Report Title

CO_2 Capture Project - An Integrated, Collaborative Technology Development Project for Next Generation CO_2 Separation, Capture and Geologic Sequestration

Technical Progress Report

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Abstract

The CO_2 Capture Project (CCP) is a joint industry project, funded by eight energy companies (BP, ChevronTexaco, EnCana, Eni, Norsk Hydro, Shell, Statoil, and Suncor) and three government agencies (European Union {DG Res & DG Tren}, Norway {Klimatek} and the U.S.A. {Department of Energy. The project **objective** is to develop new technologies, which could reduce the cost of CO_2 capture and geologic storage by 50% for retrofit to existing plants and 75% for new-build plants. Technologies are to be developed to "proof of concept" stage by the end of 2003. The project budget is approximately $24 million over 3 years and the work program is divided into eight major activity areas:

- **Baseline Design and Cost Estimation -** defined the uncontrolled emissions from each facility and estimate the cost of abatement in $/tonne CO_2.
- **Capture Technology, Post Combustion**: technologies, which can remove CO_2 from exhaust gases after combustion.
- **Capture Technology, Oxyfuel**: where oxygen is separated from the air and then burned with hydrocarbons to produce an exhaust with high CO_2 for storage.
- **Capture Technology, Pre-Combustion**: in which, natural gas and petroleum coke are converted to hydrogen and CO_2 in a reformer/gasifier.
- **Common Economic Model/Technology Screening**: analysis and evaluation of each technology applied to the scenarios to provide meaningful and consistent comparison.
- **New Technology Cost Estimation**: on a consistent basis with the baseline above, to demonstrate cost reductions.
- **Geologic Storage, Monitoring and Verification (SMV)**: providing assurance that CO_2 can be safely stored in geologic formations over the long term.
- **Non-Technical**: project management, communication of results and a review of current policies and incentives governing CO_2 capture and storage.

Technology development work dominated the past six months of the project. Numerous studies are making substantial progress towards their goals. Some technologies are emerging as preferred over others. Pre-combustion Decarbonization (hydrogen fuel) technologies are showing good progress and may be able to meet the CCP's aggressive cost reduction targets for new-build plants. Chemical looping to produce oxygen for oxyfuel combustion shows real promise. As expected, post-combustion technologies are emerging as higher cost options that may have niche roles. Storage, measurement, and verification studies are moving rapidly forward. Hyper-spectral geo-botanical measurements may be an inexpensive and non-intrusive method for long-term monitoring. Modeling studies suggest that primary leakage routes from CO_2 storage sites may be along wellbores in areas disturbed by earlier oil and gas operations. This is good news because old wells are usually mapped and can be repaired during the site preparation process.

Many studies are nearing completion or have been completed. Their preliminary results are summarized in the attached report and presented in detail in the attached appendices.

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Executive Summary

The CO_2 Capture Project (CCP) is a joint industry project, funded by eight energy companies (BP, ChevronTexaco, EnCana, Eni, Norsk Hydro, Shell, Statoil, and Suncor) and three government agencies (European Union {DG Res & DG Tren}, Norway {Klimatek} and the U.S.A. {Department of Energy}). The merger of Chevron and Texaco (both were participants) at the end of 2001 caused the number of industry participants to drop from nine to eight for 2002.

The project **objective** is to develop new technologies, which could reduce the cost of CO_2 capture and geologic storage by:

50% for retrofit to existing plants and
75% for new-build plants.

Technologies are to be developed to "proof of concept" stage by the end of 2003.

Cost reductions will be benchmarked against four practical case studies (termed **scenarios within the CCP context),** which were chosen to represent real-life energy industry applications:

- An existing large European refinery (Grangemouth, UK).
- A large new-build electrical power generation facility in Norway.
- A group of existing distributed gas turbines Alaska, USA.
- A new-build integrated gasification combined cycle coke de-gasification facility in Canada.

The project budget is approximately $24 million over 3 years and the work program is divided into eight major activity areas:

- **Baseline Design and Cost Estimation.** For each of the four applications baseline designs have been developed. These define the uncontrolled emissions from each facility, developed a design for CO_2 abatement using the current best available technology (BAT), and estimated the current cost of abatement in $/tonne CO_2. Technology advances made by CCP will be benchmarked against the best available technology on a consistent basis.
- **Capture Technology, Post Combustion**: technologies, which can remove CO_2 from exhaust gases after combustion.
- **Capture Technology, Oxyfuel**: where oxygen is separated from the air and then burned with hydrocarbons to produce an exhaust with high CO_2 for storage.
- **Capture Technology, Pre-Combustion**: in which, natural gas and petroleum coke are converted to hydrogen and CO_2 in a reformer/gasifier. The CO_2 is compressed for storage and the hydrogen is mixed with air for combustion, emitting only nitrogen and water.
- **Common Economic Model/Technology Screening**: analysis and evaluation of each technology applied to the scenarios to provide meaningful and consistent comparison.
- **New Technology Cost Estimation**: on a consistent basis with the baseline above, to demonstrate cost reductions.
- **Geologic Storage, Monitoring and Verification (SMV)**: providing assurance that CO_2 can be safely stored in geologic formations over the long term.
- **Non-Technical**: project management, communication of results and a review of current policies and incentives governing CO_2 capture and storage.

The two charts (Figures 1 and 2) below illustrate spend over the life of the project, split by technology and funder (the dotted line shows status at the end of July 2003):

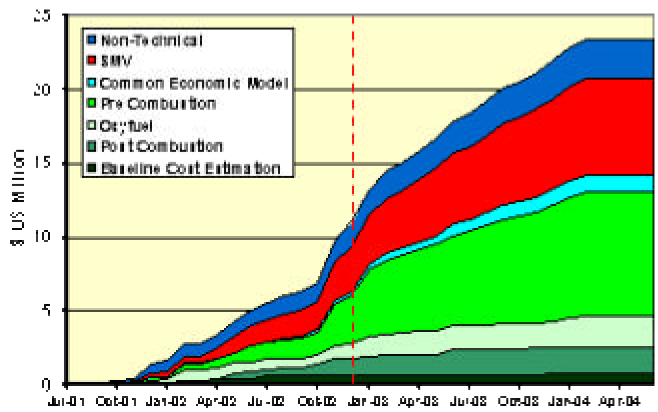

Fig 1. CCP Spend By Technology

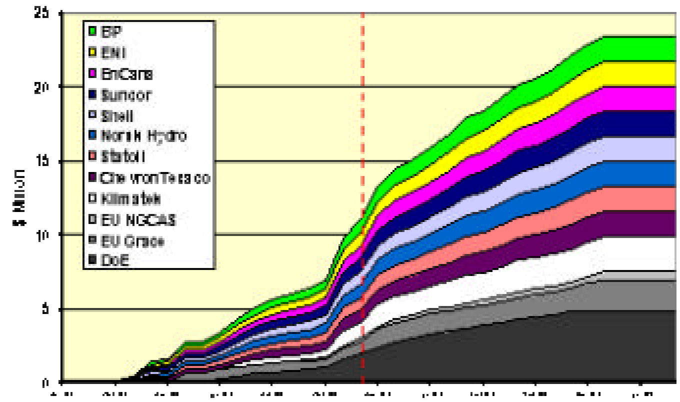

Fig. 2 CCP Spending By Funder

During 2001, the project completed a comprehensive review and analysis of existing commercial technologies, technologies under development and identified high-potential technologies for further analysis. Fifty technologies were chosen for development within the CCP and over eighty contracts were signed with technology providers in multiple countries, to deliver that program. A **Common Economic Model** (CEM) was completed and peer reviewed by industry experts Ed Rubin (Carnegie Mellon University, Pittsburgh Pennsylvania, USA) and Howard Hertzog (Massachusetts Institute of Technology Boston, Massachusetts, USA). The model was used to evaluate each scenario baseline (with and without CO_2 capture) as well as key capture technologies that show most promise.

During 2002, it became apparent that the cost of performing rigorous cost estimation for every technology in every scenario would be prohibitive, so the Executive Board established a **Technology Screening Task - Force** (TSTF) to provide early indications of abatement costs and help to choose the technologies most likely to meet CCP objectives. At the end of the year, the work of the CEM & TSTF yielded CO_2 avoidance costs (+/-30%) for several technologies of up 60% below BAT. At major decision points, CCP processes and decisions were peer reviewed by a **Technology Advisory Board** (TAB) comprising independent experts from industry, government and academia. A **Policies and Incentives** team was formed during 2002 with the objective of producing a comprehensive review of existing policies governing CO_2 Capture & Storage. **Outreach** to stakeholders built on the two successful workshops held in Europe and the USA in 2000 and 2001. The project website

http://www.co2captureproject.org/

is updated regularly as the project develops and reports are delivered. The website has over 5000 non-project visitors monthly. Technical papers were delivered at several industry conferences - notably the International Energy Association's (IEA) Sixth GreenHouse Gas Technology conference (GHGT-6) in Kyoto, Japan.

February 2003-August 2003 Progress

Post-Combustion Studies

Post-combustion capture of CO_2 from flue gas has been studied for over 30 years so there are few opportunities to significantly reduce the cost of capture relative to conventional amine technology. However a small but steady stream of ideas continues to emerge. Many are at the concept stage and will not reach the full proof of concept stage in the lifetime of this program. The team felt it was important to continue to review and evaluate these as they appear. Thus, the CCP Post-Combustion team takes a balanced approach with regards to maturity and technical risk in technology selection. The CCP has funded several engineering studies and technology development programs in the post-combustion area. The individual programs all vary in degrees of maturity, technical risk, and cost-reduction potential.

Co-funded by NORCAP:
- Amine Scrubbing with a Membrane Contactor (Mitsubishi Heavy Industries (MHI) and Kvaerner Process Systems (KPS))
- Cost Effective Design and Integration Study (Nexant)
- Radical Chemistry Concepts (Norsk Hydro and numerous academic partners)

Funded directly by CCP:
- Baseline Design and Cost Estimation (Fluor)
- Electric Swing Adsorption (Oak Ridge National Laboratories and Kvaerner Process Systems)
- Novel Channel adsorption technology (Norsk Hydro)

Co-funded by DOE
- Self-Assembled Nanoporous Materials for CO2 Capture (SRI)

The CCP has learned that entirely new approaches would be required to reduce the cost of post-combustion CO_2 capture by the levels specified at the outset: by 50% for retrofit and 75% below conventional amine technology for new-build scenarios. The only CCP project sponsored by DOE, "Self-Assembled Nanoporous Materials for CO_2 Capture," is a high-risk program that may be useful in retrofit and new-build applications as well as pre-combustion CO_2 capture. The planned study on electric swing adsorption technology was abandoned when CCP funded studies demonstrated that the benefits anticipated from this approach would not materialize for our scenarios.

Pre-Combustion Studies

The four major projects in the pre-combustion technology program were subjected to stage-gate reviews. Three projects passed their stage-gate reviews while the Sulfur Tolerant Membrane Study passed part of the criteria and was re-directed in March 2003. The study is underway based on the new focus and direction.

- 1.2.1.1 Sulfur Tolerant Membrane Study
- 1.2.1.1.6 Hydrogen Membrane Reactor
- 1.2.1.3 Hydrogen Membrane Reformer
- 1.2.1.2 Production of Hydrogen Fuel by Sorbent Enhanced Water Gas Shift Reaction,

The results indicate that the membrane technologies have advanced much more than anticipated at the beginning of the project in view of the short development work periods (12-16 months.) The projects were high risk with a substantial likelihood of failure. The membrane developers have overcome significant barriers and are well positioned to continue their work.

Oxyfuel

The principle of CO_2 capture by **oxyfuel** combustion is to burn fuel with oxygen rather than air so that the flue gas consists mainly of CO_2 and water with little nitrogen. However, oxygen combustion would result in very high combustion temperatures without the nitrogen diluent from air. Studies, including pilot scale testing on coal, indicate that oxyfuel combustion with flue gas recycle can be retrofitted to boiler and other heating plants with no major technical obstacles. Gas turbine applications would require costly development of new combustors, compressors, and turbines to accommodate the change in working fluid.

These studies have shown that the major additional capital and operating costs in oxyfuel combustion for CO_2 capture are those associated with oxygen production when new gas turbine design costs are excluded. Combustion in pure oxygen or in oxygen enriched air in special high temperature furnaces is widespread in the metallurgical, glass and other industries, and therefore the operational and safety issues of oxygen combustion are well understood.

New and lower cost oxygen production methods are under active development which means that the overall cost of oxyfuel concepts, i.e. those using flue gas recycle, should fall significantly. The potential for oxyfuel combustion to be retrofitted to existing boilers and heaters makes this route attractive to the CCP. Other concepts under consideration are integration of oxygen generation directly with the combustion system that may have further cost reduction potential. Other proposals seek to take advantage of the distinctive characteristics of oxyfuel combustion to conceive power plants with higher efficiency and/or lower capital cost, in order to offset the cost of generating oxygen. One technology, chemical looping, looks at a novel, potentially energy saving, process that combines air separation with fuel oxidation.

The future economic driver for the adoption of oxyfuel technologies lies mainly in novel technologies for air separation that are able to reduce drastically the cost of oxygen production. The CCP may benefit from DOE co-funded R&D projects aimed to develop novel ceramic membranes for air separation that are able to permeate oxygen with 100% selectivity. The CCP funded several studies to assess the technical and economic potential of these technologies applied to CO_2 capture. A baseline using conventional air separation for oxygen supply was also established.

Other approaches, considered in the technology selection phase of CCP (high pressure boilers, zero recycle boilers, advanced cycles), were discarded after preliminary studies showed no promising economics.

Storage, Measurement, and Verification Studies

The CCP-SMV program is comprised of four major technology areas:

1) Integrity – evaluation of natural and engineered systems and their suitability for CO_2 sequestration,
2) Optimization – realizations of efficiencies and tradeoffs that improve the economics of CO_2 sequestration,
3) Monitoring – the development of performance evaluation tools and safeguards in the CO_2 sequestration "life cycle" and

4) Risk Assessment – identification and quantification of HSE risks associated with CO_2 sequestration.

5) A fifth program comprises an effort to integrate results of the studies and strategies for their dissemination outside of CCP.

Since CCP's inception in 2000, the SMV program has contracted 33 studies, including NGCAS (6 projects). Presently, nine of these studies are complete, sixteen have been active since before early 2003 and eight are newly contracted in the present reporting period. Most projects will be completed by the end of 2003 with the exception of NGCAS (European Union funded) and, possibly, some of the Risk Assessment projects. The following is an overview of the progress of the SMV projects for the present reporting period

Integrity

Integrity studies include examination of competent and incompetent natural systems for CO_2 storage, CO_2 exposure experiments on natural reservoir and cap-rocks and well materials and predictive modeling of reservoir / cap rock response to CO_2 injection. Two studies use natural geologic systems to characterize a formation's competence to store CO_2. Prototypically incompetent geyser systems from the East-Central Colorado Plateau are examined for features that preclude effective CO_2 storage (Utah State University; Evans). Detailed geologic, hydrologic and geochemical work showed that despite the potential for fault gouge sealing or sealing by mineralization of fractures and faults, the geyser systems have been releasing abundant CO_2 charged water since the early Tertiary. The chemistry showed that the system is fed meteoric water, which reacts to release CO_2 from minerals. CO_2 evolves from the water as it travels to shallower depths up through the fault system. In contrast, the naturally occurring CO_2 fields assessed by ARI (Stevens) have apparently hosted CO_2 for geologic-scale time periods. Structural and stratigraphic characteristics as well as details on reservoir and cap rock systems will define features favorable to CO_2 accumulation and retention. As some of these fields are operated to produce CO_2, valuable information on drilling, performance and safety will become available.

Experiments on reservoir and seal rocks under reservoir pressure and temperature are ongoing at GFZ-Potsdam (Borm). The purpose of these experiments is to ascertain physical and chemical transformations that alter rock properties with CO_2 exposure. There is evidence for changes in the physical strength of the rocks, possibly due to mineralogical transformations (dissolution and precipitation). The susceptibility of well materials (cement and steel) to weakening by erosion / corrosion or strengthening by scaling / mineral precipitation in the presence of elevated CO_2 addresses perhaps the weakest link in CO_2 containment (Lindeberg, SINTEF). Recommendations for new, less susceptible well materials, completion procedures and intervention will be included in the final study.

The integrity program has identified the principal weaknesses to CO_2 containment in natural and engineered systems. The obvious solution includes careful evaluation of natural systems using analogs and experiments and the development special well materials / construction and remediation.

Optimization

Optimization studies attempt to identify more efficient ways to store CO_2 in settings familiar to the oil and gas industry (e.g., EOR and EGCR), anticipate difficulties in CO_2 storage in other venues (e.g., aquifers) and look for economic tradeoffs with the CO_2 capture. The survey conducted by the New Mexico Institute of Mining and Technology (Grigg) identified areas for improvement in CO_2 EOR operations that have implications for CO_2 storage. Research recommendations included CO_2 injectivity, conformance, monitoring and remediation. Further work could also examine the ultimate storage capacity of these reservoirs as well as leakage detection and rates. The Texas Tech University (Frailey / Lawal) and Tieline Technology (Stenby) studies address phase behavior of CO_2 in gas and gas condensate reservoirs and in oil reservoirs (respectively).

An extensive survey of Canadian and European natural gas storage experience has been compiled by GTI (Perry). Although the focus of this work was on leakage identification and remediation, there are valuable insights into geological features that make such operations successful. Issues identified are keyed to how the CO_2 storage might be impacted. As with the natural gas storage experience in the USA, it is remarkable how few incidents have been reported. The hazard levels anticipated from CO_2 storage would seemingly be less, given that the technology to identify appropriate storage venues are improving and CO_2 is not flammable.

A baseline for piping, compression and injection systems needed to transport CO_2 is the topic of the Reinertsen Engineering study. An optimization of materials and necessary hydration levels will be the product of this study.

Economic tradeoffs between the purity of CO_2 (with various levels of SOx and NOx) captured at the surface and the behavior of impure CO_2 in the subsurface are the topics of studies by Battelle (Gupta) and The University of Texas (Bryant), respectively. In the surface study, possible untoward effects on amine and other solvent systems and piping and compression equipment will be evaluated. Subsurface phase and solubility behavior of impurities and their effects on subsurface equipment and reservoirs will be estimated in the subsurface study.

These optimization studies, once integrated and attached to realistic scenarios, will be of considerable value in approaching workable CO_2 capture, transportation and storage programs.

Monitoring

Numerous remote (satellite and aerial), geophysical and geochemical approaches to monitoring CO_2 storage performance and leakage / seepage have been proposed. The resolution and expense of these techniques varies considerably. The principal goal of the monitoring studies is identify the most useful and cost effective approaches. TNO (Arts) presented a comprehensive, comparative survey of monitoring technologies in addition to seismic modeling of aquifer CO_2 storage and ECBM. LBNL (Hoversten) provides field, experiment, model and theoretical examples of novel non-seismic geophysical monitoring techniques. Ongoing work includes surface seismic, AVO analysis and electromagnetic modeling.

The single geochemical-based monitoring project investigates the use of noble gas isotopes as tracers and leakage indicators. The CO_2 EOR Mabee Field of West Texas is used as an example application. Doping of supply gas with such chemically distinctive gases allow, in addition to tracing CO_2 conformance, a means to establish ownership of leaked gas is made available.

The early study by Tang (CalTech) evaluated the state-of-the-art in atmospheric monitoring technologies. A follow-up study aims at identifying technologies capable of detecting leakage rates as small as 1% and developing scenarios at which such techniques might be applicable.

Satellite and aerial hyperspectral analysis of plant stress and mineral anomalies, thought to be induced by high surface CO_2 concentrations were investigated by LLNL (Pickles). An aerial survey of the CO_2 EOR Rangely Field, CO, has been examined for anomalies and a field trip is planned to determine what features might be associated with these anomalies. A recently contracted study will evaluate the near surface approaches to detect CO_2 leaks (Davis, Penn State). The favored technology, IR laser, will be evaluated for capability of measuring near surface vertical turbulent flow of CO_2.

A broad range of monitoring technologies has been investigated for the monitoring program. Future research direction will focus on the few most promising remote / aerial, near surface and subsurface approaches. Additional programs should also include direct analyses of subsurface fluids (e.g., well water and gas sample analysis, soil gas analysis).

Risk Assessment

Risk assessment was identified as a critical research area early in the SMV program. Initial studies contracted and completed include an HSE assessment and lessons learned by other industries involved in the disposal of industrial wastes or storage of natural resources (Benson, LBNL) and one focusing mostly on political and regulatory lessons learned by the nuclear waste industry. Subsequently, three large risk assessment methodologies development studies evolved and are ongoing (Wildenborg, TNO; Liang, INEL; Oldenburg, LBNL). An additional study, involving reactive transport modeling to assess transformations in reservoir and cap-rocks, is also summarized but the results are also applicable to the "Integrity" program outlined above.

The TNO study proposed two scenarios to test their risk assessment methodology (Southern North Sea aquifer and onshore Netherlands gas field). Extensive work has been done on FEP (features, events and processes) that is now destined to become a standard, shared database. A Monte Carlo simulation (>1000 parameter combinations) of a reservoir seal model has recently been successfully completed. Simulations of a shallow subsurface / surface (atmosphere) model was been conducted recently with LBNL (Oldenburg). The probabilistic tool developed earlier in 2003 was tested and found to be user friendly and fast. Work continues on collecting data needed to run simulations of the two scenarios.

The coal bed-based (ECBM) risk methodology by INEL (Liang) continues apace in conjunction with a larger San Juan Basin coal bed methane storage capacity study. Geomechanical studies have elucidated mechanisms for gas leakage from fractures in coal and its overburden. Relative risks of poorly designed fracturing attempts and uncemented versus cemented wells have been estimated. Using the larger Fruitland coal seepage model, simulations suggest guidelines for locating injection relative to the water table and outcrops.

The reactive transport modeling by LLNL (Johnson) incorporates coupled thermal, hydrological and geochemical processes to address key technical issues related to cap rock integrity (particularly that associated with the well bore) in aquifer storage of CO_2. Significantly, there is evidence for continuous improvement of hydrodynamic seal integrity via mineral trapping mechanisms

Communication of Results

Dissemination of CCP results to the broader scientific community and to policy makers is a key activity. Detailed planning for that technology transfer activity is underway. Plans for integration and dissemination of CCP research results coordinating the SMV, Capture, and Economic Modeling efforts are being prepared. LBNL (Benson) has been contracted to arrange publications at the technical specialist, general scientific / engineering, government / regulator, NGO and general public levels for the SMV program. ARI (Thomas) will carry out a similar program for Capture and Economic modeling studies

Summary Report

CCP's agreement with the U.S. DOE includes a number of tasks that are reported upon in this document. Each summary refers to the relevant task - number in its title. The tasks covered by this agreement reported here are identified in the following Table 1. Not all the technology areas defined below are currently under study with DOE funding as noted in the technology development discussions.

Table 1
Relationship Between U.S. DOE Project Tasks and CCP Projects

Task	Description	Related Report Section
0.0	**Project Definition**	Technology Selection
0.1	Identify Relevant Separation, Capture, and Sequestration Scenarios	Scenarios
0.2	Establish State-of-the-Art Separation and Capture	3. Technology Screening 4. Economic Modeling
0.3	Develop and Apply Common Economic Model	3. Technology Screening 4. Economic Modeling
0.4	Define Work Plan	See 0.0 Project Definition above.
0.5	Select Technology Developers	See 0.0 Project Definition above.
1.0	**Develop Post-Combustion Separation and Capture**	1.1 Post Combustion Studies - studies under this heading
1.1	Advanced Solvents	Not U.S. DOE funded in CCP
1.2	Advanced Absorbers/Desorber Designs	Not U.S. DOE funded in CCP
1.3	Systems Integration and Optimization	Not U.S. DOE funded in CCP
1.4	New and Novel Concepts	1.1.1.1 Radical Post-combustion technologies. 1.1.1.2 Self-Assembled Nanoporous Materials.
2.0	**Develop Pre-Combustion Decarbonization Techniques**	1.2 Pre-combustion Decarbonization (PCDC) Program - studies under this heading
2.1	Gas Turbine Fuels	1.2.1.2 Sorption Enhanced Water Gas Shift (SEWGS)
2.2	Fuel-Grade Hydrogen Generation	1.2.1 Membrane Studies 1.2.1.1.7 Membrane Water Gas Shift (MWGS)
2.3	Systems Integration and Optimization	1.2.3 Integration & Scale-up Studies
2.4	New and Novel Concepts	1.2.1.1 Sulfur Tolerant Water Gas Shift Reactor Systems
3.0	Develop Oxyfuel Technologies	1.2.1 Capture Studies - studies under this heading
3.1	Advanced New/Retrofit Boiler Designs	1.3.1 Advanced Boiler Study
3.2	Membrane Air Separation Units	Not U.S. DOE funded in CCP
3.3	Systems Integration and Optimization	Not U.S. DOE funded in CCP
3.4	New and Novel Concepts	Not U.S. DOE funded in CCP
4.0	**Establish Key Geologic Sequestration Controls and Requirements**	2. Storage, Monitoring and Verification (SMV) Studies - studies under this heading
4.1	Understanding Geologic Storage	2.1 Integrity - studies under this heading 2.2 Optimization- studies under this heading 2.3 Integrity - studies under this heading
4.2	Flexibility in CO_2 Purity	2.2.4 CO_2 Impurities Tradeoff – surface 2.2.5 CO_2 Impurities Tradeoff - subsurface
4.3	Maximizing CO_2 Sequestration	2.2 Optimization - studies under this heading 2.3 Integrity - studies under this heading
4.4	Measurement and Verification	2.4 Monitoring - studies under this heading
4.5	Risk Assessment and Mitigation Options	2.1 Risk Assessment and Analysis- studies under this heading
5.0	**Project Management, Reporting, and Technology Transfer**	3. Technology Screening 4. Economic Modeling Technology Advisory Board
5.1	Project Management	Technology Advisory Board
5.2	Routine Project Reporting	1.2.4 Capture Studies Integration and Reporting Integration Into Topical Reports 2.5.1 Technical Report Integration into Topical Reports
5.3	Technology Transfer	2.5 Integration and Communications - studies under this heading

Scenarios

Task - 0.1 Identify Relevant Separation Capture, and Sequestration Scenarios

CCP uses real plant and refinery applications rather than idealized model studies to ensure that the developed technologies and costs will represent practical circumstances. Each scenario includes all the operations necessary to:

- Capture the carbon dioxide from the combustion process,
- Separate it from other stream components (water, particulates, and other gaseous contaminants),
- Process it for further handling (cooling and compression)
- Transport it to a storage site (by pipeline)
- Provide for monitoring to assure the public and regulators that that the carbon dioxide is safely stored for the required period.

The scenarios are defined by fuel type, combustion method, and the availability of storage sites. Separation technologies can be matched to the fuel type and plant configuration and the range of combustion methods represents the vast majority of systems used in industry. The four scenarios are summarized in Table 2 below:

Table 2: Industrial Scenarios Used in CCP as Basis for Technology Comparison

Scenario	Fuel Source	CO_2 Source	Geologic Sink	Location
Refinery	Hydrocarbon Gas & Liquids	Heaters & Boilers	Storage	European Refinery
Very Large Gas Turbines	Natural Gas	Large Electric Power Generation (CCGT)	Storage	Western Europe
Distributed Gas Turbines	Natural Gas	Small Distributed turbines	Storage	Alaska North Slope
Gasification	Solid via gasification (petroleum coke)	Syngas Purification Process	Storage	Western Canada

The **Geologic Sink** to be used is chosen from a reservoir type available near the CO_2 source and may be:

- Saline aquifers
- Depleted gas reservoir with or without potential for additional gas recovery,
- Depleted, or late stage, oil reservoirs usually with the potential for additional recovery of oil, or
- Unmineable coalbeds with or without the potential for methane recovery.

The geologic sink will be selected for its potential to ensure safe sequestration at minimum cost to the operator. It may be combined with oil or gas recovery from the target reservoir to provide cost recovery and potential economic benefits from the sequestration project.