=1030

The FutureGas project, South Australia[362]

The FuturGas Project is Hybrid Energy Australia's initiative to develop a world-leading coal-to-liquid fuels and low-emissions power generation project. Hybrid Energy Australia intends to utilise above-ground gasification technology for the FuturGas Project. The highly reactive properties of the Kingston lignite make it ideal for the gasification process, as well as for Fischer Tropsch synthesis.

Approximately 10,000 barrels per day (bpd) of high-quality synthetic fuels will be produced from the gasification process following the commissioning of plant operation in 2016. This will be a combination of synthetic diesel with ultra-low sulphur, and naphtha – a refinery feedstock.

Synthetic fuel is fully compatible with existing petroleum-based fuels and is suitable for use in existing engines without modification. It is expected that the production of diesel will be approximately equal to the current level of South Australian retail diesel consumption.

The investigation of CCS technology is an integral component of the FuturGas Project.

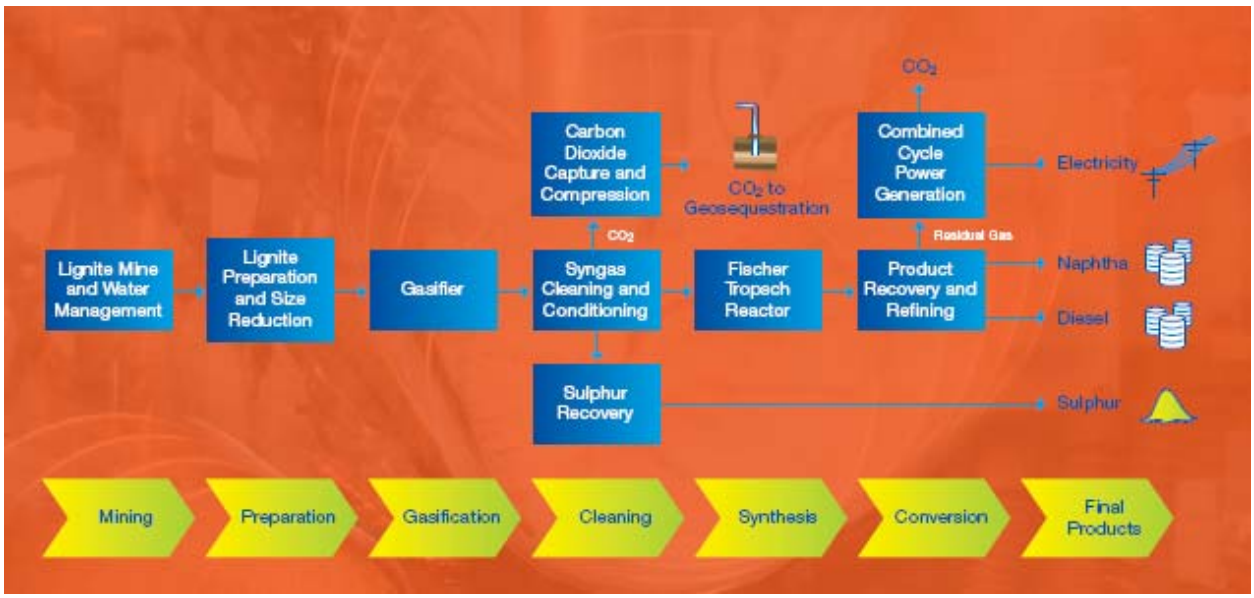


Figure 33: The FutureGas technology. Source: Hybrid Energy Australia[363]

It is proposed that the CO2 captured post-gasification will be stored in the Otway Basin to the south of the lignite resources.

Hybrid Energy's partent company, StrikeOil, deferred the pre-feasibility study in March 2009.

The Monash Coal-To-Liquid Project, Victoria[364]

The ***proposed*** Monash project involves conversion of brown coal to synthetic fuel and pre-combustion capture of CO_2.

The Monash Energy Project encompasses:

- A Demonstration Plant to integrate the required drying and gasification technologies at a commercial scale;
- A new mine, supplying brown coal (lignite) at a rate of approximately 25 Million ton per year from the Flynn field in the Latrobe Valley, over which Monash Energy currently holds an exploration license;
- A Coal to Liquids plant including the capacity to capture excess CO_2 and compress it to a supercritical fluid; and
- The associated infrastructure for transport of the liquefied CO_2 to locations in the depleting oil and gas fields of the offshore Gippsland Basin, for injection and permanent storage deep underground in the geological strata.

The capture amounts could be up to 15 million ton per year. The storage potential is as large as 6,000 million ton.

[362] hybridenergyaustralia.com.au/pdf/hybridenergyaustraliabrochure_april2008.pdf
[363] hybridenergyaustralia.com.au/pdf/2007_08_Activity_Report.pdf
[364] www.monashenergy.com.au/project/project.html

The overall project proposal is indicated to cost A$ 6-7 billion, of which about A$1.5 billion would be spent on the geo-sequestration sub-project. The first stage, which will cost between A$300 million and A$400 million, would be a demonstration plant that could be up and running in six years. The entire project should be operational in 10 years.

The project partners are Monash Energy, Anglo American and Shell Gas and Power.

A precursor to this project was the Latrobe Valley CO_2 Storage Assessment Project (LVCSA)[365] started in 2003 performed by Monash Energy (at that time Australian Power and Energy Limited). The study of disposal of CO_2 in 2, 15 & 50 million ton/year scenarios from new coal developments in Gippsland basin depleted fields and saline aquifers gave very positive indications for large scale CO_2 storage potential.

On December 2nd, 2008, the partner announced that due to higher project costs and falling oil prices, they will delay this project[366]. The partners have so far spent more than A$25 million on studying the viability of the project and will continue to assess "on a regular basis" the potential for moving it forward.

COMPANIES ENGAGED IN CCS ACTIVITIES IN AUSTRALIA

Australia has generally not a strong manufacturing industry, and thus no Australian technology manufacturer has specialized on CCS technologies – especially not on capture technologies. The ongoing and planned projects do therefore mainly rely on technologies from overseas – such as Japan and US. The partnership with the Japanese engineering company IHI on the CS Energy oxy-fuel project is a good example.

On the storage technology and demonstration side, Australian technology companies are much more present. Here gas, oil and coal companies and associations, both Australian and subsidiaries of e.g. US companies are actively engaged in various projects.

The list below is of private sector Australian companies/associations or foreign subsidiaries currently engaged in CCS activities (may not be complete).

Company / association	Web site	Core business / technology	Project involvements
Australian Coal Association	www.australiancoal.com.au www.acarp.com.au	Assoc. of black coal producers. Clean coal development, oxy-fuel, storage projects. Australian Coal Association Research Program (ACARP) with five priorities: Underground storage; Sustainability; Open Cut; Coal Preparation; Technical Market Support; Greenhouse Gas Mitigation. Participant in CCSD, CO2CRC and cLET.	Callide, Munmorah, ZeroGen
AngloCoal	www.anglocoal.com.au	Anglo Coal Australia is one of Australia's leading coal producers adding value to Australia and the world. Anglo Coal Australia has extensive coal mining interests and prospects in Queensland and New South Wales.	Otway, Monash
Aviva Corp.	www.avivacorp.com.au	Aviva is an integrated energy company listed on both the Australian Stock Exchange and Botswana Stock Exchange with its head office in Perth. The company is growing a portfolio of integrated energy assets. Aviva's most advanced asset is the Coolimba Power project in Western Australia.	Coolimba,
BHP Billiton	www.bhpbilliton.com	BHP Billiton is the world's largest diversified resources company.	Otway,
BP	www.bp.com www.bpalternativenergy.com	BP is one of the world's largest oil and gas companies with operations in more than 100 countries across six continents. The company's main businesses are exploration and production of oil and gas; refining, manufacturing and marketing of oil products and petrochemicals; transportation and marketing of natural gas; and a growing business in renewable and low-carbon power, BP Alternative Energy. BP's low carbon interests combined in BP Alternative Energy include: BP Solar; the company's fast growing interests in wind power; gas-fired power generation; and BP's interest in Hydrogen Energy.	Otway,
Chevron Australia	www.chevron.com/countries/australia	Chevron Australia is a subsidiary of Chevron Corporation. Leading the Gorgon storage project.	Otway, Gorgon,
CS Energy Ltd (CSE)	www.csenergy.com.au	CS Energy is one of the fastest growing electricity companies in Australia with 4 power stations in Queensland.	Callide,
Delta Electricity	www.de.com.au	Delta Electricity is an electricity generation company in	Munmorah

[365] www.co2crc.com.au/PUBFILES/GEN0506/LVCSA_ExecutiveSummary.pdf
[366] www.bloomberg.com/apps/news?pid=20601087&sid=aiSHrlh9b9zM&refer=home

		New South Wales, and produce around 12% of the electricity needed by consumers in South Australia, Queensland, New South Wales, Victoria and the ACT.	
ExxonMobile	www.exxonmobil.com/Australia-English/PA/AU_HomePage.asp	ExxonMobil is one of Australia's largest oil and gas producers and a major refiner and marketer of petroleum products.	Gorgon
GE	www.ge.com/au	GE Australia and New Zealand operates 6 businesses including power generation.	
Harbin Power Engineering Co.	www.chinahpe.com	HPE is a subsidiary of one of China's largest power equipment and engineering service providers.	HRL IDGCC,
International Power	www.ipplc.com.au	International Power entered the Australian energy industry in 1996 and has grown to become the country's largest private generator of electricity. International Power Australia owns and operates 3,723 MW (gross) of renewable, gas-fired and brown coal-fired generating plants in Victoria, South Australia and Western Australia.	Hazelwood PCC
HRL Technology	www.hrl.com.au	HRL Limited is an unlisted Australian-owned public company that provides industry-leading services and technologically innovative solutions to the coal, energy and power sectors.	HRL IDGCC,
Hydrogen Energy	www.hydrogenenergy.com	Hydrogen Energy is developing alternative energy solutions in the form of decarbonised energy projects. It is a joint venture between BP and Rio Tinto.	Abu Dhabi and California projects.
Loy Yang Power	www.loyyangpower.com.au	Loy Yang Power owns and operates the 2,200 megawatt Loy Yang power station and the adjacent Loy Yang coal mine.	Loy Yang PCC
Monash Energy	www.monashenergy.com.au	Monash Energy is a collaboration of Shell and Anglo American to jointly develop a clean coal to liquid project in Australia's Latrobe Valley, utilising the latest low-emissions technologies.	Monash
Origin Energy	www.originenergy.com.au	Origin Energy is a major Australasian integrated energy company involved in gas and oil exploration and production, energy retailing and power generation.	Moomba
Rio Tinto	www.riotinto.com	A leading international mining group headquartered in the UK, combining Rio Tinto plc, a London listed public company, and Rio Tinto Limited, which is listed on the Australian Stock Exchange.	Otway
Santos	www.santos.com	Major Australian oil and gas exploration and production company with interests and operations in every major Australian petroleum province.	Moomba
Schlumberger Carbon Services	www.slb.com	Schlumberger Carbon Services provides comprehensive geological CO2 sequestration solutions. Site assessment, characterization, design and risk management.	Callide, Otway
Shell Australia	www.shell.com/home/content/au-en	Shell is a major global energy organisation which employs around 3,000 people in Australia. The upstream business finds, develops and supplies liquefied natural gas (LNG), condensates and liquefied petroleum gas (LPG) to overseas markets and natural gas to domestic customers in Western Australia. The downstream business manufactures petroleum products, supplying 25% of Australia's petroleum requirements. We trade with over 45,000 customers throughout the country.	Otway, Gorgon, Monash, ZeroGen
Stanwell Corp.	www.stanwell.com	A Queensland Government owned corporation to deliver smarter energy for Queensland. Operates thermal and hydro generating sites of more than 1,500 MW.	ZeroGen
Strike Oil	www.strikeoil.com.au	Australia based oil and gas exploration and production company.	FutureGas
Woodside	www.woodside.com.au	Woodside is one of Australia's top ten companies by market capitalisation, and the nation's largest publicly-traded oil and gas exploration and production company. Woodside operates Australia's largest resources project, the North West Shelf Venture in Western Australia, which produces about 40 per cent of Australia's oil and gas.	Otway
Xstrata Coal	www.xstrata.com/prod_coal.php	World largest exporter of thermal coal; 5th largest producer of coking coal. Engaged in FutureGen Alliance and Coal21. Xstrata Coal is investing around A$ 250 million to address the company's greenhouse footprint and support research development and demonstration for low emission technologies through: Contributor to the	Otway

		Australian coal industry's voluntary A$ 1 billion COAL21 Fund; Corporate participant in the A$ 220 million CS Energy Oxyfuel Demonstration Project in Queensland; Invest A$ 25 million in coal seam methane gas drainage at our operations in 2008;	
ZeroGen Pty Ltd	www.zerogen.com.au	ZeroGen Pty Ltd is a subsidiary of Stanwell to operate the ZeroGen project.	ZeroGen

CCS RESEARCH AND DEVELOPMENT

The Federal Government's Cooperative Research Programme has initiated a number of research partnerships, creating so-called Cooperative Research Centers (CRCs):

Cooperative Center for Greenhouse Gas Technologies (CO2CRC)[367]

The Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) is one of the world's leading collaborative research organizations focused on CO2 capture and geological sequestration.

CO2CRC commenced in October 2003 to take over the GEODISC project on geological storage/geo-sequestration. The research area was extended to also include CO2 capture, where research on pre-, post- and oxy-fuel combustion is done in collaboration with e.g. NTNU and US/Canadian universities. CO2CRC also contributes on the Sleipner project.

Headed by Dr. Peter Cook, CO2CRC is an unincorporated joint venture comprising participants from Australian and global industry, universities and other research bodies from Australia and New Zealand, and Australian Commonwealth, State and international government agencies. Its resources come from the Federal Government's Cooperative Research Centres Programme, other Federal and State Government programs, CO2CRC participants, and wider industry.

.

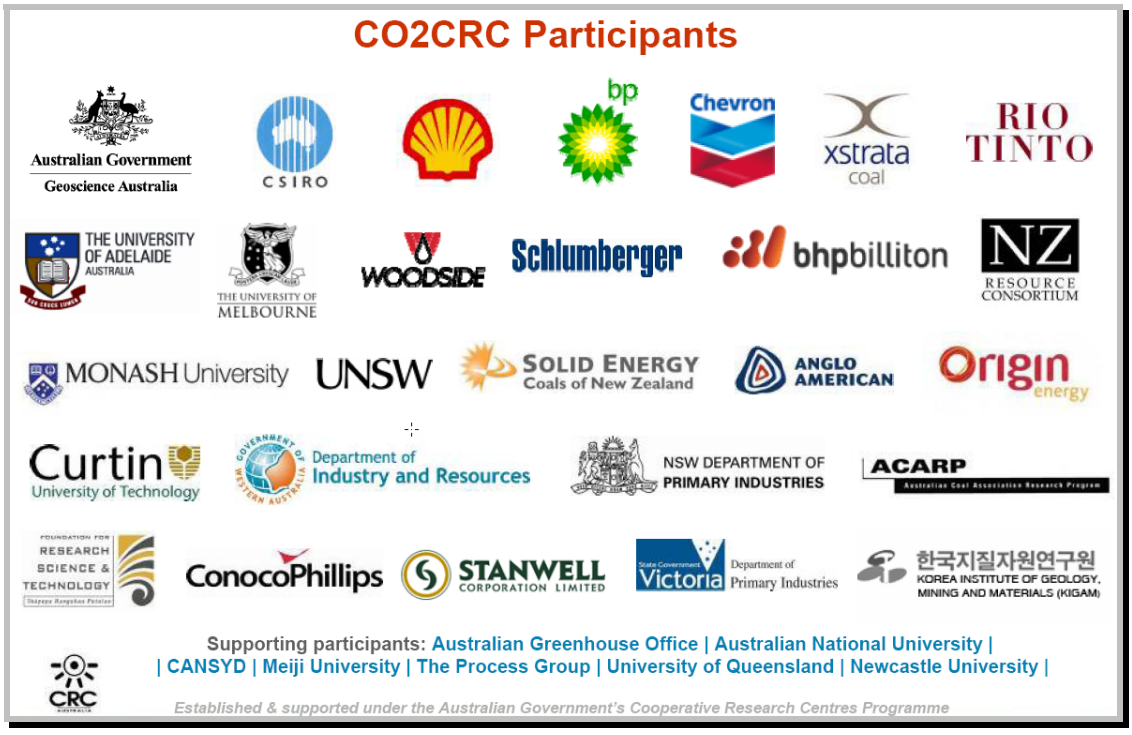


Figure 34: Participants in CO2CRC.[368]

CO2CRC are involved in a number of projects within CO2 storage and CO2 capture technologies. In addition, the centre is central in the Otway Basin Pilot demonstration project.

The budget over 7 Year (2003-2010) is in the order of $A140 million.

[367] www.co2crc.com.au

[368] Source: Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)

Cooperative Center for Coal in Sustainable Development (CCSD)[369]

The Cooperative Research Centre for Coal in Sustainable Development (CCSD) is one of 64 Cooperative Research Centre's (CRCs). CCSD is mainly engaged in assessment and technology development of zero-emission coal power plants, such as oxy-fuel and Integrated coal Gasification Combined Cycle (IGCC). CCSD is part of the Callide-A oxy-fuel working group.

Center for Low Emission Technologies (cLET)[370]

The Centre for Low Emissions Technology (cLET) is a partnership between the Queensland Government, CSIRO, Stanwell, Tarong, ACARP and the University of Queensland. The primary focus of the Centre is on research and development of next-generation low emission technologies with an emphasis on improved gas cleaning, gas separation and gas conditioning technologies for the development of Pulverised Coal (PC) and IGCC based, advanced power and/or hydrogen and syn-fuels production technologies. Five main program areas of work associated with the development of the core technologies identified above will be pursued in the work undertaken by the centre. These include gasification and core facility development, gas cleaning, gas processing (or conditioning), gas separation and social and economic integration.

Commonwealth Scientific and Industrial Research Organization (CSIRO)[371]

CSIRO conducts research and technology transfer in pre- and post-combustion capture as well as technical developments in CO2 storage in relevant Australian situations. CSRIO is involved in a number of projects in collaboration with various institutions as listed below:

- Energy futures: scenario development and modeling program with Government, industry and community groups to develop possible scenarios for future Australian energy demand/supply and to model the scenarios for their economic and environmental (GHG) impacts.
- Pre-combustion: develop expertise and knowledge through gasification research of Australian coals. Programs are conducted with the CRC for Coal in Sustainable Development.
- Gas Separation: key technology for clean coal gasification and CO_2 separation with the principal research vehicle the Centre for Low Emissions Technology. The focus areas of work comprise gas cleaning, gas conditioning, gas separation and a social and economic integration projects.
- Post-Combustion: proposal for demonstration of post-combustion capture for existing black coal and brown coal fired generators. This proposal is conceived around a 50,000 ton per year plant based on existing, emerging and novel concepts for CO2 capture using solvents designed to accommodate the relevant properties of flue gases from the different coal sources and in situations without de-NO_x and de-SO_x.
- CO_2 Sequestration: CSIRO is a partner in the CO2CRC.

Australian Petroleum Production and Exploration Association (APPEA)[372]

APPEA is the main organization representing the oil and gas exploration and production industry. Introduced a Greenhouse Plus Program[373] to reduce CO2 emissions from members.

International collaboration

Australia is member country of the Carbon Sequestration Leadership Forum (CSLF)[374], and they hosted the 3rd meeting in 2004 and play an active role in various task teams and committees.

Australia is partner in the following CSLF recognized projects:

- CO2CRC Otway Project (listed above)
- The Frio Brine project[375] in the US. This is a pilot-scale project that will demonstrate CO2 sequestration in an on-shore underground saline formation.

[369] www.ccsd.biz
[370] www.**clet**.net
[371] www.csiro.au
[372] www.appea.com.au
[373] www.appea.com.au/Publications/Documents/Greenhouse/2005%20GHC%20Progress%20Report.pdf%20-%202.pdf
[374] www.cslforum.org

Most of Australia's international activity related to CCS R, D &D is under the APP and a majority of these initiatives are actually in Australia, with other countries such as Japan, and US participating in Australia. Some exemption is CSIRO's participation in the recently completed RECOPOL project ('Reduction of CO2 emission by means of CO_2 storage in coal seams in the Silesian Coal Basin of Poland')[376] in Poland, and CO2CRC's participation in the Frio Brine Project[377] in Texas.

Asia Pacific Partnership on Clean Development and Climate (AP6)[378]

AP6 partners Australia, Canada, China, India, Japan, Republic of Korea, and the United States have agreed to work together and with private sector partners to meet goals for energy security, national air pollution reduction, and climate change in ways that promote sustainable economic growth and poverty reduction. The Partnership will focus on expanding investment and trade in cleaner energy technologies, goods and services in key market sectors.

PCC Demo Project[379].

In November 2007, Australia and China signed a partnership agreement that will pave the way for the installation of a post combustion capture (PCC) plant in Beijing 2008. Signed by CSIRO (Commonwealth Scientific and Industrial Research Organisation) Energy Technology Chief Executive, Dr Geoff Garrett, and Mr Li Xiaopeng, the President of China's state-owned energy enterprise, the China Huaneng Group, the agreement will see the plant installed at the Huaneng Beijing Co-generation Power Plant.

This project is China's first Post Combustion Capture (PCC) demonstration project. As part of Asia-Pacific Partnership (APP) on Clean Development and Climate (APP), the project is based on the agreement between the Australian government research organization CSIRO and China's Thermal Power Research Institute (TPRI). TPRI will install, commission and operate a PCC pilot plant at the *Huaneng* Beijing Thermal Power Plant, with all of its equipment domestically made.

The A$4 million research project funded by CSIRO will fit a post-combustion capture (PCC) system to one of the Huaneng Group's pilot plants in Beijing. The project was put into operation on July 17, 2008, with a capability of recovering more than 85 percent of CO2 from flue gases and can thus trap 3,000 tons CO2 annually.

Australia-China Joint Coordination Group on Clean Coal Technologies was announced in April 2008. The Australian government will invest A$ 20 million in this partnership as part of it's A$500 million Clean Coal Fund.

Australia is furthermore partners in the following AP6 projects:

- CO2 Capture and Storage Program (capacity building)
- Ultra-Supercritical Pulverized Coal and Carbon Capture and Storage (USC PC/CCS) Near Zero Emissions Workshop and Design Guides for APP Countries
- Ultra Clean Coal Project
- Oxy-Fuel Combustion Program and Working Group
- Assessing Post-Combustion Capture for Emissions from Coal-Fired Power Stations
- Integrated Gasification Combined Cycle with Carbon Capture and Storage Workshop, and Design Information for APP Country Coals
- CO2 Enhanced Coal Bed Methane (ECBM) (CSIRO-JCOAL-ECBM)

Development of Advanced Adsorption Process Technologies for Pre-Combustion Capture of CO2 in Coal Gasification Processes (IGCC)

[375] www.cslforum.org/documents/FrioProject.pdf
[376] recopol.nitg.tno.nl
[377] www.utexas.edu/research/projects/frio.html
[378] www.asiapacificpartnership.org
[379] www.csiro.au/news/CarbonCaptureMilestone.html

China

GOVERNMENTAL PROGRAMS AND STRATEGIES

General policy

China is the world's largest CO2 emitter with more than 3 billion ton CO2 per year, surpassing the U.S. in 2007. Despite its impressive nuclear and renewable energy growth rates, about 75 percent of China's electricity still comes from coal-fired power plants. Without emission reducing measures, China's CO2 emissions from using coal are set to double by 2030. In view of the essential role of coal in China's energy system, it is vital to minimise emissions where coal is used. The government argues that although China is now the largest emitter of CO2, per capita emissions of CO2 is still be less than one half the world's average of 1.2 ton per head, or one sixth of the 3.3 ton per head average of industrialized countries.

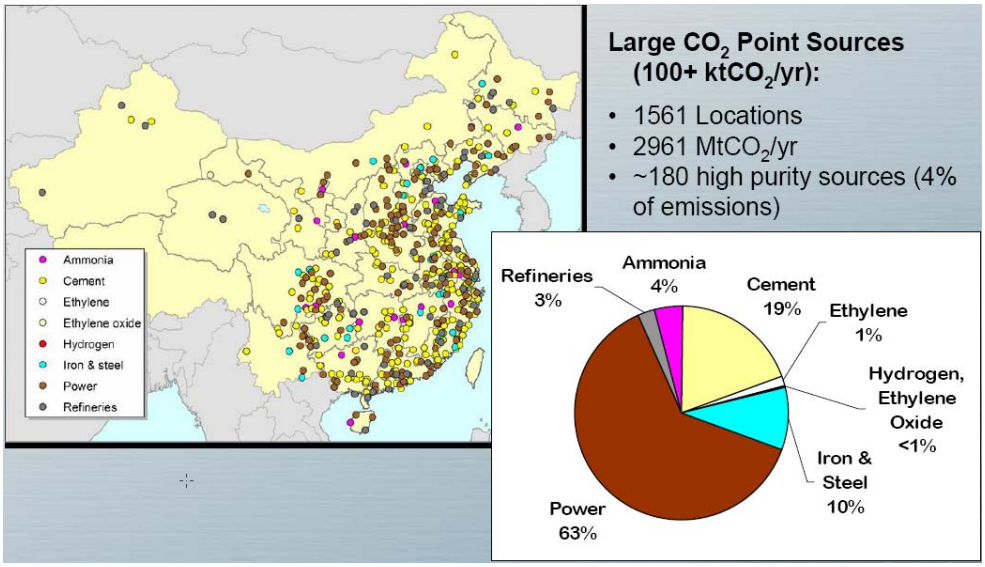


Figure 35: Location and distribution of large CO2 emitters in China. Source: Battelle, USA.

Two main governmental organs are actively engaged in Chinese CCS policy and technology development; namely the Ministry of Science and Technology (MOST)[380] which is overlooking technology development and research; and the National Development and Reform Commission (NDRC)[381] which is responsible for CCS policy.

[380] www.most.gov.cn/eng
[381] en.ndrc.gov.cn

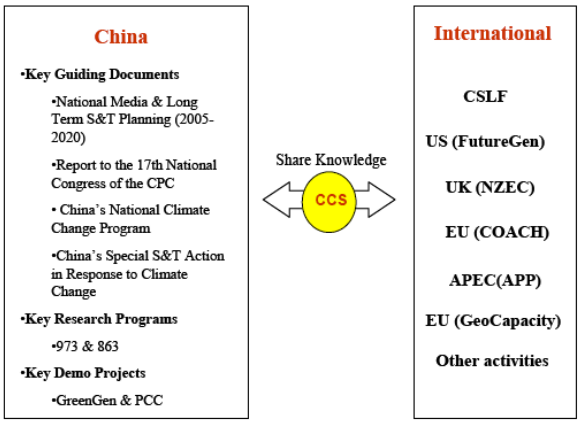


Figure 36: China's official CCS activities. Source: Hengwei Liu 2009.[382]

China's Agenda 21[383] is a White Paper on China's Population, Environment & Development in the 21st Century, and chapter 18 covers the needs to reduce CO2 emissions, without being specific on technologies such as CCS. China will actively participate in international activities aimed at controlling greenhouse gas emissions. In keeping up with China's use of energy resources and level of economic development, adjustments in industrial and energy structures will be made to improve terminal energy utilization technologies to reduce emissions of CO2. In 2005, CCS technology was integrated into the National Medium- and Long-term Science and Technology Development Plan towards 2020 as *a leading technology*. CCS is furthermore mentioned explicitly in China's Scientific & Technological Actions on Climate Change; the State High-Tech Program (863) R&D Project and in China's National Climate Change Programme.

During a state visit to Japan in May 2008, Prime Minister Wen Jiabao made a statement expressing increased willingness to join the international Kyoto Protocol regime[384]. Furthermore, Japan and China will step up their climate change collaboration, including a concrete project for CCS in Harbin and Daquin oil field (see below). The statement also mentions Japan's support for China's plan on measures to deal with climate change. In the plan released in June 2007, China commits itself to reducing 950 million tons of emissions by 2010 in the energy sector.

China apparently has sufficient CO2 storage sites and capacities sufficient for its own and potentially other countries (e.g. Japan, Korea) deposits, and considers CO2 deposition for EOR purposes favourably. According to MOST[385] a preliminary assessment includes:

- 46 oil & gas reservoirs totaling 7.2 billion ton CO2
- 68 unmineable coal beds with methane recovery totaling 12 billion ton CO2
- 24 saline aquifers totaling 1,435 billion ton CO2

A general observation is that China is positive to CCS as a feasible technology to reduce CO2 emissions from e.g. coal power plants, but concerned about the high development and implementation costs, and also the penalty in plant efficiency. There are also concerns about storage reliability and regulation issues. These are concerned shared by most countries, and the Chinese government seems to welcome international collaboration and investments/financial support in domestic CCS projects[386].

The European Commission set out a plan on June 24th to help finance the design and construction of a power plant to demonstrate carbon capture and geological storage (CCS) technology in China. The commission said it has programmed funding of up to 50 million euros (US$70 million) for the construction and operation phase of the project, out of a total of 60 million euros (US$84 million) that has been earmarked for cooperation with emerging economies on cleaner coal technologies and CCS. But the funding is only a fraction of the project's total cost, which is estimated at 300 to 550 million euros (US$420 to 770 million). Therefore, the commission called on EU member states and China to contribute additional funding.

According to Gao Li from MOST[387]: "Chinese Government will support the research of CCS in China. However, in near future, the scope and scale of CCS activities in China will mainly depend on the fund from the international community. China believes that international mechanisms are important to develop and demonstrate CCS

[382] Driving Carbon Capture and Storage forward in China, Hengwei Liu, and Kelly Sims Gallaghera, 2009, www.sciencedirect.com
[383] www.acca21.org.cn
[384] www.chinadaily.com.cn/bizchina/2008-05/09/content_6672446.htm
[385] Presentation at IEA/CSLF Workshop on Near Term Opportunities for Carbon Capture and Storage, Aug. 2006. Li Gao; Office of Global Environmental Affairs, MOST
[386] Presentation at Sino – Norwegian Framework Agreement on Cooperation and Dialogue on Climate Change by Dr. Lu Xuedu, Office of Global Environmental Affairs, Ministry of Science and Technology of China. April 2008.
[387] Presentation at IEA/CSLF Workshop on Near Term Opportunities for Carbon Capture and Storage, Aug. 2006. Li Gao; Office of Global Environmental Affairs, MOST

technology and these mechanisms should be able to provide sufficient financial support to CCS activities in developing countries and helpful for technology transfer.

China will continue to seek more CCS cooperation opportunities with other partners, which are funded by foreign governments and international organizations. In near future, China will pay special attention on relevant capacity building issues, such as information sharing, exchange of professionals, and introduction of measures, tools and models, etc., and will focus on the areas that can bring direct economic returns, for example, EOR."

Inclusion of CCS in a future Kyoto Protocol/CDM framework may further attract foreign investments in Chinese CCS projects.

PROJECTS IN CHINA

The current Chinese CCS-related projects are in cooperation with foreign partners and largely based on foreign investment. CCS projects are governed under Ministry of Science and Technology (MOST). A number of key research centers, agencies and universities are engaged in the projects listed below.

GreenGen[388]

The $1 billion GreenGen was founded in 2005. The objectives are to research/develop and demonstrate (RD&D) integrated coal gasification, hydrogen production, hydrogen power generation and CO2 sequestration systems in China.

GreenGen is a joint venture representing China's largest electric utilities and coal companies. China Huaneng Group is managing partner. Partners include: China Datang Corp., China State Development and Investment Corp., China Guodian Corp., China Huadian Corp., China Power Investment Corp., China National Coal Group and Shenhua Group, along with Peabody Energy. Peabody, the only non-Chinese partner, has a 6 percent equity position in the project.

Led by managing partner China Huaneng Group, the group will design, develop and operate an integrated gasification combined cycle power plant near Tianjin, southeast of Beijing. Huaneng is also a member of the FutureGen Alliance.

- The first stage (2006 to 2009) is the starting period for GreenGen with an estimated investment of 2.5 billion Yuan ($360 million). In this stage, GreenGen Co. will build a 250 MW level IGCC power plant to complete the key technology research, development and demonstration, such as the dry-coal-powder compression gasification system (2000 tons/day), syngas purification, low-heating value gas turbine and the 250 MW level IGCC power plant construction and operation. In addition, a 2 MW GreenGen laboratory will be built and connected with the IGCC power plant , aims to research and test of the key technologies for next stage, such as the hydrogen production through coal gasification system, fuel cell power generation, CO2 capture and sequestration (CCS) , the system long term safe and reliable operation.
- The second stage is to improve the IGCC poly-generation technology, to evaluate the technical and economic aspects of 3,500 tons per day or 2×2,000 tons per day gasifiers for a 400 MW IGCC power plant. In addition, an industrial-size test system will be built based on the 400 MW IGCC power plant to research, develop and demonstrate the key technologies, such as the hydrogen production, the CO2 disposal, the hydrogen turbine and the fuel cell, etc.
- The third stage includes a 400 MW GreenGen power plant and complete the research and development of key technologies, including the large-scale hydrogen production from coal, power generation from fuel cells, the hydrogen and gas combined-cycle power generation, the CO2 capture and sequestration. The system design, integration and operating technologies will be developed for high efficiency power generation with near zero emissions. The technical and economic viability will be evaluated to pave the way for large-scale GreenGen power plant's commercialization.

GreenGen joined both the NZEC project and the COACH project and will play an important role in both projects.

[388] www.greengen.com.cn/en/index.asp

PCC Demo Project[389].

This project is China's first Post Combustion Capture (PCC) demonstration project. As part of Asia-Pacific Partnership (APP) on Clean Development and Climate (APP), the project is based on the agreement between the Australian government research organization CSIRO and China's Thermal Power Research Institute (TPRI). TPRI will install commission and operate a PCC pilot plant at the *Huaneng* Beijing Thermal Power Plant, with all of its equipment domestically made.

The A$4 million research project funded by CSIRO will fit a post-combustion capture (PCC) system to one of the Huaneng Group's pilot plants in Beijing. The project was put into operation on July 17, 2008, with a capability of recovering more than 85 percent of CO2 from flue gases and can thus trap 3,000 tons CO2 annually.

Figure 37: The post-combustion capture pilot plant at Huaneng Beijing Co-Generation Power Plant. Source CSIRO.

OTHER PROJECTS AND INTERNATIONAL COLLABORATION

Key research centers

Two national level key programs are involved with CCS:

- National Basic Research Program of China ("973" Program): Geologic Carbon Storage with Enhanced Oil Recovery (2006–2011). This project will carry out the basic research on geological, physical, and chemical problems of geologic carbon storage and EOR, non-linear flow mechanics problems of EOR, and carbon capture and anti-corrosion problems. The total research funding of this project is RMB 35 million. The objectives would be to enhance the oil recovery ratio by efficient use of CO2, to achieve tremendous economic benefits, and to mitigate the CO2 emissions[390].
- National High-tech Research & Development Program of China ("863" Program): Carbon Capture and Storage (2008–2010). This project will focus on advanced technologies for the capture of CO2 from flue gases and carbon sequestration technologies in saline aquifers. The government and industry provided about RMB 20 million and RMB 10 million respectively for the project. The objectives are to develop carbon capture technologies and to explore carbon sequestration technologies[391].

The Department of Thermal Engineering at Tsinghua University (DTE TU)[392] is engaged research and technology development in various CCS technologies, including amine scrubbing; ammonia scrubbing; membrane separation; and investigation and analysis on sequestration such as Enhanced Coal Bed Methane (ECBM) techniques. The department is also engaged in CCS policy including inclusion of CCS in the CDM.

Environment Research Institute of National Development and Reform Commission (ERI)[393], established in 1980, is a national research organization conducting comprehensive studies on China's energy issues. ERI is engaged in most of the ongoing and planned CCS projects in China through two centers; Center for Energy, Environment and Climate Change Research and Center for Clean Development Mechanism project management.

Other academic centers actively engaged in projects such as NZEC and COACH includes: Chinese Academy of Sciences (Institute of Geology and Geophysics)[394]; Centre for Energy and Environmental Policy (CEEP)[395], China University of Petroleum[396], North China Electric Power University[397] and Thermal Power Research Institute[398], University of Zhejiang[399] and Research Institute of Petroleum Exploration and Production (RIPED).

[389] www.csiro.au/news/CarbonCaptureMilestone.html
[390] http://7058.973program.org
[391] www.most.gov.cn/tztg/200802/t20080228_59390.htm.
[392] te.tsinghua.edu.cn
[393] www.eri.org.cn
[394] english.cas.cn
[395] www.ceep.net.cn/ceepen/index.asp
[396] wlzx.hdpu.edu.cn/english
[397] www.ncepu.net.cn/en
[398] www.tpri.com.cn/en/enindex.htm
[399] www.zju.edu.cn/english

Clean Energy Commercialisation Centre (CECC)[400]

BP and the Chinese Academy of Sciences (CAS) agreed on November 26th, 2008 to establish a Clean Energy Commercialization Centre (CECC) joint venture in Shanghai, jointly investing some RMB500 million ($73 million) to commercialize Chinese clean energy technologies.

Subject to final government approvals, the CECC joint venture is expected to be established in early 2009.

The Centre will draw on the expertise and experience of both partners to integrate individual energy-related technologies - such as coal gasification and conversion, carbon capture and storage, coal bed methane and underground gasification - developed by CAS institutes and other organizations both within and outside China, into competitive integrated manufacturing systems and solutions. The CECC will also serve as an international platform for further collaboration among research institutes, enterprises and other institutions to improve indigenous Chinese innovation capabilities and market applications in areas such as clean coal conversion, zero emission technologies, and carbon capture and storage.

NZEC – Near Zero Emissions Coal project[401]

The EU-China NZEC agreement was signed at the EU-China Summit under the UK's presidency of the EU in September 2005 as part of the EU-China Partnership on Climate Change[402]. The agreement has the objective of demonstrating advanced, near zero emissions coal technology through carbon capture and storage (CCS) in China and the EU between 2010 and 2015.

On June 29, 2009, the EU set out the Commission's plans for establishing an investment scheme to co-finance the design and construction of a power plant to demonstrate CCS technology in China. The Commission has programmed funding of up to €50 million for the construction and operation phase of the project, out of a total of €60 million that has been earmarked for cooperation with emerging economies on cleaner coal technologies and CCS.

Depending on the choice of technology used, and assuming China introduces some form of carbon pricing instrument, the additional cost of constructing and operating over 25 years a new power plant equipped with CCS in China has been estimated at €300-€550 million.

The project partners[403] consist of 20 Chinese participants from academia, government and industry, plus the international partners AEA[404], Alstom Power[405], British Geological Survey, BP[406], Doosan Babcock[407], Heriot Watt University[408], Imperial College[409] and Shell[410]. The Chinese partners are Tsinghua University (3E Research Institute, Tsinghua-BP Clean Energy Research and Education Centre, Dept of Environmental Engineering and Science), Zhejiang University, China University of Petroleum (Beijing and Huadong), North China Electric Power University Institute of Engineering and Thermophysics, Chinese Academy of Sciences (CAS), Institute of Geology and Geophysics (CAS), Institute of Policy and Management (CAS), Energy Research Institute (NDRC), TPRI, DCE, DTE GreenGen, PetroChina, Jilin Oilfield, China United Coalbed Methane Co.

A UK-China bilateral NZEC initiative was developed in support of this wider agreement, constituting the following three phases:

Phase 1 is a study of the feasibility of building coal fired power plants in China fitted with CCS. The geotechnical aspects of the research will involve selecting strategic sedimentary basins to be mapped for potential regional CO2 storage assessments (geocapacity), followed by more detailed assessment of sites potentially suitable for a demonstration of CO2 storage in China linked to a demonstration of CO2 capture from a coal-fired power station. Phase 1 was initiated November 2007 and will be concluded in autumn 2009.

Phase 2 will carry out further development work on storage and capture options leading to definition and design of one or more storage project. The timeline is 2 years.

Phase 3, which will construct and operate a demonstration plant by 2014-2015.

[400] www.bp.com/genericarticle.do?categoryId=2012968&contentId=7049483
[401] www.nzec.info/en/what-is-nzec
[402] ec.europa.eu/external_relations/china/summit_0905/index.htm
[403] www.nzec.info/en/project-partners
[404] www.aeat.co.uk
[405] www.alstom.com
[406] www.bp.com
[407] www.doosanbabock.com
[408] www.pet.hw.ac.uk
[409] www3.imperial.ac.uk/mechanicalengineering/research/thermofluids/sustainableenergy
[410] www.shell.com

COACH[411]

The EU COACH (Cooperation Action within CCS China-EU project) will prepare for demonstration of near-zero emissions coal technology (see NZEC project above) through CCS in China. The project has 20 partners of which 8 Chinese and funding from EU of 1.6M Euro.

COACH addresses the following issues:

- Enhancement of knowledge sharing and capacity building;
- Preparation of the implementation of large scale clean coal energy facilities by 2020;
- Addressing of the cross-cutting issues, eg. Legal, regulatory, funding and economic issues;
- Coordination of activities performed under the EU-China Memorandum of Understanding (MoU) on NZEC (Near Zero Emissions Coal).
- Identification of reliable geological storage capabilities of CO2 in China,

The objectives are to prepare for implementation of large scale "clean coal" power stations with CO2-capture – including IGCC and post-combustion, and provisions for Enhanced Oil Recovery using CO2 injection. That plant will include facilities to capture CO2 and the project will also deal with transport and storage of CO2 in a mature oil and gas reservoir. Building work is scheduled to begin in 2011, and the capture and storage chain should come on stream in 2015.

EU partners include IFP[412] (France) (coordinator), SINTEF[413], Geus (Denmark)[414], BGS (UK)[415], KTH (Sweden)[416], BP (UK)[417], StatoilHydro[418], Shell[419], Schlumberger[420], Alstom[421], Air Liquide[422] and Atanor. The Chinese partners are ACCA21, Tsinghua University, Zhejiang University, Inst. Of Engng Thermophysics, Thermal Power Research Inst., Inst. Of Geology and Geophysics, RIPED and GreenGen/Huaneng Group.

Yantai IGCC

The Yantai 400 MW Integrated Gasification Combined Cycle (IGCC) project in Yantai, Shandong Province has been included in China's 10th 5-year plan as a key element in developing and deploying clean coal technologies. Feasability studies were conducted since 1995, and the project is now under construction. The European Commission regards this project as a great opportunity to promote European technology in China and several international subcontractors are involved. Japan, trough Mitsubishi Heavy Industry, is also engaged in the project[423].

The State Power Grid Company, Shandong Electric Power Group, Shandong International Investment and Trust Co., and Yantai Power Development Company form a Special Purpose Company to build, operate and manage the Yantai IGCC plant.

The total project cost is estimated to be about $420 million, of which 20% will be financed by equity, 75% by a domestic loan and (China has requested) the balance by a $15-18 million GEF grant. The Chinese Government has decided bear the bulk of the $120 million cost difference between constructing a comparable PC plant (the least cost option) and the IGCC plant[424].

Japan-China EOR project

The governments of Japan and China have agreed on May 7th, 2008, to cooperate in carrying out a project to inject CO_2 emitted from a thermal power plant in China into an oil field. [425]

[411] www.co2-coach.com
[412] www.ifp.fr
[413] www.sintef.no
[414] www.geus.dk
[415] www.bgs.ac.uk
[416] www.kt.se
[417] www.bp.com
[418] www.statoilhydro.com
[419] www.shell.com
[420] www.slb.com
[421] www.alstom.com
[422] www.airliquide.com
[423] www.berr.gov.uk/files/file20018.pdf
[424] http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2003/08/19/000094946_0308190402026/Rendered/PDF/multi0page.pdf
[425] Nikkei financial news, May 3, 2008

According to the project plan, from 1 to 3 million tons of CO2 will be captured annually from the Harbin Thermal Power Plant in Heilungkiang Province and potentially other plants elsewhere. It will then be transported by pipeline about 100 km to China's largest oil field – the Daqing Oilfield, and injected and stored into the oilfield.

CCS alone will be unprofitable, but the two countries have determined that it makes financial sense if CCS is combined with an oil-exploitation (EOR) project. More than 40 million tons of oil is produced from the said oilfield annually. The project is expected to increase this figure by 1.5 to 2 million tons. It reportedly will also become possible to keep more than 150 million tons of CO2 into storage in the future.

Under the plan, more than one million tons of CO2 annually from will be transferred to the Daqing Oilfield, about 100 km from the plant, and will be injected and stored in the oilfield. The viscosity of crude oil there is thick but will be decreased by injecting CO2, making it easier to exploit the oil.

From Japan, the METI-affiliated Research Institute of Innovative Technology for the Earth (RITE) and other organizations plan to take part in the project, in addition to Toyota Motor Company and JGC Corp. From China, China National Petroleum Corporation and other organizations will participate. The two sides will begin negotiations on cost-sharing.

The project will cost 20 to 30 billion yen and is intended to start in 2009.

According to the Ministry of Economy, Trade, and Industry (METI), if realized, it will be the first case of injecting CO2 from a thermal power plant into an oil field.

Asia-Pacific Partnership (APP) on Clean Development and Climate[426].

APP partners Australia, Canada, China, India, Japan, Republic of Korea, and the United States have agreed to work together and with private sector partners to meet goals for energy security, national air pollution reduction, and climate change in ways that promote sustainable economic growth and poverty reduction. The Partnership will focus on expanding investment and trade in cleaner energy technologies, goods and services in key market sectors. One of the projects is a CCS capacity building program for it's member countries[427].

China is co-chair with Australia of the Cleaner Fossil Energy Task Force, and co-chair with the USA of the Power Generation and Transmission Task Force.

GeoCapacity[428].

GeoCapacity is co-funded by the EU within FP6. The main objective of the project is to *Assess the European Capacity for Geological Storage of CO2*. The project will include full assessments of a number hitherto not covered countries, and updates of previously covered territory. Also a priority is the further development of innovative methods for capacity assessment, economic modeling and site selection criteria. Finally, an important mission is to initiate scientific collaboration with China and possibly other CSLF members.

MOST has joined the GeoCapacity initiative as a full project partner. Under the supervision of MOST, Tsinghua University and Chinese Academy of Sciences participated into the GeoCapacity research project.

INTERNATIONAL COLLABORATION.

China is engaged in several international forum and research programs:

Carbon Sequestration Leadership Forum[429]. China was one of the initial members of CSLF, and the Chinese Ministry of Science and Technology (MOST) is engaging in the forum on behalf of China. Two Chinese projects has been recognized by the forum:

- The China Coalbed Methane Technology / CO2 Sequestration Project[430] was initiated in 2005. The $9 million test project at the South Qinshui Basin in Shanxi province, involving Canadian agencies, the Chinese Ministry of Commerce and China United Coal Bed Methane Corp., showed that methane rates rose to 55% from 30% within a month of CO2 being injected into the coal bed. It is now completed[431].
- Regional Opportunities for CO2 Capture and Storage in China[432] started 2005 under leadership of US.

China is engaged in several international co-operation projects in e.g. EU such as Geocapacity[433], Movecbm[434], STRACO2, Caprice[435].

[426] www.asiapacificpartnership.org
[427] www.asiapacificpartnership.org/APPProjects/CFETF/CFE-06-01.pdf
[428] www.geology.cz/geocapacity
[429] www.cslforum.org
[430] www.cslforum.org/documents/China_ECBM.pdf
[431] www.cslforum.org/documents/FinalReportCCBMproject.pdf
[432] www.cslforum.org/documents/Assessing_Market_Opportunities_for_CO2_CCS_in_China.pdf

Australia-China Joint Coordination Group on Clean Coal Technologies was announced in April 2008. The Australian government will invest A$20 million in this partnership as part of it's A$500 million Clean Coal Fund.

FutureGen Alliance[436]. China Huaneng Group joined FutureGen Alliance in 2005. The investment from Huaneng in FutureGen accounts for two percent of the total investment. However, Huaneng is in a position to share the technology and achievements of FutureGen as a shareholder.

In November 2007, Australia and China signed a partnership agreement that will pave the way for the installation of a post combustion capture (PCC) plant in Beijing 2008. Signed by CSIRO (Commonwealth Scientific and Industrial Research Organization) Energy Technology Chief Executive, Dr Geoff Garrett, and Mr Li Xiaopeng, the President of China's state-owned energy enterprise, the China Huaneng Group, the agreement will see the plant installed at the Huaneng Beijing Co-generation Power Plant.

Britain's BP Plc (BP) has been working with Tsinghua University and Dalian Institute of Chemical Physics since 2002 on membranes for separation of CO2 from flue gas. The BP Tsinghua University Clean Energy Research and Education Centre[437]. was launched the British Prime Minister Tony Blair in July 2003. It aims to combine the strengths to create a "world-leading institute for energy strategy study for China". It has attracted a broad range of important players in various aspects of energy, industry and environment to serve on the Advisory Board of the Centre. The current projects at the centre include the BP Clean Energy projects. In addition, there are conferences and seminars on Clean Energy related topics are held in the Center. Since it was opened by Tony Blair the centre has hosted hundreds of meetings of the Energy and Resources team for China's Long Term Science and Technology strategy. The Clean Energy Centre is the academic unit of Tsinghua having academic freedom to pursue any aspects of clean energy policy or strategy that appears attractive to China.

China United Coalbed Methane Corportation (CUCBM)[438] is state-owned company, established in 1996 with exclusive rights to explore, develop and produce coalbed methane in cooperation with overseas companies. CUCBM has signed 21 production sharing contracts with 10 overseas companies, with a total foreign investment of $119 million. The company is engaged in the N-ZEP project among others.

There is a number of EOR (Enhanced Oil Recovery) projects in China. Projects have been implemented in Shengli, Zhongyuan, Jilin, Daqin, Jiangsu, Songliao oil fields.

[433] www.geology.cz/geocapacity
[434] www.movecbm.eu
[435] www.caprice-project.eu
[436] www.futuregenalliance.org/alliance.stm
[437] www.bp.com/sectiongenericarticle.do?categoryId=9011369&contentId=7025853
[438] www.chinacbm.com (currently in Chinese only)

Other Regions

ALGERIA

In Salah reinjection project[439]

In 2004 BP launched a CO2 capture and storage project at the In Salah gas field, in the Algeria desert. In Salah is a joint venture between Sonatrach[440], the Algeria national energy company, BP and Statoil. Approximately 10% of the gas in the reservoir is made up of CO2. Rather than venting the CO2, which is the established practice on other projects of this type, the project is compressing it and injecting it in wells 1,800 metres deep into a lower level of the gas reservoir where the reservoir is filled with water. Around one million ton of CO2 is injected into the reservoir every year, and the total storage is expected in the order of 17 million tons[441].

The project cost is $ 100 million, with CO2 capture and storage cost at $6 per ton CO2.

UNITED ARAB EMIRATES

Masdar Precombustion CCS project [442]

The WWF and Masdar, The Abu Dhabi Future Energy Company, launched in January 2008 a "Sustainability Action Plan" to deliver the world's greenest city – Masdar City. Located near Abu Dhabi International Airport, Masdar City will be the world's first zero-carbon, zero-waste, car-free city, aiming to exceed the 10 sustainability principles of "One Planet Living™"– a global initiative launched by the Worldwide Fund for Nature and environmental consultancy BioRegional. Masdar is driven by the Abu Dhabi Future Energy Company (ADFEC), a wholly owned company of the government of Abu Dhabi through the Mubadala Development Company. In January 2008, Abu Dhabi announced it will invest $15 billion in Masdar, the largest single government investment of its kind.

The CCS project includes a 420 MWe hydrogen-fired power generation project with CO2 capture. The captured CO2 would then be available for EOR and storage[443]. The capture capacity is in the order of 1,7 million ton CO2 / yr.

According to the pre-feasibility study done by the Canadian engineering company SNC Lavalin, the overall project would require total capital investment, excluding the investment in CO2 transportation and sequestration, of about $2 billion to $3 billion[444].

Masdar announced November 18 the selection of Houston, Texas-based Mustang Engineering, a subsidiary of international energy services company John Wood Group PLC, to provide front-end engineering and design (FEED) services for Masdar's Carbon Capture and Storage (CCS) project in the United Arab Emirates.[445] The first phase consists of 5 million Tons of CO2 gas captured per year as of end 2013 from 3 emission sources: a gas-fired power plant, an aluminum smelter and a steel mill.

Other CCS projects in UAE

SNC Lavalin has in an feasibility study identified 4 to 6 possible CCS projects in the UAE[446]. These projects could amount to 6 to 8 million ton CO2 captured per year, from a total forecasted emission of about 76 million tons. CO2 captured in the UAE region can relatively be used for EOR purposes, making CCS projects in the region attractive. The identified projects are in the order of $ 500 million each.

[439] www.bp.com/sectiongenericarticle.do?categoryId=9012195&contentId=7024392
[440] www.sonatrach-dz.com
[441] www.opec.org/home/Press%20Room/EU-OPEC%20presentations/HaddadjiSonatrach%20Algeria.pdf
[442] www.masdar.ae
[443] www.hydrogenenergy.com/FullStory.aspx?m=51&amid=582
[444] www.arabianbusiness.com/508919-carbon-capture-storage-to-cost-up-to-3bn
[445] www.masdar.ae/text/news-d.aspx?_id=66
[446] www.upstreamonline.com/live/article147474.ece