CO_2 Capture Project

November 14, 2000

Dear Workshop Participant,

Thank you for your participation in the CO_2 Capture Project (CCP) NGO Workshop, held October 3-4 at the Washington Monarch Hotel. We enjoyed an open and honest discussion of the objectives of the CCP, and we appreciate the feedback that we received. I think this represents a good start to our outreach program and we look forward to an ongoing dialogue, which we believe will result in a more successful project.

Enclosed is a summary of the workshop, including copies of the slides from some of the key presentations.

A few items of follow-up need to be mentioned:

- The CCP will be assessing this feedback and developing specific action items by the end of the year. These action plans will be communicated to all workshop participants.
- A similar workshop is planned for European NGO's on March 22-23, 2001 in Amsterdam.
- I would like to request that NGO's indicate to the CCP (care of the undersigned) their willingness to be involved in an Advisory Panel to address some of the issues discussed at the workshop.
- It is our intention to continue the dialogue initiated at this workshop through similar meetings in the future.

Please do not hesitate to call me if you have questions or additional comments. The CCP now has an Internet website located at www.co2captureproject.org I encourage you to visit it soon.

Gardiner Hill
Executive Steering Board Chairman
CO_2 Capture Project

Enclosure

CO_2 Capture Project – NGO Workshop Attendees

Monarch Hotel
Washington, DC
Oct. 3-4, 2000

1.	Sally Benson	Lawrence Berkley National Lab
2.	Ranjit Bharvirkar	Resources for the Future
3.	Geoff Browning	Natural Resources Canada
4.	Tom Brownscombe	Shell
5.	Anita Burke	Shell
6.	Charles Byrer	Department of Energy
7.	Melissa Farrell	Pacific Visions Communications
8.	David Hawkins	Natural Resources Defense Council
9.	Howard Herzog	MIT
10.	Gardiner Hill	BP
11.	Ken Humphries	Pacific Northwest National Laboratory
12.	Peter Jaffe	Princeton University
13.	Geoffrey Johns	Suncor Energy Inc.
14.	Olav Kaarstad	Statoil
15.	Robert Kane	Department of Energy
16.	David Keith	Carnegie Mellon University
17.	Helen Kerr	BP
18.	Miriam Lev-On	BP
19.	Craig Lewis	Chevron
20.	Patti Lewis	Suncor Energy Inc.
21.	Tom Marr-Laing	Pembina Institute
22.	Emily Matthews	World Resources Institute
23.	Tom Mikus	Shell
24.	Jennifer Morgan	World Wildlife Fund
25.	Jeff Morgheim	BP
26.	Naomi Pena	Pew Center on Global Climate Change
27.	Bill Reynen	Environment Canada
28.	Lloyd Ritter	Union of Concerned Scientists
29.	Paul Rutter	BP
30.	David Sawyer	ManageMentor, Inc.
31.	Jeff Seabright	Texaco
32.	Robert Socolow	Princeton University
33.	Dave Thomas	BP
34.	Ram Uppuluri	Environmental Defense
35.	Sarah Wade	Environmental Defense
36.	Mark Weggeland	BP
37.	Mike Wriglesworth	BP

Reception Speaker: Jeff Seabright, Texaco

Attachment II

Workshop Agenda

	Tuesday October 3, 2000
2:30 pm	Registration
3:30 pm	Session Welcome *Gardiner Hill, CO_2 Capture Project Executive Board Chairman* *David Sawyer, Workshop Facilitator*
	Building a Foundation, Finding Common Ground *Mark Weggeland, BP*
	Perspectives on CO2 Capture and Geologic Storage *Paul Rutter, BP* *Howard Herzog, MIT* *David Keith, Carnegie Mellon Univ.* *Sarah Wade, Environmental Defense*
	Tuesday Discussion Groups
6:00 pm	Adjourn
6:00 - 8:00 pm	**Reception** *Hosted by the CO_2 Capture Project*

	Wednesday October 4, 2000
7:30 am	Continental Breakfast
8:30 am	**Session Welcome** *David Sawyer, Workshop Facilitator*
	State of The Art - Issues and Opportunities *Anita Burke, Shell International* *Geoffrey Johns, Suncor Energy*
9:30 am	Break
	The CO_2 Capture Project Technology Program *Helen Kerr, BP* *Olav, Karstad, Statoil* *Craig Lewis, Chevron*
	Wednesday Discussion Groups
12:00 pm	Lunch served in workshop
1:00 pm	**Developing a Working Relationship** *David Sawyer, Workshop Facilitator*
	Workshop Summary and Wrap-up *Gardiner Hill, CO_2 Capture Project Executive Board Chairman*
2:30 pm	Adjourn

CO_2 Capture Project

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CO_2 Capture Project

NGO Workshop

Washington Monarch Hotel
Washington, DC
October 3-4, 2000

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.

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 storage is an important option.
  - A bridging technology to cleaner energy solutions.
- **Aims and Objectives of the Project.**
  - Develop new technologies to reduce cost of CO_2 Capture and storage.
- **Progress through Partnership.**
  - With industry, governments and other stakeholders.
- **The style of the project/how we want to work.**
  - International nature of the project, working in Canada, Europe, USA and Norway.

Context for this Meeting

- 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
- Getting into action
- Setting real targets to be delivered by a set time.
- Responsible and proactive measures.

What this is Not About!

- It is not about Ocean Sequestration.
- Causing a distraction from our goals and commitment to move towards cleaner energy solutions.
- Not a conversation about the philosophies or activities of the individual companies – but a conversation about the CCP project.

Building a Foundation; Finding Common Ground

Mark Weggeland
BP Amoco

The CO_2 Capture Project

- **Aims to reduce the cost of capturing CO_2 emissions when fossil fuels are burned.**
- **Is developing methods for safely storing CO_2 underground.**
- **Is a joint project between**
  - BP Amoco
  - Chevron
  - Norsk Hydro
  - Shell
  - Statoil
  - Suncor
  - Texaco
- **Is a 3 year, $20 million technology development program.**
- **Is not involved with ocean sequestration in any form.**

A View on Climate Change

- **Man's activities are having a discernable effect on the climate. The combustion of fossil fuels for power, transport, and domestic use is a significant contributor to rising atmospheric CO_2 levels.**
- **The demand for energy is expected to grow, and in the short to medium-term will be met with fossil fuels.**
- **Capturing CO_2 and storing it underground offer a new set of options for reducing greenhouse gas emissions that complement the current strategies of improving energy efficiency and increasing the use of non-fossil energy resources.**

How We Got Started

- **The CO_2 Capture Project is the result of two years of work:**
  - Conversations, meetings, and presentations to government agencies, technology providers, and potential industrial partners.
  - An international workshop to build support for a joint industry project that promotes progress through partnership.
- **Based on the recognition that the challenges of cost-effective CO_2 capture are not unique to our company or industry.**
- **A desire to engage the best minds and resources.**
- **A willingness to be open, listen to new ideas, and work together.**

Building A Foundation

Our Objectives

- **Develop new, breakthrough technologies to reduce the cost of CO_2 separation, capture, and geologic storage from combustion sources such as turbines, heaters, and boilers.**
  - Perform benchtop R&D to prove the feasibility of advanced CO_2 separation and capture technologies, specifically targeting flue gas scrubbing, pre-combustion decarbonisation, and oxyfuel.
  - Develop guidelines for maximizing safe geologic storage, for measuring and verifying stored volumes, and for assessing and mitigating storage risks.
  - Develop an economic model to establish lifecycle CO2 separation, capture and storage costs.
  - Actively transfer the new technologies to industry via publications, presentations, conferences, an Internet website, patent licenses and commercial services.

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Slide 5
Meeting Date

Building A Foundation

Where the CCP Stands

- **We share society's concern over global climate change.**
- **We are confident that the CCP can deliver technology that is safe, cost-effective, and will lead to reduced CO_2 emissions during the transition to cleaner energy sources.**
- **This work is not intended to replace or delay the development of cleaner energy sources and improved energy efficiency - we will need a broad array of options to reduce CO_2 emissions.**
- **We will work with industry, governments, NGO's, and others to develop solutions to climate change that are acceptable to all.**

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Slide 6
Meeting Date

Geologic Carbon Storage:
An industrial perspective

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The CO_2 Capture project

Presentation to the NGO Workshop
Washington October 2000

bp

Paul Rutter
bp Senior Advisor Environmental Technology

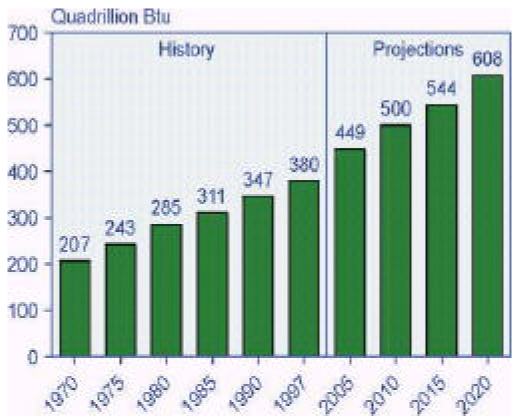
Storage in Geological formations may be a necessary option

> World Energy demand is increasing
> Increased energy consumption is adding to atmospheric carbon dioxide
> Dramatic changes will be required to reduce atmospheric carbon dioxide to even double pre- industrial revolution levels

bp

World Energy Demand

> World Energy demand is projected to increase at 60% during the next 20 years (International Energy Outlook 2000; US DoE)



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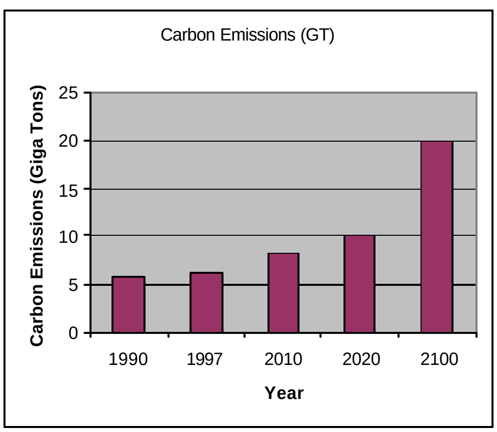
Impact of Energy Generation on the Atmosphere

> The projected increase in energy consumption will add substantial carbon to the atmosphere



Assumes 40% of Primary World's Energy comes from nuclear, solar, hydro, and biofuels by 2100.

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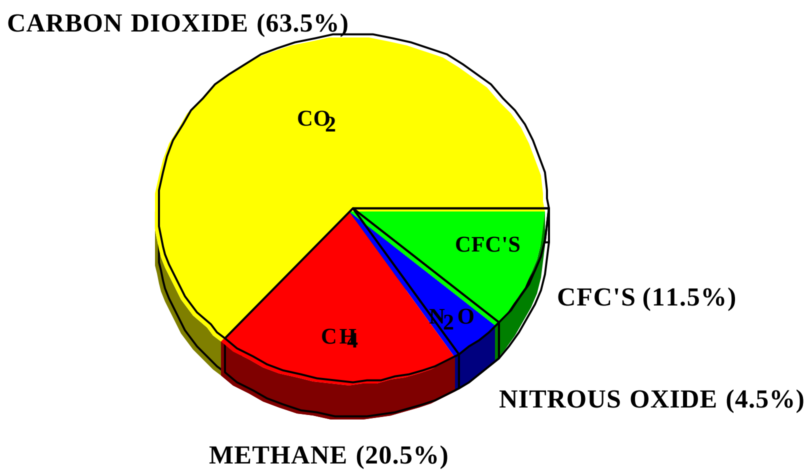
Contributions to Climate Change



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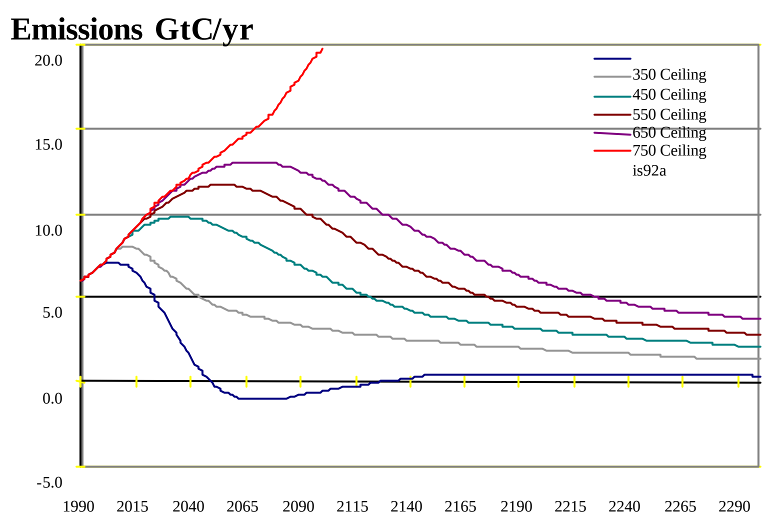
Direct contributions due to anthropogenic emissions

Paths to Atmospheric Stabilisation



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Battelle Memorial Institute

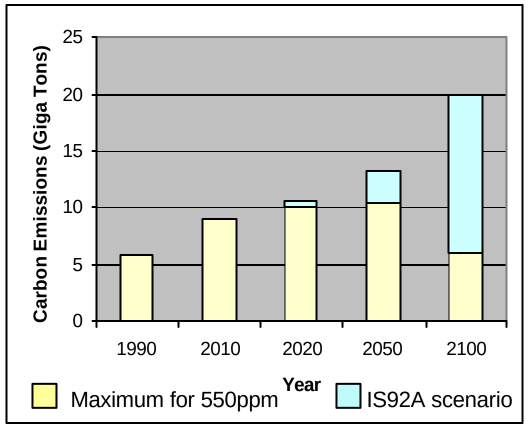
Pacific Northwest National Laboratory

Technical Options

> Reduce Carbon Intensity
> Reduce Energy Intensity
> Store carbon safely

Emissions reductions required to reach 550ppm

A 60% reduction in carbon emissions compared to a business as usual base case is required to stabilise the atmosphere at 2x the pre-industrial level of carbon dioxide.



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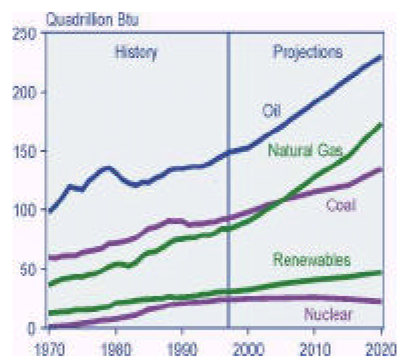
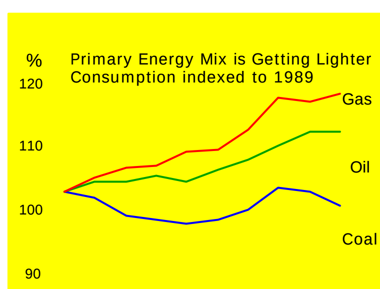
Reduce Carbon Intensity

> Natural Gas
> Renewable Energy
> Nuclear
> Hydrogen



Opel Zafira
Hydrogen Fuel Cell Car



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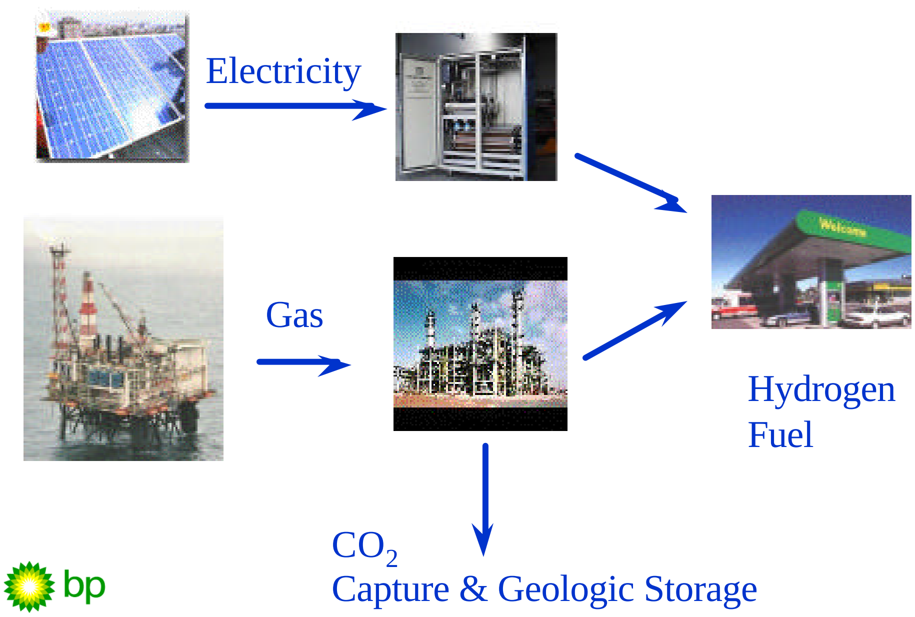
Hydrogen



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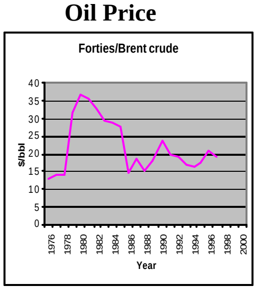
Reduce Energy intensity

Drivers

- Oil price shocks - Between 70s and 80s USA reduced energy intensity by 3%
- Shift away from energy intensive industries and processes-
- Policy factors and regulations - Current progress against Kyoto targets

Oil Price



Industry Initiatives

Several Oil majors have promised to make substantial reductions in Greenhouse Gas emisions over the next 10 years.

The European Chemicals industry have agreed a volutary target to reduce the energy intensity of their products by 20% of 1990 levels by 2005

Kyoto

OECD emissions grew by 10.8% between 1990 and 1999.
For most countries, the Kyoto targets have become less achievable than when they were negotiated in Dec 1997.

bp

Carbon Storage

> **In order to reduce the atmospheric concentration of carbon dioxide to 550ppm we need to capture and store 200 - 300 GT Carbon (~1000GT CO_2)** (Edmonds, Freund and Dooley Aug 2000 GHGT-5)

Potential Global Storage Capacity

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

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

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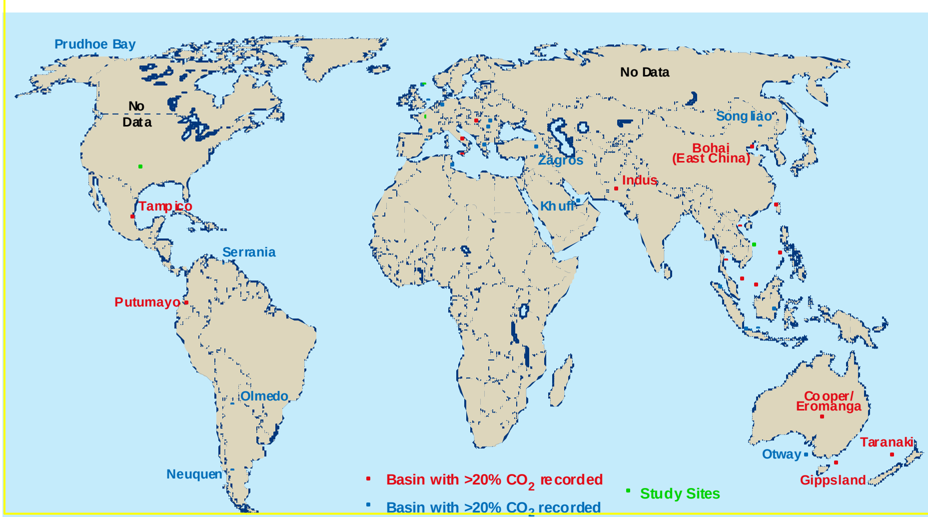
Global occurrence of CO_2 in Petroleum Reservoirs



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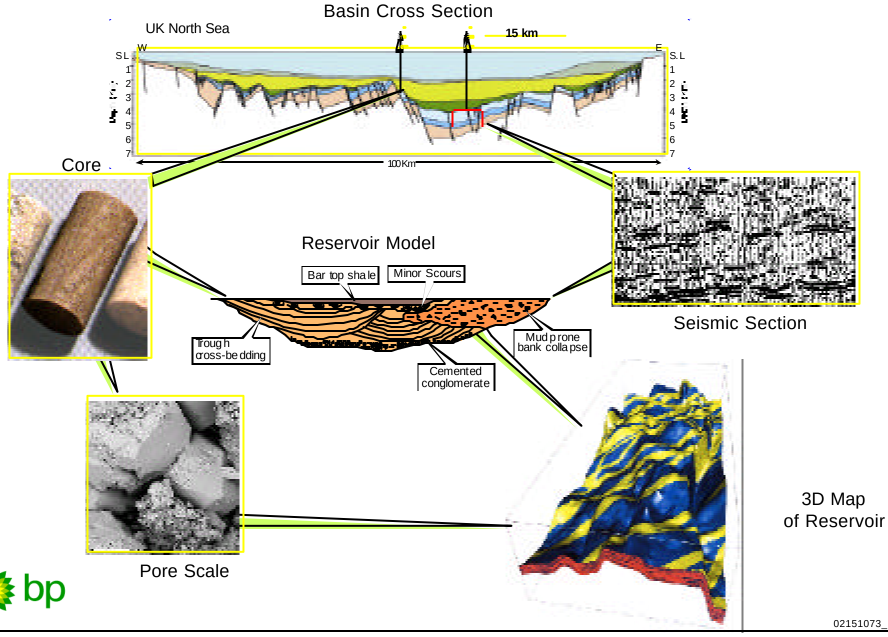
Technologies for evaluating geologic storage



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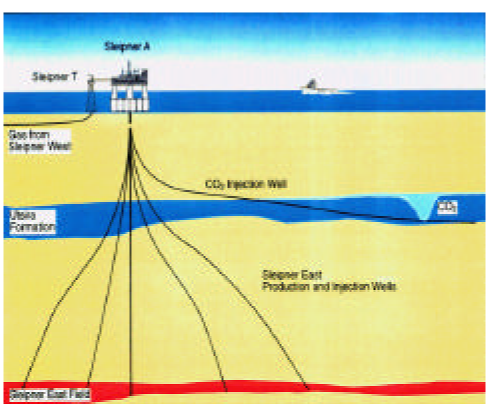
Saline Formation CO_2 Storage



CO_2 re-injection at Sleipner, UKCS

- world's 1st commercial scale CO_2 storage project
  - 1 million tonnes CO_2 injected /year since 1996
  - CO_2 separated from produced gas by amine scrubbing off-shore
  - injection into shallow (1km), saline aquifer

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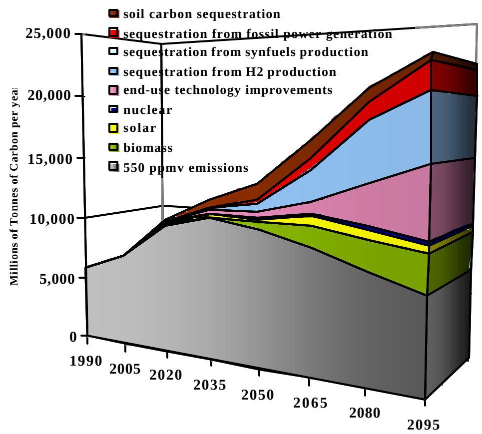
Modeling Carbon Capture & Storage:

Reproduced with kind permission from Jae Edmonds, Pacific NorthWest National Laboratory



Conclusions

Geologic carbon storage is an option we need to have available because:

> Policy measures may not work

> We may not be able to deploy renewables fast enough

> Some countries may wish to continue the substantial use of coal and other hydrocarbons

The CO_2 Capture Project NGO Workshop

Perspectives on CO_2 Capture and Storage: A View from Academia

Howard Herzog

MIT Energy Laboratory

October 3, 2000

What is Carbon Capture and Storage?

- One of 3 complementary approaches to controlling atmospheric CO_2 levels
- Carbon emissions are still generated, but they are captured either at the source or from the atmosphere
- The captured carbon may then be sequestered by a variety of storage options.

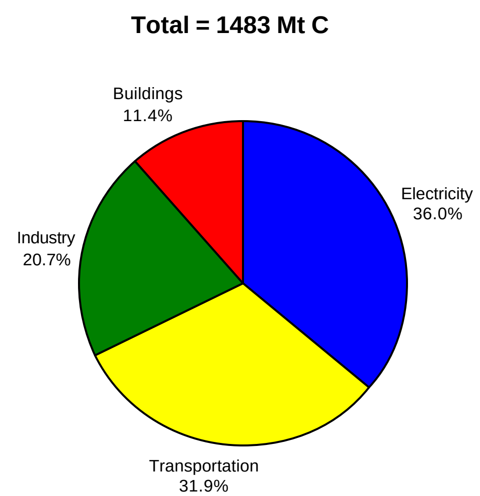
CO_2 Mitigation Options

- Improved Efficiency
  - Supply Side
  - Demand Side
- Decarbonization
  - Lower C/H Ratio
  - Nuclear
  - Renewables Solar, Wind, Geothermal
- Sequestration
  - Direct (capture)
  - Indirect (biological)

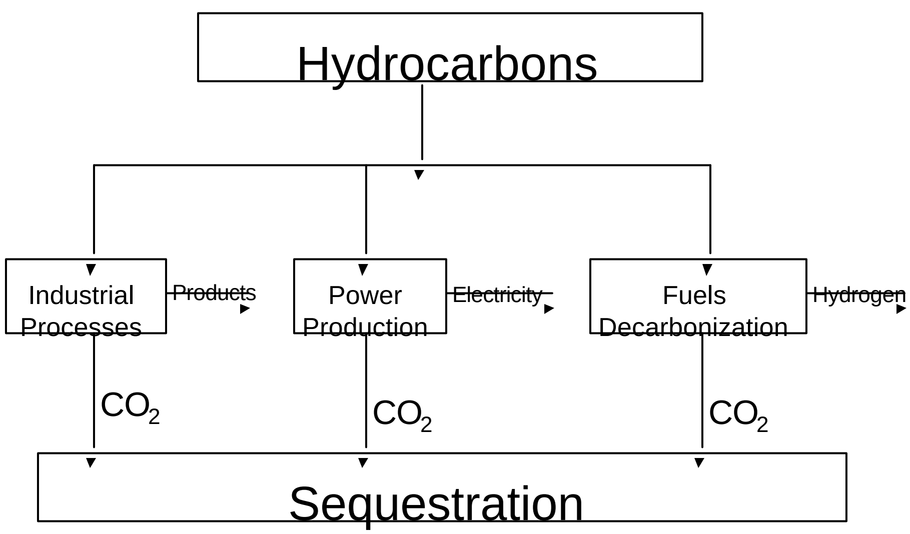
Sources

- Direct (from point sources)
  - Industrial plants
  - Power plants
  - Fuel “decarbonization” plants
- Indirect (from atmosphere)
  - Biological processes
  - Engineered processes

US Carbon Emissions, 1997



Large Stationary Sources



Approaches to CO_2 Separation

Approach	Coal	Gas
Flue Gas	Flue gas clean-up followed by CO_2 separation process (e.g., amines)	CO_2 separation from flue gas (e.g., amines)
Oxygen	Oxygen plus recycled flue gas in place of air Steam turbine	Oxygen plus recycled flue gas in place of air Modified turbine/CC
Hydrogen (or Syn-Gas)	Gasificaton Shift Capture H_2 to turbine/CC	Steam Reforming Shift Capture H_2 to turbine/CC

Composite Cost Model Results

	IGCC Today	IGCC 2012	PC Today	PC 2012	NGCC Today	NGCC 2012
Cost of Electricity without capture (cents/kWh)	5.0	4.1	4.4	4.1	3.3	3.1
Cost of Electricity with capture (cents/kWh)	6.7	5.1	7.7	6.3	4.9	4.3
Incremental Cost of Electricity (cents/kWh)	1.7	1.0	3.3	2.2	1.6	1.2
Energy Penalty	15%	9%	25%	15%	13%	10%

Sinks

- Geologic
  - Oil and gas reservoirs
  - Deep saline formations
  - Coal seams
- Ocean
  - Direct injection
  - Enhanced uptake
- Terrestrial
  - Vegetation
  - Soils
- Conversion
  - Commercial products
  - Fuels
  - Rocks

Requirements for Implementation

- There is an incentive to reduce GHG emissions.
- The technology is effective.
- The technology meets safety and environmental standards.
- The technology is cost competitive with other mitigation options.

It Takes a Portfolio

- There is no one solution - a mix of technologies will be required
- Local circumstances will influence technology choices
- Advanced and innovative technologies will become increasingly important in the future to achieve reductions in GHG emissions at an affordable price

Research Perspective

- A major research goal is to generate objective data so we can make informed decisions.
- It is too premature to say what are the best approaches at this time. We need a broad-based research portfolio.
- To address the problem, we need an objective and civil discourse on the solutions.

We Need to Work Together

- We are united by a common goal.
- We must realize that most proposed solutions are not mutually exclusive, but complementary.
- We need to develop options and knowledge today so we can make informed decisions tomorrow.

CO_2 Capture Project

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CO_2 Capture Project

State-of-the-Art: CO_2 Capture

Geoffrey Johns
Suncor Energy
Washington DC, October 4, 2000

Overview

- **Introduction**
- **Key Issues**
- **CO_2 Capture**
  - **Post Combustion**
  - **Oxyfuel**
  - **Precombustion Decarbonization**
- **Areas of future development**
- **Summary**

Key Issues

- **CO_2 separation and capture account for 75% of the total cost.**
- **Studies conducted by the IEA and others indicate that electricity generation costs to the consumer would increase by 50% with full CO_2 capture using today's technology.**
- **Capture technology is relatively immature because of:**
  - Limited industrial market for CO_2 outside of EOR.
  - Large supplies of naturally occurring CO_2.
  - High process cost; CO_2 is too expensive therefore no "pull" from potential end users.

Post Combustion State-of-the-Art

- CO_2 is separated and captured from flue gases after the combustion process.
- Primary method is to strip CO_2 from flue gas by chemical wash – usually amines.
- 20+ years of industrial application, but not at same scale as potential applications, and with high energy penalty.
- Is considered “Baseline Technology” in CCP.

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, increasing costs.

Post Combustion Opportunities

- **Advancements in amines and other solvents.**
- **Improved system integration to increase energy efficiency.**
- **Membrane separation techniques have high potential.**
- **Other promising technologies include Swing Adsorption methods (both electric and vacuum).**

Oxyfuel State-of-the-Art

- **Consists of combustion in an oxygen environment resulting in a flue gas with high CO_2 concentration.**
- **Boiler with flue gas recycle**
  - **no installations**
  - **but tests & studies indicate no major risks**
  - **based on existing technology**
- **Gas turbine with flue gas recycle**
  - **costly development of new gas turbine needed**

Oxyfuel Challenges

- Lack of nitrogen results in very high combustion temperatures. Some exhaust recycle would be required.
- Oxygen separation is expensive.

Oxyfuel Opportunities

- 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 temperature reduce operating expenses
- Take advantage of oxyfuel characteristics to:
  - Increase turbine cycle efficiency
  - Reduce boiler size and cost
  - Eliminate NO_X and SO_X
- Novel technologies

Precombustion Decarbonization

- **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 large volumes of high-purity H_2 for chemical and refining uses.**
- **Cost reductions will come through relaxed H_2 purity requirements.**

PCDC Challenges

- **Integration of compartmentalized technologies into one complete process.**
- **Defining the process design criteria that is optimal for H_2 as a fuel source rather than a chemical.**

PCDC Opportunities

- Advanced syngas generation.
- Very large scale partial oxidation and autothermal reforming.
- Combined syngas generation and CO_2 separation.
- Improved CO_2 separation techniques.
- Hydrogen utilization.

State-of-the-Art: CO2 Capture

Areas of future development

- Identifiable processes include…
  - physical and chemical absorption
  - adsorption
  - low temperature distillation and gas separation membranes
  - turbine applications: ceramic coatings and rocket engine design
- The main challenge is to reduce overall cost by lowering both energy and capital cost requirements.

Summary

- **The capture technologies are well known but applying the technologies in better novel ways is where the challenge lies...**

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CO$_2$ Capture Project

State-of-the-Art: Geologic Storage

Anita Burke
Shell International
Washington DC, October 4, 2000

Overview

- **Introduction**
- **Key Questions & Issues**
- **Industry's Track Record & Competencies**
  - Natural CO_2 Reservoirs - stored CO_2 for geologic time
  - Enhanced Oil Recovery using CO_2
  - Natural Gas Storage
  - CO_2 Storage in Europe
  - Significant 3rd Party R&D Work Already Underway
- **Areas of future development**
- **Summary**

State-of-the-Art: Geologic Storage

Key Questions & Issues

- **How much does the industry really know about underground CO_2 storage?**
- **Is underground CO_2 storage safe & effective?**
- **What are the advantages of underground storage vs. other mitigation alternatives?**
- **How fast might CO_2 migrate?**
- **What are the issues around caprock integrity?**
- **Could Pre-Combustion Capture coupled with underground storage build a bridge to the Hydrogen Future?**

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Slide 3
NGO Workshop, 3 -4 October, 2000

State-of-the-Art: Geologic Storage

Industry Competencies

- **Significant Industry Experience**
- **Industry's Safety Record**
- **Industry Core Areas of Expertise**
  – Natural CO_2 Reservoirs
  – Enhanced Oil Recovery
  – Natural Gas Storage
  – CO_2 Storage in Europe
  – Significant 3rd Party R&D Already Underway

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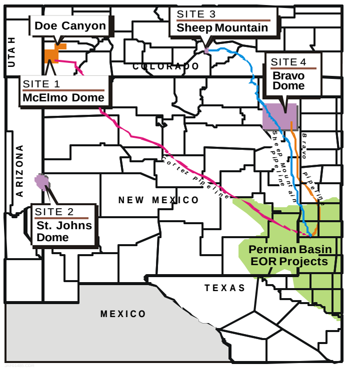
Slide 4
NGO Workshop, 3 -4 October, 2000

Natural CO_2 Reservoirs



LOCATION OF NATURAL CO_2 FIELDS IN THE SOUTHWESTERN U.S.

	Original CO_2 in Place		1998 CO_2 Production		Reservoir Lithology	Depth (m)
	10^6 t	Tcf	10^6 t/yr	MMcfd		
McElmo Dome, CO	1,600	30	15.9	820	Carbonate	2,300
St. Johns, AZ	830	16	0	0	Sandstone	500
Bravo Dome, NM	260	5	7.2	375	Sandstone	700
Sheep Mtn., CO	100	2	2.9	150	Sandstone	1,500

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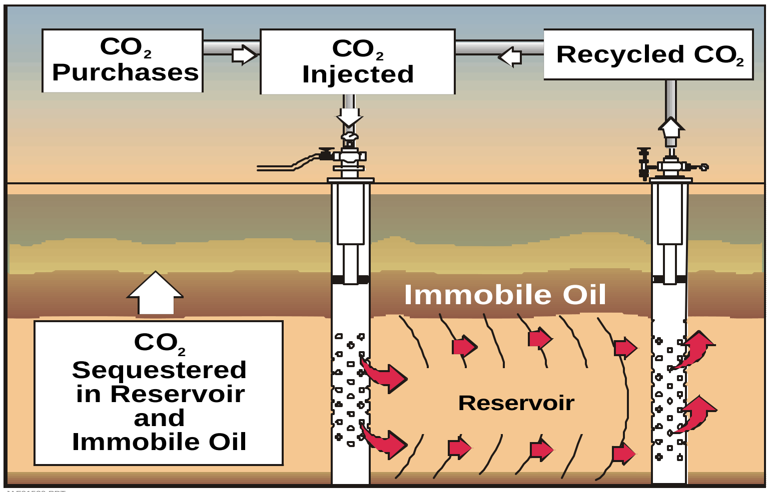
Advanced Resources International, Inc.

Experience w/ Natural CO_2 Reservoirs

- **CO_2 is stored naturally over long periods of time without safety problems**
  - The technology issues of natural CO_2 vs. sequestered CO_2 are similar or identical depending on technical area
- **In the Southwest alone, ~ 26 million tonnes of CO_2 are captured & safely transported to West Texas & New Mexico each year**
- **Natural CO_2 is generally cheaper than CO_2 captured from exhaust stacks**
- **This is why reducing CO_2 capture cost is so important**
  - If the goal is to achieve deep CO_2 emissions reductions

Enhanced Oil Recovery

(Courtesy of ARI)



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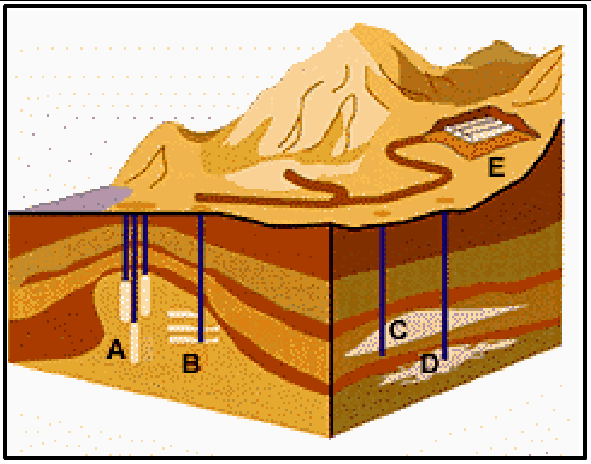
Enhanced Oil Recovery Experience

- **Industry has over 30 years of safe operations**
- **80 EOR fields worldwide**
- **CO_2 "breakthrough" from producers is re-injected again to minimize escape to the atmosphere**

Natural Gas Storage



A = Salt Caverns B = Mines C = Aquifers
D = Depleted Reservoirs E = Hard Rock Caverns

Experience w/ Natural Gas Storage

- **Decades of safe operations in US**
- **Over 500 underground facilities in US**
- **Without this storage, US could not meet the winter-time demand for natural gas and consumers would go short**

State-of-the-Art: Geologic Storage

CO_2 Storage in Europe **(Courtesy of Statoil)**

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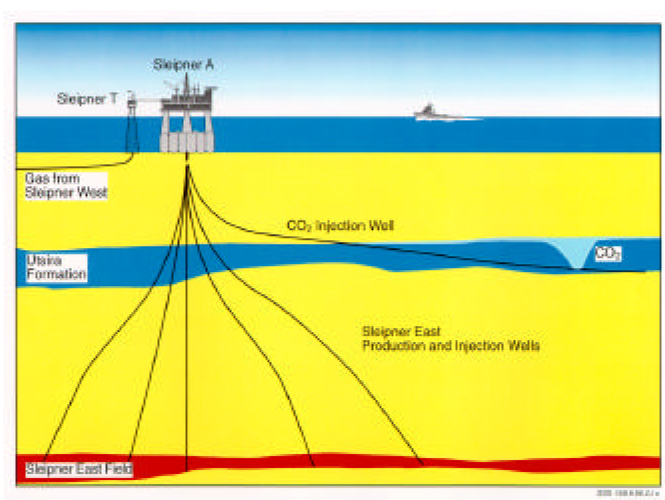
Slide 11
NGO Workshop, 3 -4 October, 2000

State-of-the-Art: Geologic Storage

Sleipner West Schematic **(Courtesy of Statoil)**



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State-of-the-Art: Geologic Storage

Experience w/CO_2 Storage in Europe

- **Large-scale, commercial operation of CO_2 capture and sequestration**
  - In operation for 3 years now
  - Important major natural gas field delivering lower Carbon intensity fuel
  - ~1 million tonnes per year captured which otherwise would be vented
- **CO_2 from the ground is captured, then returned safely to a geologic formation**
- **Early geophysics show CO_2 is being safely stored and sequestered**

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External R&D Projects Ongoing

Significant R&D Already Underway...

- **GEODISC JIP, Australia**
- **GEO-SEQ Lawrence Berkeley NL, USA**
- **SACS JIP, Offshore Norway**
- **Weyburn Field JIP, Canada**
- **Sandia / Los Alamos NLs, USA**
- **Alberta Research Council JIP, Canada**
- **British Geological Survey**
- **Several new DOE-funded programs**
- **GESTCO, Denmark**
- **IFP JIP, France**
- **Lawrence Livermore NL, USA**
- **MIT JIP, USA**
- **Pacific NL, USA**

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Current Areas of Development

- **Reservoir characterization with coupled flow/geochemical models.**
- **Assesment of cap rock integrity.**
- **Monitoring and verification.**
- **Risk evaluation and mitigation**

Summary

- **Industry already has significant competencies and experience over decades of time**
  - Have demonstrated downhole operations safe & effective over decades
  - Natural reservoirs demonstrate the long-term storage potential of geologic storage
- **We believe underground storage is a viable option for reducing CO_2 emissions**
- **Risk evaluation and mitigation are areas of current focus**
- **Modeling and monitoring technologies are expected to develop rapidly**
- **Demonstration projects are already underway**