European Workshop on CO_2 Capture Project
– A Joint Industry Project –
Co-operating for a better environment

12:00 noon on Tuesday, 12 June to 4:30pm on Wednesday, 13 June 2001

Salon A and B the Grand Ballroom
Amsterdam Marriott Hotel, Stadhouderskade 12,
Amsterdam 1054 ES, Netherlands

Workshop Agenda

	Tuesday, 12 June
12.00 pm	Registration followed by a Light lunch
1:00 pm 1:30 pm	Welcome, Bob Frith, Shell *Project Context: Gardiner Hill, CO_2 Capture Project Chairman* *What do you want to learn about Carbon Capture and Storage?*
2:45 pm	Break
3:00 pm	Perspectives on *CO_2* Capture and Storage *A Panel Discussion with representatives from:* *Industry, Else Hafstad, Statoil* *Academia, Arnulf Gruebler, International Institute for Applied Systems Analysis* *NGO, Rob Bradley, Climate Network Europe*
4:15 pm	Presentation of the CO_2 Capture Project *Helen Kerr, BP*
5:30 pm	Reception Comments: *Dutch Viewpoint on Greenhouse Gas* *Jip Lenstra, VROM, Dutch Environment Ministry*
	Wednesday, 13 June
8:00 am	Continental Breakfast
9:00 am	Review of day one
9:15 am	Carousel process *An opportunity to discuss your thoughts on:* 1. *CO_2 Capture* 2. *CO_2 Storage* 3. *Monitoring and Verification*
11:00 am	Break
11:30 am	*Plenary session gathering recommendations*
12:30 pm	Lunch
1:30 pm	*Developing the issues that emerged from the morning session*
3:30 pm	*Next steps and future possibilities*
4:15 pm	Wrap-up
4:30 pm	End of Workshop

CO_2 Capture Project – NGO Workshop Attendees
Amsterdam
June 12-13, 2001

1.	Coralie Abbott	Earthwatch
2.	Knut Alfsen	Cicero
3.	Rob Bradley	Climate Network Europe
4.	Ken Brown	Pan Canadian
5.	Tom Brownscombe	Shell Chemical Co.
6.	Georgia Callahan	Texaco
7.	Charles Christopher	BP America
8.	Lynne Clark	Climate Network Europe
9.	Jos Cozijnsen	Environmental Defense
10.	Lars Ingolf Eide	Norsk Hydro ASA
11.	Francesco Ferrante	General Manager
12.	John Gale	IEA Greenhouse Gas R&D Programme
13.	Pierpaolo Garibaldi	ENI Technologies
14.	Peter Gerling	Bundesanstalt fur Geowissenschaften und Rohstoffe (BGR)
15.	Claire Gough	Tyndall Centre (North)
16.	Arnulf Gruebler	International Institute for Applied Systems Analysis
17.	Wolf Heidug	Shell Global Solutions
18.	Gardiner Hill	BP
19.	Sam Holloway	British Geological Survey
20.	Giuseppe Iorio	ENI
21.	Paul Johnston	Greenpeace Int'l Science Unit
22.	Olav Kaarstad	Statoil R&D Centre
23.	Helen Kerr	BP
24.	John Lanchberry	Royal Society for Protection of Birds
25.	Jip Lenstra	Ministry of Environment
26.	Rachel Lewis	BP
27.	Giovanni Lozza	Politecnico di Milano-Dept. Energetica
28.	Peter Radgen	Fraunhofer Inst. For Systems and Innovation Reasearch
29.	Fokke Rispens	Ministerie van Economische Zaker
30.	Erik Schmersal	VROM
31.	Sybil Schone	WWF-NL
32.	Mike Slovacek	Chevron Overseas Petroleum
33.	Eve Sprunt	Chevron
34.	Helge Stiksrud	Norsk Hydro ASA

CO_2 Capture Project

European Workshop

June 12th and 13th, 2001
Amsterdam. NL

“Cooperating for a Better Environment”

CO_2 Capture Project

CO_2 Capture Project: Project Context

- Introduce the players
- Workshop Objectives
- Context for the Meeting
  - What the CCP is about
  - What the CCP is NOT about
- Project Goals

CO_2 Capture Project

CO_2 Capture Project

bp · Chevron · Eni · Hydro · Shell · Statoil · Suncor Energy · Texaco

Participating Companies

CO_2 Capture Project

Workshop Objectives

Inform:

- Present the objectives and goals of the CO_2 Capture Project. Describe the technology development program and the expected timing of key program elements.

Listen:

- Establish an open dialogue where the issues of CO_2 capture and geologic storage can be discussed.

Explore:

- Look for opportunities to communicate and collaborate in the future.

CO_2 Capture Project

Context for this Meeting

Why these companies have come together.

- Shared concern about climate change.
- Like minded in our approach.
- Portfolio of actions required but Capture and geologic storage is an important option.

Aims and Objectives of the Project.

- Develop new technologies to reduce cost of CO_2 Capture and geologic storage.

Progress through Partnership.

- With industry, governments and other stakeholders.

CO_2 Capture Project

Context for this Meeting (continued)

The style of the project/how we want to work.

- International nature of the project, working in Canada, Europe and USA.

This is the start of a conversation and process, which we hope will continue throughout the project and will help make the project a success.

What this is About!

- Leadership and Understanding
- Getting into action
- Technology development to be delivered by a set time.
- Responsible and Proactive measures
- Partnerships

CO_2 Capture Project

What this is Not About!

- It is not about Ocean Sequestration.
- Causing a distraction from goals and commitments each of the participants may have taken on in other areas.
- Not a conversation about the Policy, Philosophy or activities of the individual companies – but a conversation about the CCP project.

CO_2 Capture Project

Project Goals

- Achieve major cost reductions for CO_2 capture and geologic storage:
  - 50% reduction when applied to retrofit applications
  - 75% reduction when applied to new build applications
- Demonstrate that CO_2 storage is safe, measurable, and verifiable
- Develop new and existing technologies to:
  - 'Proof of concept' stage by 2003/4
- Share learnings with others:
  - Technologies could apply to power generation, chemical plants

CO_2 Capture Project

European Meeting: Project Context

End of presentation

Questions?

Capturing Carbon: Technology and Systems Issues

Arnulf Grübler
IIASA A-2361 Laxenburg
gruebler@iiasa.ac.at

European Workshop
Carbon Capture Project
Amsterdam, 12-13 June 2001

IIASA A. Grübler, 2001

Capturing Carbon: Systems Aspects

- Scarcity: From supply to disposition constraints
- Vast optional demand in DCs
- Inertia of large socio-technical systems: turnover times 50-100 yrs
- Next 100 years: at least 2x (up to 10x) more carbon than since 1800
- Decarbonization: long-term trend to higher H/C ratios (coal→gas) and zero-carbon energy (electricity, hydrogen)

IIASA A. Grübler, 2001

Fossil Use, Reserves and Resources, GtC

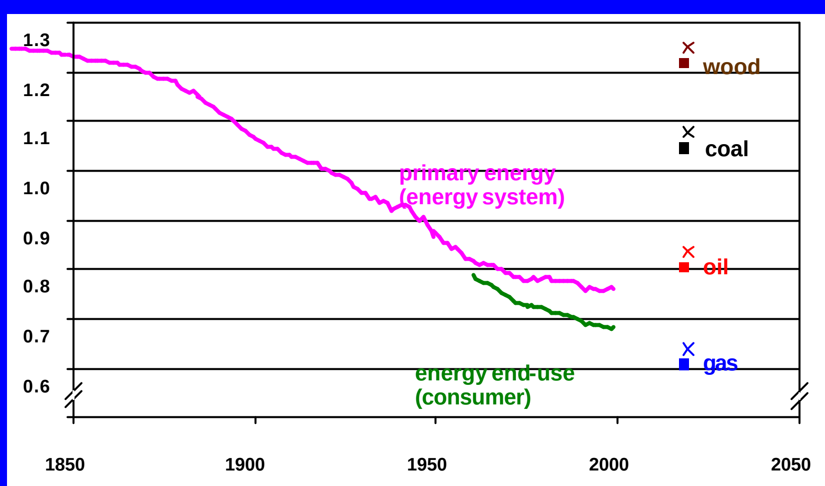
	Coal	Oil	Gas	Total
1800-2000	148	103	38	289
IPCC SRES min	77	220	230	765
to 2100 max	1,754	1,021	842	2,531
Reserves*	650	260	180	1,090
Resources*	2,590	230	370	4,280
Occurrences*	>3,300	>500	>13,000	>16,800

* includes conventional and unconventional hydrocarbons

Source: IPCC SAR (1996), Rogner (1997), IPCC SRES (2000)

IIASA A. Grübler, 2001

USA - Decarbonization (tC/toe)



Source: US DOE EIA (2001): 1960-1999; Grübler (1998): <1960.

IIASA A. Grübler, 2001

CO_2-Capture: Technological Opportunities

- New lines of business: hydrogen via methane economy
- Initial markets: store available CO_2 streams (e.g. refineries), substitute fossil CO_2 (e.g. EOR), recovery of deep coal-bed methane (e.g. old coal mines)
- Long-term: closed sytem cycles and CH_4 - CO_2 - H_2 integration; clathrates as source and storage medium

IIASA A. Grübler, 2001

CO_2-Capture: Technological Risks

- Maintain long breath in RD&D
- Price (markets) for CO_2?
- Leakage (EOR, aquifers)?
- Monitoring and certification?
- End-of-pipe focus vs. systems change (CO_2-capture vs. hydrogen economy)
- Fossil fuel lock-in (block alternatives)
- Loss of premium market (H_2) if alternatives (solar, HTR) develop faster

IIASA A. Grübler, 2001

An Industry View on CO_2 Storage

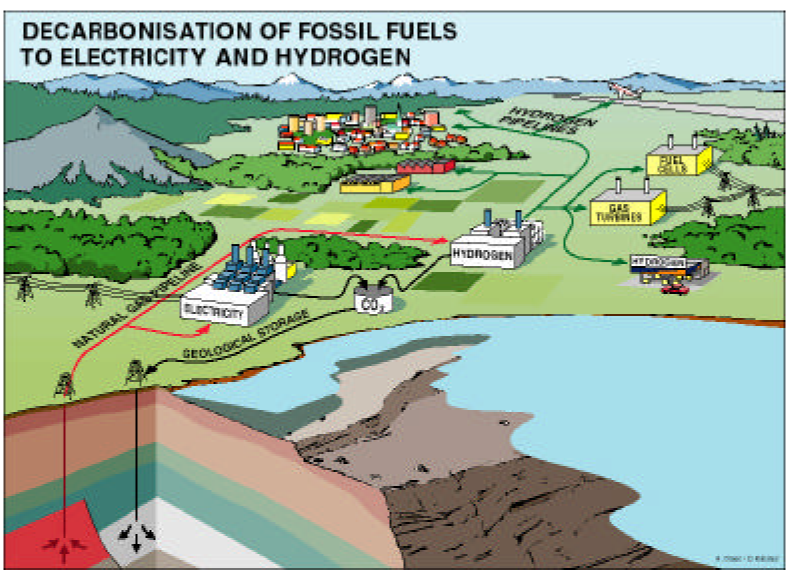
By

Olav Kaarstad

Statoil R&D Centre, Norway

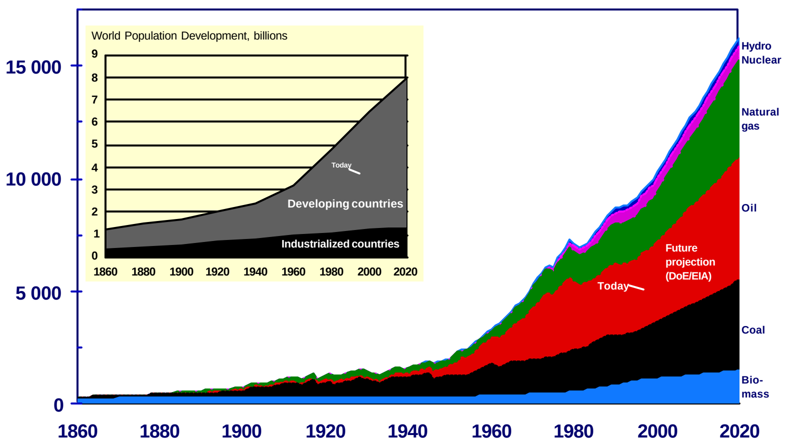
Workshop on the CO_2 Capture Project

Amsterdam, 12th-13th of June, 2001



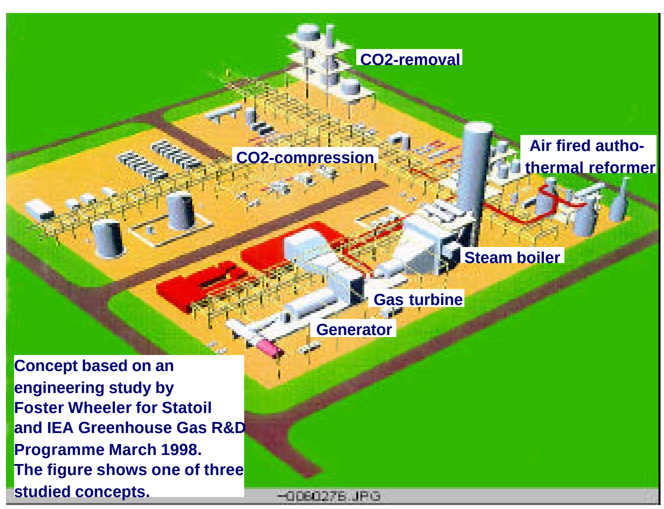
World Energy Consumption and Population 1860 - 1997 with Projections to 2020

Mill. tonnes oil equivalents per year

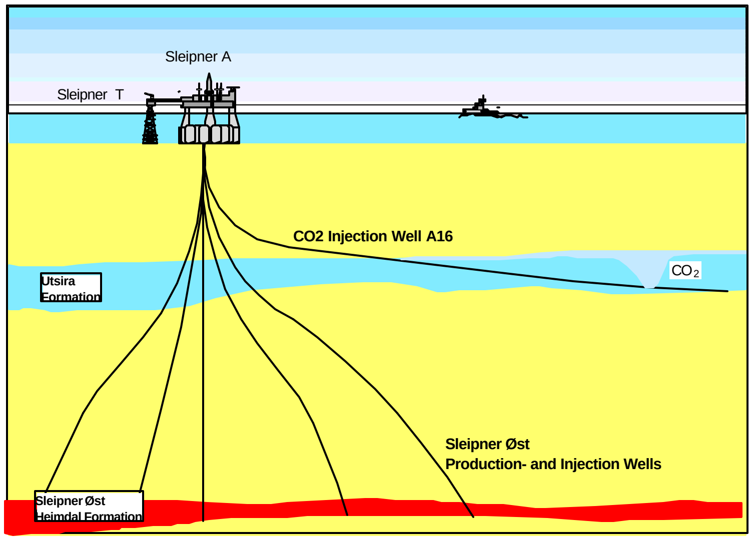


Sources: BP Stat. Rev. of World Energy 1998, Scientific American, Sept. 1990, DoE/EIA; International Energy Outlook, 1998 (projection), UNEP Grid Arendal (population)

500 MW hydrogen fired combined cycle power plant based on natural gas feed and CO2-capture



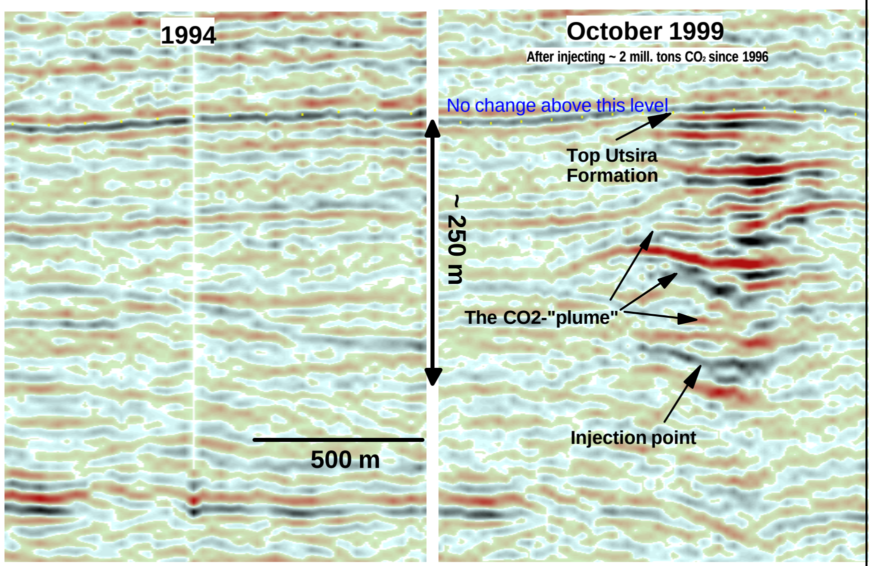
SLEIPNER CO_2-STORAGE IN THE UTSIRA FORMATION



The Sleipner CO2-injection (cont.)

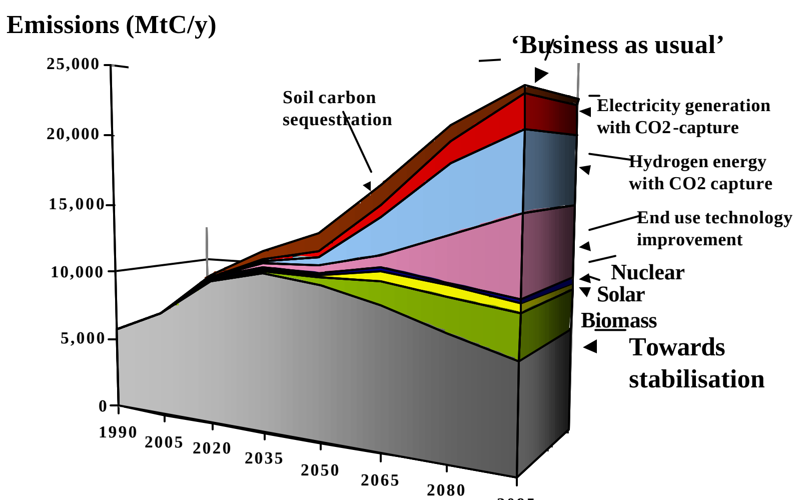
- **The removal process is based on an amines (MDEA) in a system operating at 100 bar**
- **Injection takes place in a single well into the so-called Utsira formation located 800-1000 meters below the seabed**
- **Decision to inject was taken in 1991 following the introduction of a CO2-tax which was then in the order of 50 US$/ton CO2**
- **First injection started in September 1996**

Sleipner CO_2 injection seismic monitoring – Preliminary comparison of 1994 and 1999 data



Achieving deep reductions

- Model results of J Edmonds (PNNL)



CO2 Capture Project

CO_2 Capture & Storage JIP
Technical Program Overview

Dr Helen Kerr – Technical Program Manager
EU NGO Workshop
12-13th June 2001
Amsterdam

Technical Program Overview

Introduction

- **Program Overview**
- **Organization**
- **Process to date**
- **Technology Team Activities**
  - Post Combustion CO_2 Capture
  - Oxyfuel CO_2 Capture
  - Precombustion Decarbonization Capture
  - Geologic Storage, Monitoring & Verification
  - Economic Modeling

CO2 Capture Project

Program Overview

- **EU 28 mm ($25mm) 3.5 year program**
- **5 Technical Teams, full time Program Manager plus support staff provided through non-cash contributions from JIP participants.**
- **Objectives**
  - Reduce the total cost of capture by 75% for new plants and by 50% for existing plants (capture said to account for 2/3rds cost capture and storage)
  - Identify technologies that could be commercially available in the near term i.e. by 2010
  - Develop solutions which are applicable over a wide range of processes from which CO_2 is emitted in significant volumes
  - Understand & evaluate the Health, Safety & Environmental impacts if any of solutions developed
  - Develop guidelines for monitoring and verification of amounts CO_2 stored geologically

Organization

- **Executive Board**
  - Responsible for the strategic direction and management of the JIP
- **Program Manager**
  - Responsible for technology assurance processes and delivery of the technical program
  - Reports to the Executive Board
- **5 Technical Teams**
  - Post combustion CO_2 capture
  - Oxyfuel CO_2 capture
  - Pre-Combustion De-Carbonisation Capture (PCDC)
  - Geologic Storage, Monitoring and Verification (SMV)
  - Economic modeling

Scenarios

- Real life examples of processes in our business where capture and storage technologies will have to work
- Will ensure that we develop capture and storage technologies that are broadly applicable
- Examples where we understand the costs of current operations that can be used to create baseline economic models to track our cost reduction performance against
- Facilitates conversations about what this technical project is about with external stakeholders and technology providers.

Scenario Matrix

Scenario	fuel	equipment	sink: depleted Resv	sink: Saline Aq	sink: Coal Beds	sink: EOR	sink: Offshore EOR	location
A	mixed gas and liquid	boilers, heaters			✓		✓	Europe
B	gas	gas turbines combined cycle		✓			✓	Norway
C	gas	distributed gas turbines	✓			✓		U.S.
D	solid/liquid gasification	cogeneration				✓		Canada

Technical Program Overview

Geologic Sinks- Clarification

- **Depleted oil and gas reservoirs >1000m below the earths surface. These are reservoirs which have been producing oil or gas but are now not in use.**
- **Saline reservoirs are deep zones of rock containing non-drinkable water, with salt quantities up to 10 times saltier than seawater.**
- **EOR (enhanced oil recovery), means to inject CO_2 down into oil or gas reservoirs where it will pressurize the reservoir and act like a piston to push out oil which would otherwise be left behind, be produced very slowly or not at all.**
- **Coal-bed methane production can also be stimulated in a similar fashion to EOR.**

CO₂ Capture Project

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Technical Program Overview

Key Steps

- **We want to run this program in an open and transparent way and to engage key stakeholders at an early stage to provide the project with the best chance of success**
- **Not planning to duplicate work done or ongoing and to build in the best of the best available technology. You can really help us here.**
- **One of the key criteria in the selection of capture and storage technologies for further study will be understanding the environmental impacts if any.**
- **This program will focus on capture and storage technologies that can be applied in the near future (2010 range) and could provide the infrastructure to move towards the hydrogen economy.**

CO_2 Capture Project

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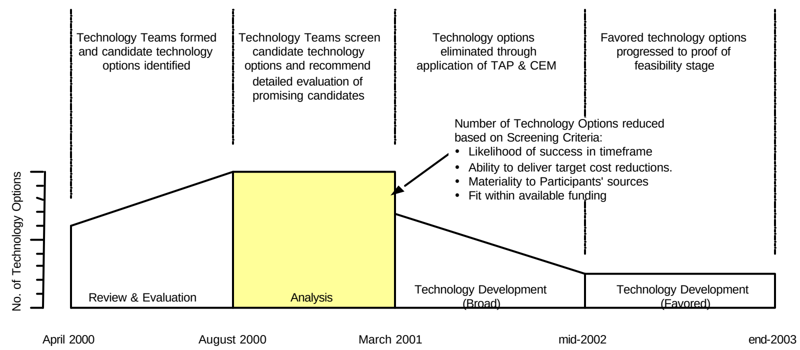
Technical Program Overview

CCP Project Phases



Technical Program Overview

What have we done so far

- **Generated State Of the Art (SOA) reports**
  - in the capture and storage focus areas we are working in.
- **Performed some preliminary technical studies**
  - to confirm the cost reduction potential of some technologies and enable us to rank and prioritize which ones should be developed further.
- **Prepared co-funding study applications to government agencies**
  - an important component of our external stakeholder engagement in this project.
- **Held our first workshop with external stakeholders**
  - to present our process to date and forward plans and invite their views and advice which we have incorporated in our program.

What else?

- **Storage Monitoring & Verification (SMV) team held an external workshop**
  - to solicit proposals for work in the focus areas. 61 proposals received were ranked and screened to produce the short list and some reserve items which we hope to fund as budgets are firmed up
- **Capture teams screened and ranked technologies**
  - using a preliminary economic model and key screening criteria (environmental, technical, commercial, scenario applicability and development timeframe)
- **Peer review**
  - independent external panel of experts and government advisors. The peer review feedback was extremely positive on both the process and outcome to date. Gaps highlighted have been addressed.

Forward look

- **Capture teams are preparing requests for proposals**
  - which outline the detailed work programs to be undertaken in each technical area and the SMV team are beginning to place contracts
- **Engaged in discussions leading to agreements with the US DOE, the EU and the Norwegian Klimatek agencies**
  - following our successful applications and hope to be in a position to place contracts and start work on the regional programs in the near future
- **There is still time to reflect, discuss and modify the program in the light of discussions at this workshop.**
- **Funds will be available to incorporate new items which meet our selection criteria as the program goes forward**

Economic Modeling Team

- **Produced a first pass economic model**
- **Working scenario baseline cost estimates**
  - for the uncontrolled CO_2 emissions case and the cost of abatement when the best available technology today is applied.
- **Key tool to evaluate progress against objectives.**
- **Commercialization**
  - Many of the technologies studies will require millions of dollars to reach proof of concept in 3 years. We will use the economic model to make sure we invest in those technologies with the greatest probability of success.

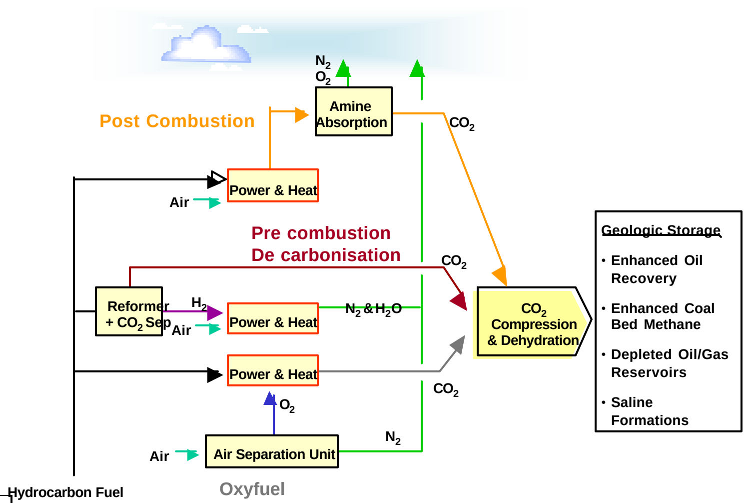
CO2 Capture Project

Post Combustion CO_2 Capture

Dr Helen Kerr – Technical Program Manager
EU NGO Workshop
12-13th June 2001
Amsterdam

Technical Program Overview

CO_2 Capture Options



Technical Program Overview

Post Combustion State of the Art

- **CO_2 is separated and captured from flue gases after the combustion process**
- **20+ years of industrial application producing food grade quality CO_2**
  - but not at same scale as some potential applications
- **Primary method is to strip CO_2 from flue gas by chemical wash**
  - usually amines, an acid-base reaction. The amine is regenerated often by heating.
- **Is considered "Baseline Technology" in CCP.**
  - Is very close to market and thus the first step on the bridge to large scale CO_2 capture and Storage.

Post Combustion Challenges

- **Flue gas CO_2 concentrations are typically quite low:**
  - 2% to 12% of total gas volume, and at low pressure.
- **Process is energy intensive and equipment is very large.**
- **Acid gases in flue gas can degrade amine performance**
  - pretreatment is required to maximize amine performance.

Improvement Options

- **Advanced solvents**
  - result in lower energy consumption
- **Novel chemistries**
  - could lead to smaller volumes and longer lifetimes
- **Reduce the cost of direct contact cooler and absorber**
- **Investigate the impact of non oilfield fabrication and construction standards recognizing:-**
  - absence of pressure and hydrocarbons
  - non critical operation, therefore reduced need for spare equipment

More Efficient CO_2 Isolation

- **Replace conventional packed columns with a Gortex–like (PTFE) semi-permeable membrane**
  - separating the exhaust gas and amine
- **Advantages include**
  - high mass transfer area, reduced size, cost and sensitivity to amine decomposition and corrosion.
- **Current efforts focus on bringing together various vendors to allow combined advanced amine solvents with the membrane contactor**

Physical Removal without Solvents- Electric Swing Adsorption

- **Carbon substrate adsorption process**
- **Release of CO_2 by an electric current, without heating**
- **Requires development from bench scale**
- **Radically different and new technology**
- **Can also be applied in pre-combustion applications**

Technical Program Overview

Other New Technologies

- **Two further technologies are recommended for initial engineering evaluation:-**
  - Radical Exhaust Channel technology (this is currently confidential to Norsk-Hydro)
  - Pressure / temperature swing adsorption process for solvent regeneration

CO2 Capture Project

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Oxyfuel CO_2 Capture

Dr Helen Kerr – Technical Program Manager
EU NGO Workshop
12-13th June 2001
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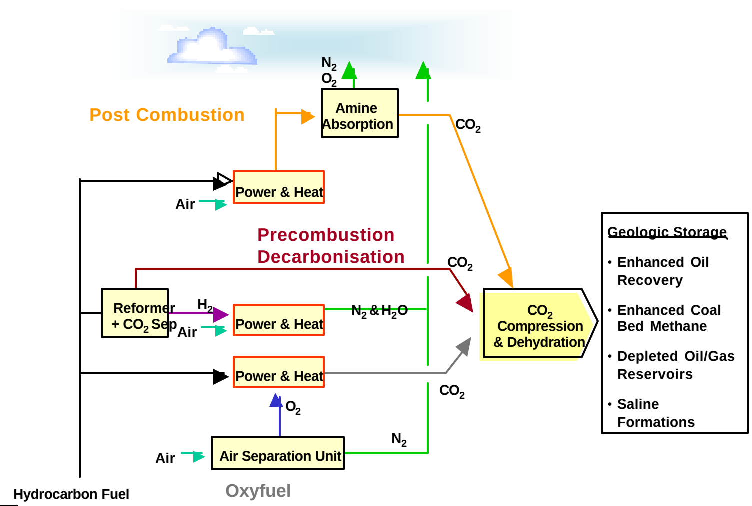
Technical Program Overview

CO_2 Capture Options



Technical Program Overview

Oxyfuel State of the Art

- Combustion in an oxygen environment resulting in a flue gas with high CO_2 concentration
- Nitrogen added to reduce the combustion temperature by recycling flue gas
- Boiler with flue gas recycle
  - no installations
  - tests & studies indicate no major risks
  - based on existing technology
- Gas turbine with flue gas recycle
  - costly development of new gas turbine needed

Technical Program Overview

Oxyfuel challenges

- **Lack of nitrogen results in very high combustion temperatures. Some exhaust recycle would be required for cooling or some alternative method for cooling**
- **Oxygen separation is energy intensive**

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Slide 25

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Technical Program Overview

Oxyfuel cost breakdown- areas to focus on

Example: Refinery boiler conversion study

	Capital	Power Consumption
Boiler	36%	2%
Air Separation Unit	33%	67%
CO_2 treatment & compression	17%	30%
Flue gas recycle, controls etc	2%	1%
Installation, precommissioning	12%	

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Technical Program Overview

Oxyfuel Cost Reduction Options

- **Lower O_2 cost**
  - (e.g. O_2 ion transport membranes)
  - will make all oxyfuel technologies more competitive
  - Integrate these membranes with combustion
    - low permeate O_2 and high temperatures reduce operating cost
- **Take advantage of oxyfuel characteristics to:**
  - Increase turbine cycle efficiency
  - Reduce boiler size and cost
- **Seeking novel technology**

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Technical Program Overview

Cooling Cycles

- **Advanced Gas Turbines with water injection**
  - Water/steam injection to control combustion temperature
  - Hybrid steam/gas turbine cycles
  - Up to 70% efficiency claimed
- **Boilers/heaters with flue gas recycle**
  - Relatively low risk development with wide application, could be retrofitted to most boilers and heaters

CO₂ Capture Project

Technical Program Overview

Ceramic Membrane Air Separation Unit - integration with combustion process

- **O_2 separation membrane forms "wall" of combustor**
- **Low O_2 content recycled flue gas "sweeps" membrane**
- **Reduces O_2 cost,**
- **Increases gas turbine (GT) cycle efficiency**
- **Application to new boilers/heaters and GTs (plus possible GT retrofit)**

CO_2 Capture Project

Technical Program Overview

Other Opportunities

- **Chemical looping**
  - Metal/metal oxide chemical cycle separates oxygen from air and oxidizes fuel in separate reactors
  - Lab studies only so far
    - Application to gas turbine and heat plant
- **CCGT with flue gas recycle**
  - Combined cycle, gas turbine development very costly and needs cooperation with gas turbine manufacturers.
- **Zero or low recycle boiler**
  - Less or no recycled flue gas
  - More compact boiler
    - Application to new build boilers

CO_2 Capture Project

Technical Program Overview

Other Opportunities

- **High pressure boilers**
  - **That can operate in the 5 - 30 bar range**
  - **Reduced CO_2 compression costs**
  - **More compact boiler**
    - Application to new build boilers

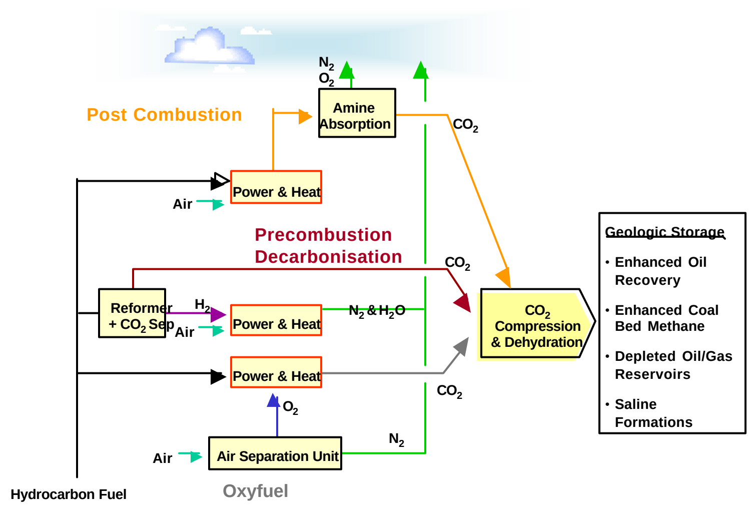
Pre-Combustion Decarbonisation

CO_2 Capture

Dr Helen Kerr – Technical Program Manager
EU NGO Workshop
12-13th June 2001
Amsterdam

Technical Program Overview

Pre-combustion Decarbonisation



Technical Program Overview

Pre-Combustion Decarbonisation (PCDC) State Of The Art

- **Removes carbon from the fuel before combustion**
  - Carbon is captured in form of CO_2
  - Hydrogen is the resulting fuel
- **Well known process used for H_2 generation for 50+ years.**
- **Currently used to produce high-purity H_2 for chemical and refining uses. No large scale applications in production**
- **Cost reductions will come through integrated designs and a review of design criteria.**

Pre-Combustion Decarbonisation (PCDC)

- **In general a PCDC plant could be divided into three sections**
  - Hydrocarbons conversion
  - CO-conversion
  - CO2 removal
- **Hydrocarbon Conversion**
  - The objective of hydrocarbon conversion is to **convert hydrocarbon into H_2, CO and CO_2.** This is normally done by either steam reforming (addition of steam), partial oxidation (addition of oxygen or air) or a combination of both. The selected technology mainly depends on the feed stock type

Pre-Combustion Decarbonisation (PCDC) Process

- **CO-conversion Section**
  - CO-conversion is the step in which the **CO is converted into hydrogen and CO_2 by water gas shift reaction.**
    - The predominant method is a two-step approach in which the major conversion takes place at high temperature called high temperature shift (HTS) and final conversion takes place at low temperature called low temperature shift (LTS).
    - Other systems using medium temperature shift (MTS) and improved reactor design exist. The shift systems are normally found in hydrogen and ammonia plants.
- **CO_2 removal Section**
  - After the CO-conversion and removal of condensate, the process gas mainly consist of hydrogen and carbon dioxide . If air has been used as oxidant , large amounts of nitrogen will be present. Traces of unconverted CO and methane will also be present.
  - **CO_2 is normally removed by use of chemical or physical absorption** systems and has mainly been used in ammonia plants and in combination with gasification plants

PCDC Capture Technology Program

- **Fuel Use**
  - We need to understand the effect of using hydrogen for power production instead of conventional fuels
- **Novel technologies to be studied include**
  - Advanced Syngas* Generation
  - Very Large Scale Hydrogen Production
  - Combined Syngas generation and CO_2 Separation System
  - Improved CO_2 separation

* Syngas is a catalytic process for converting natural gas to liquids (primarily methanol) and hydrogen is a by-product

Precombustion Decarbonisation focus

- **Focus is on the key process areas for hydrogen production and use**
- **The ability to substitute hydrogen for existing fuels is an essential requirement for the pre-combustion route.**
  - Effective utilisation without adversely affecting NOx or other emissions and the reliability of hydrogen gas turbine has not been proven for high purity (>70%) hydrogen.

CO2 Capture Project

Geologic Storage, Monitoring & Verification

Dr Helen Kerr – Technical Program Manager
EU NGO Workshop
12-13th June 2001
Amsterdam

Technical Program Overview

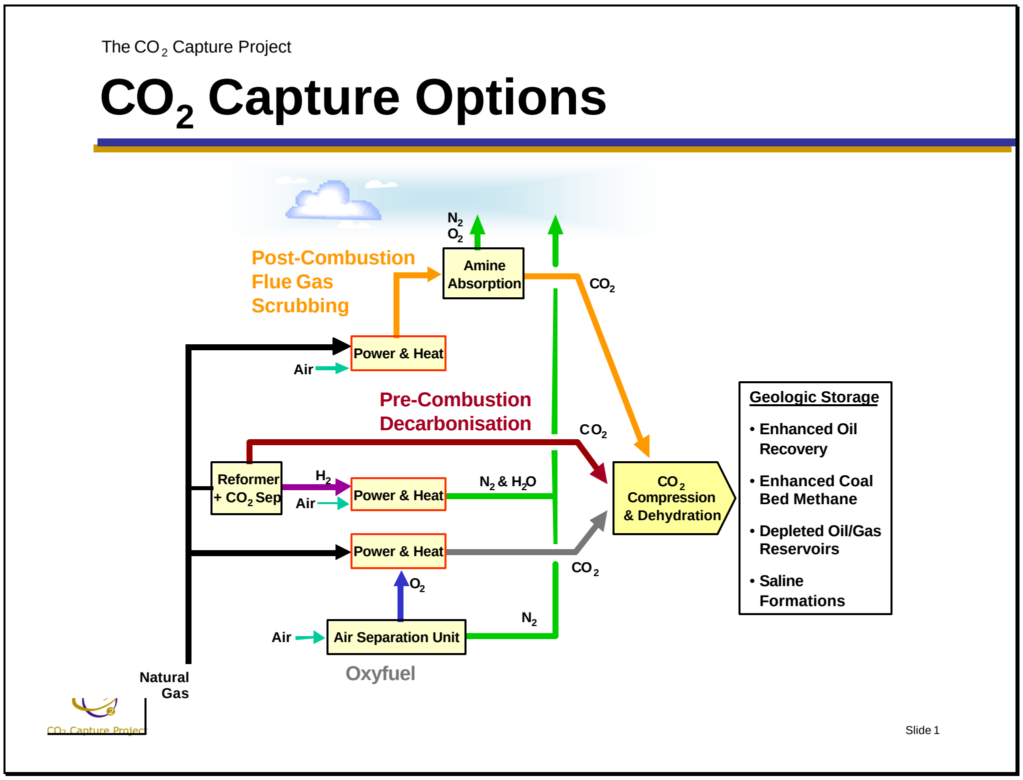
Storage, Monitoring & Verification, State-of–the-Art

- **The industry is well positioned to build on its current expertise**
  - Decades of experience in storage CO_2 in EOR fields
  - Industry has experience in naturally occurring CO_2 producing fields (analogs) in the US
  - In the US and Europe, the natural gas industry has 90 years of experience storing natural gas in 100s of fields
- **CCP should not duplicate significant, third-party research & development worldwide**
  - Understanding Geologic Storage, Maximizing Storage Efficiency, and short-term Verification & Monitoring are understood or are receiving significant third-party R&D

Storage, Monitoring & Verification, Focus Areas

- **Understanding Geologic Storage**
  - Assessing Caprock integrity
- **Maximizing Storage Efficiency**
  - Storage efficiency per unit volume of rock
  - Storage economics
- **Verification & Monitoring**
  - Understand CO_2 migration potential
  - Verification of amounts injected
- **Assess Health, Safety & Environmental Risk**

CO_2 Capture Project

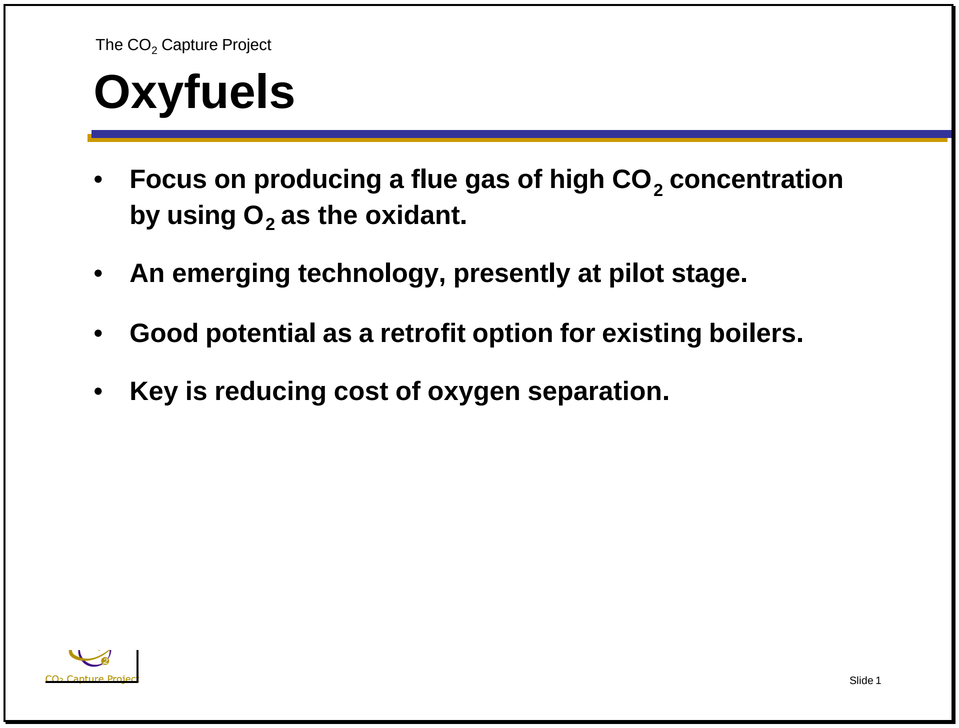


Carbon Capture Options:

- Before combustion
- After combustion
- By combustion to produce pure CO_2 for storage

CO_2 Capture Project

Separate oxygen first, so flue gas is CO_2 & H_2O:

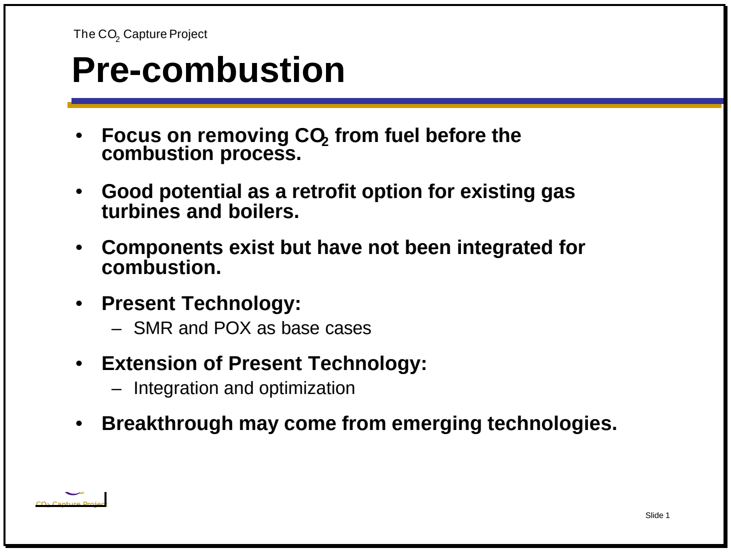


Various options pursued:

- ASU improvements
- Membrane oxygen separation (high temp)
- Integration of membrane and combustor
- Steam/CO_2 working fluid for turbines
- Pressurized combustion
- Chemical looping combustion (metal/metal oxide cycle)

CO_2 Capture Project

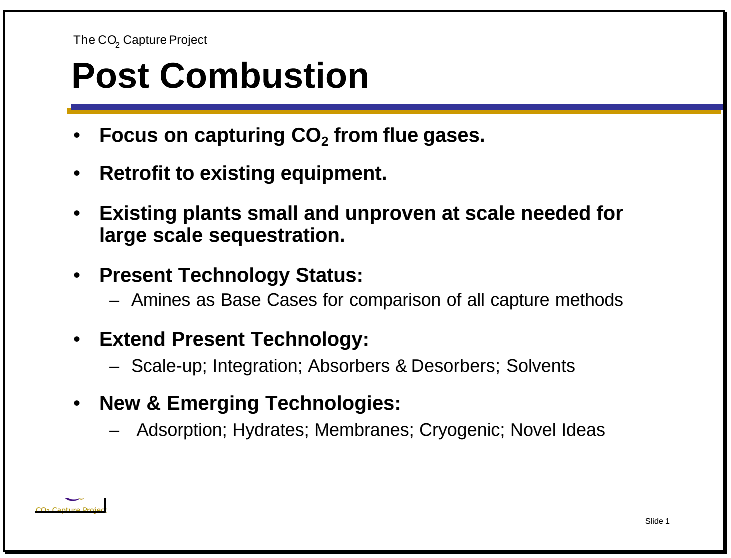
Separation of carbon before combustion: (Fuel → CO_2 + nH_2)



Technologies:

- Compact Reformer/membrane contactor
- Membrane Water Gas Shift reactor
- Steam Methane Reformer Membrane reactor
- Advanced Partial Oxidation reactor

Remove CO_2 before venting flue gas:



Options:

- Electric swing adsorption process
- Combination of amine and membrane process
- High temperature swing adsorption process
- New absorbents

Monitoring and Verification

The CO_2 Capture Project

Initial Review & Evaluation Phase

- **Process - April through July, 2000**
  - Defined "State-of-the-Art" for each Storage, Monitoring & Verification (SMV) technical area
  - Identified Gaps & Opportunities
  - Recommended Investment Direction & Strategy for CCP
- **State-of-the-Art Findings - Worldwide R&D is extensive, and, in CCP's opinion, effectively addressing the following areas**
  - Understanding Geologic Storage Mechanisms
  - Maximizing Storage Capacity
  - "Short-Term" Monitoring & Verification Technology (e.g. seismic)
- **CCP perceives Technical Gaps in:**
  - Health, Environmental & Safety (HES) Risk Assessment Methodology
  - "Long-Term", lower cost Monitoring & Verification Technology

CO_2 Capture Project

The CO_2 Capture Project

SMV Team Analysis Phase

- **Process / Progress - August, 2000 through March, 2001**
  - Refined understanding of promising technical areas
  - Established relationships with Technology Providers
  - Held international Storage, Monitoring & Verification Workshop
    - Washington DC, January, 2001
  - Solicited R&D Proposals
  - Evaluated, risked and ranked R&D Proposals
  - Developed CCP SMV Work Program & Budget
  - Made SMV Recommendations to CCP Executive Board
- **Current Activity**
  - Negotiating Work Scope & Plans with "Short List" of Technology Providers
  - Plan for all contracts to be signed in 2001

CO_2 Capture Project

CO₂ Capture Project

Monitoring and Verification

The CO_2 Capture Project

Technology Development Phase

- **Mid 2001 to yearend 2003**
- **Planning for $3.3 million (US) budget for SMV R&D**
- **Approved Investment Direction**
  - Understanding Geologic Storage 12%
  - Maximizing Storage Capacity 20%
  - Short-Term Monitoring & Verification 0%
  - Risk Assessment, Mitigation, Remediation 43%
  - Long-Term Monitoring & Verification 25%
- **In addition to CCP Cash R&D Investments, we want to**
  - Collaborate with other world class R&D activity
  - Extensive leverage of knowledge & expertise in CCP companies

CO₂ Capture Project

The CO_2 Capture Project

Storage, Monitoring & Verification Projects

Alberta GS	Bachu	Characterization of acid gas disposal sites in the Alberta Basin
ARI	Stevens	Natural CO2 Analogs - 2 field studies
GFZ Potsdam Rev.	Borm	Influence of injection on physical properties of reservoirs & caprocks
PCM Technical	Moschovidis	Fracture Mechanics Approach to Seals Evaluation
Sintef	Lindeberg	Long-term sealing capacity of cemented wells in a CO2 storage project
UTexas	Pope	Integrated simulation
Berkeley NL	Hoversten	Novel geophysical techniques for monitoring movement during storage
CalTech Univ	Tang	Lit search on detection technolgoy
Livermore NL REV	Nimz	Noble gas isotopes for screening & monitoring long-term monitoring
Livermore NL	Pickles	Hyperspectral geobotanical remote sensing for CO2 containment
NM Tech	Grigg	Long-term storage potential in maturing CO2 region
TNO-NITG	Wildenborg	Safety assessment methodology
Idaho NL	Raterman	Methodology for probabalistic assessment in coalbeds
Scientific Monitor	Stenhouse	Risk assessment framework, public perception/involvement, migration
Berkley	Benson	Lit search on HSE Risk Methology, roadmap

CO₂ Capture Project

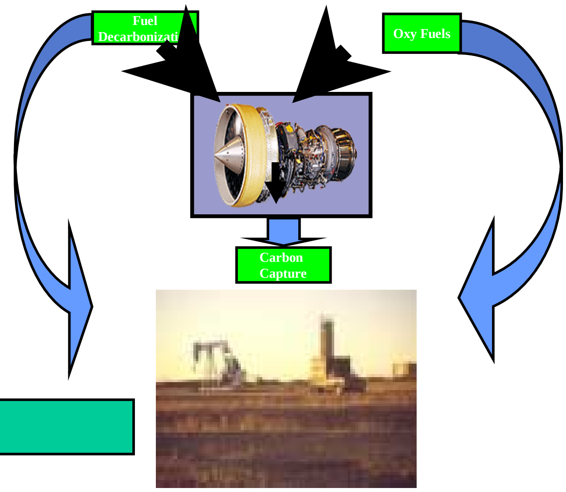
Geological Storage of Carbon Dioxide

Charles Christopher, BP - NGO Meeting Amsterdam, June 12-13, 2001

Global Geological Storage Potential is Large

	$(GtCO_2)$
Exhausted Oil & Gas Reservoirs[a]	920
Saline Formations[b]	3000

a, IEA report PH3/22 Feb 2000
b McMullan : Carbon Dioxide Collection & Disposal 1995



Geologic Storage

- Enhanced Oil Recovery
- Enhanced Coal Bed Methane
- Depleted Oil/Gas Reservoirs
- Deep Saline Formations

Storage will primarily be dense phase liquid in pore spaces

•Chemical reaction
  •Depends on rock mineralogy
  •Is slow, and potential is small
•Solubility in water and/or oil
  •Relatively rapid, potential relatively small
•Dense phase liquid is most efficient

Drivers

•Safety
•Permanence
•Cost
•Efficiency

Technology Assessment

Industry has expertise for:

–Understanding Geologic Storage Mechanisms

–Maximizing Storage Capacity

–"Short-Term" Monitoring & Verification Technology (e.g. seismic)

CCP perceives Technical Gaps in:

–Health, Environmental & Safety (HES) Risk Assessment Methodology

–"Long-Term", lower cost Monitoring & Verification Technology

CCP projects cover a wide range of technologies aimed at improving understanding of risks and long-term monitoring

Alberta GS	Bachu	Characterization of acid gas disposal sites in the Alberta Basin
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