Workshop on Carbon Sequestration Science

Workshop Overview

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Outline

- Background and Motivation
- What is carbon sequestration?
- A decade of progress
- A century of challenges
- Workshop schedule

International Negotiation Timeline

- Dec 21 1990. Negotiations begin on climate treaty as UN creates the Intergovernmental Negotiating Committee.
- Jun 1992. Framework Convention on Climate Change approved by 143 countries at “Earth Summit” in Rio.
- Mar 21 1994. FCCC comes into force 90 days after ratification by 50 countries, including US.
- Mar 1995. COP-1 issues the “Berlin mandates”.
- Dec 1997. COP-3 develops the “Kyoto protocol”.
- Nov 2000. COP-6 in Hague fails to address implementation issues related to the Kyoto protocol.
- July 2001. Continuation of COP-6.
- June 2002. Rio plus 10, target for ratifying the Kyoto protocol.

FCCC Objectives

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

Carbon Balance

- Stabilization means Accumulation = IN - OUT = 0
- IN term primarily from fossil fuel use and deforestation
- Fossil term:

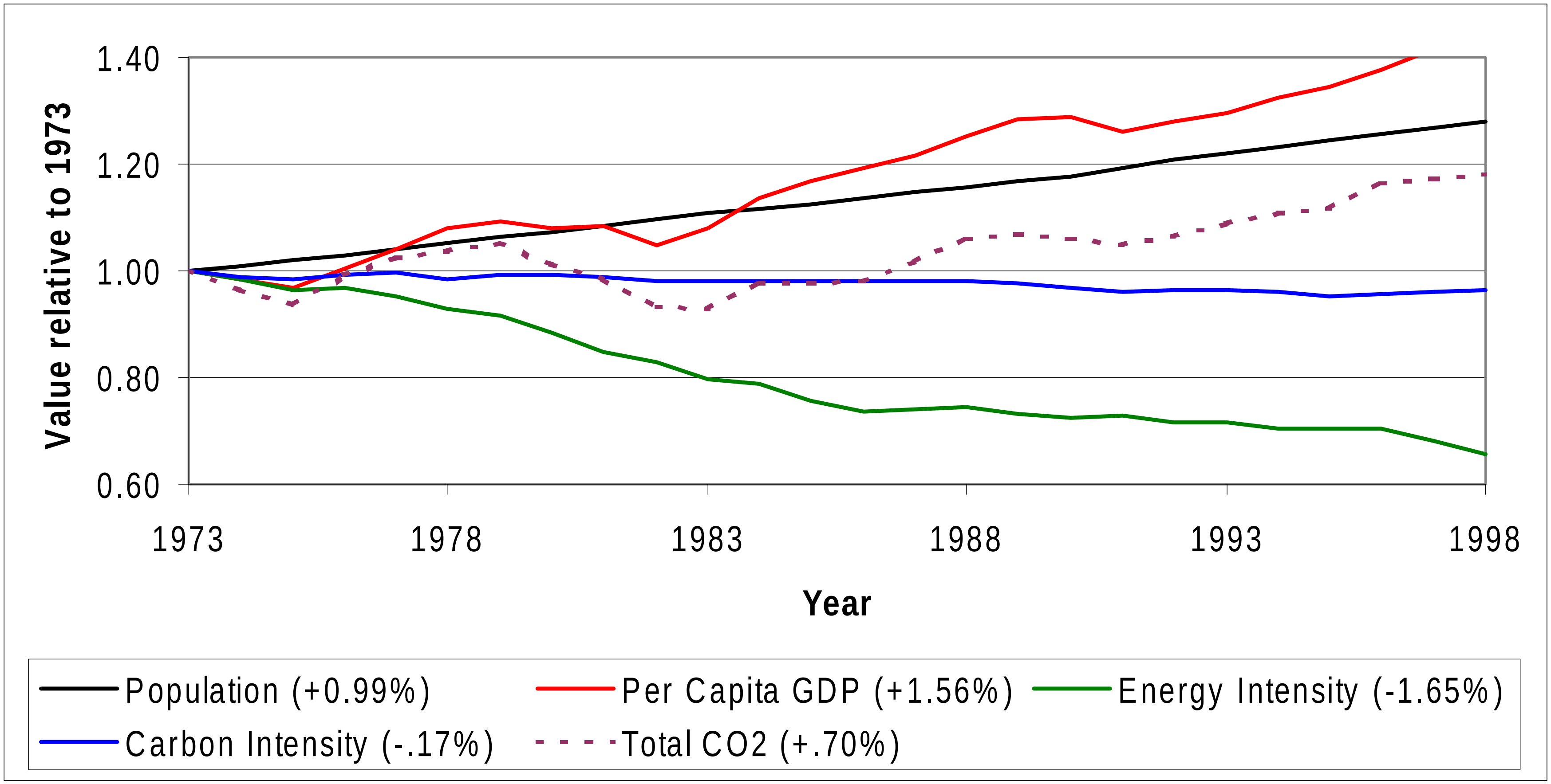
  Pop x (GDP/pop) x (Btu/GDP) x (CO_2/Btu) - Seq

  - GDP/pop represents standard of living
  - Btu/GDP represents energy intensity
  - CO_2/Btu represents carbon intensity
  - Seq represents capture and sequestration

Kaya Equation Factors 1980-1993

Region	Pop	GDP/pop	Btu/GDP	CO_2/Btu	CO_2
US	+1.0	+1.7	-1.5	-0.2	+1.0
OECD Europe	+0.5	+1.4	-1.0	-1.4	-0.5
Japan	+0.5	+3.0	-1.5	-0.7	+1.4
EE and FSU	+0.6	-1.5	+0.8	-0.9	-0.9
East Asia	+1.7	+4.9	+0.3	-0.5	+6.5
China	+1.4	+7.8	-4.4	0.0	+4.7
India	+2.0	+3.0	+1.1	+0.2	+6.3
Africa	+2.8	-1.7	+2.0	0.0	+3.2
OECD	+0.7	+1.8	-1.4	-0.7	+0.4
The World	+1.7	+0.8	-0.9	-0.4	+1.2

Kaya Factors for US
1973 - 1998



CO_2 Mitigation Portfolio

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

Toward a Sustainable Future

- Today
  - Fossil fuels supply over 85% of the world's commercial energy
  - Trillions of dollars of fossil fuel infrastructure in place
- Future: carbon-free energy sources
- Transition: carbon management and sequestration

Carbon Sequestration Milestones

- 1977 – Marchetti paper
- 1980s – Steinberg work at Brookhaven
- 1990 – RITE founded in Japan
- 1991 – IEA GHG R&D Programme started
- 1992 – ICCDR-1 in Amsterdam
- 1993 – DOE/MIT Research Needs Assessment
- 1996 – Sleipner project goes on-line
- 1997 – DOE/MIT White Paper
- 1998 – DOE Research program starts
- 1999 – DOE “Roadmap” report

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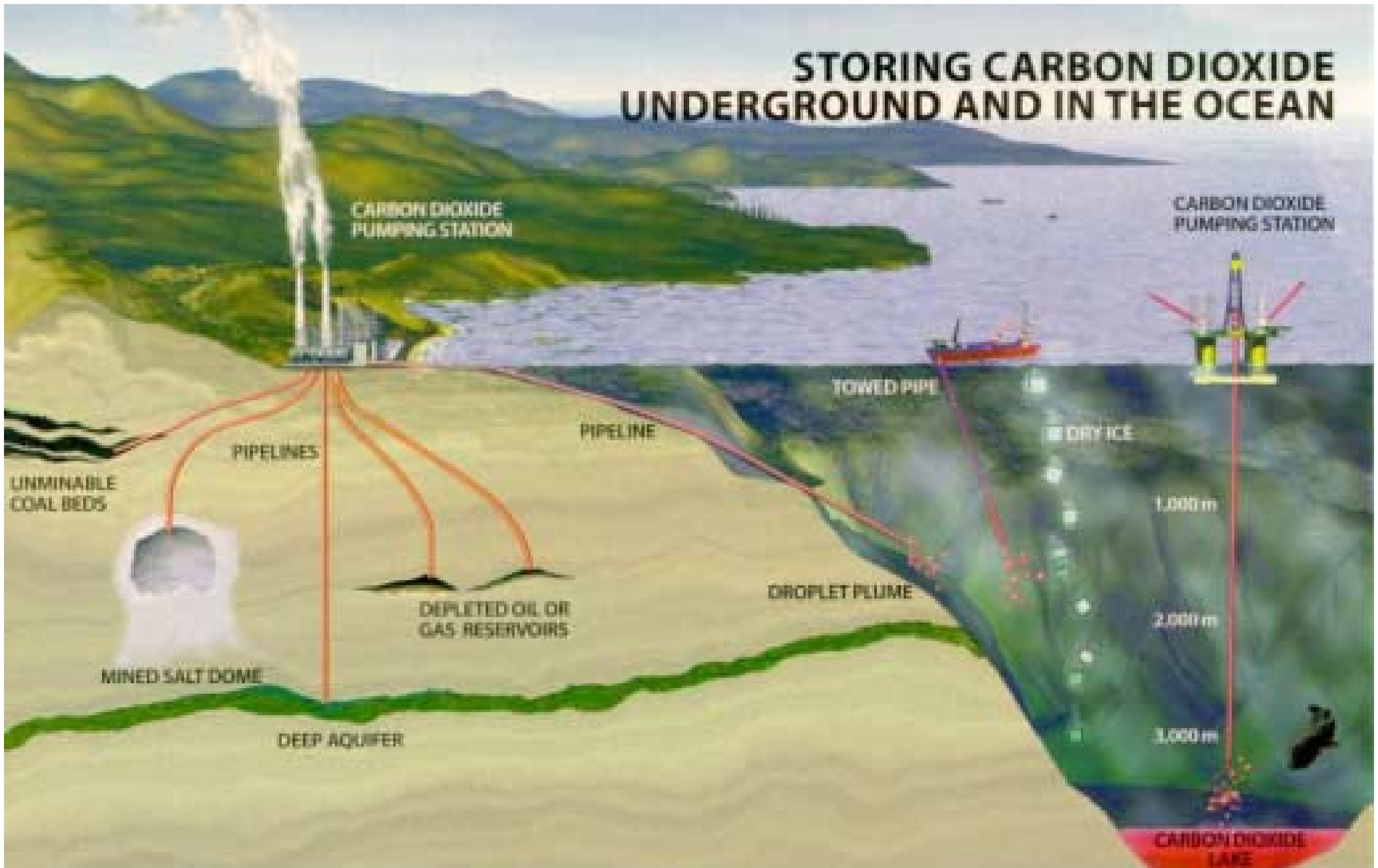
What is Carbon Sequestration?

Carbon sequestration can be defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. The idea is (1) to keep emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage, or (2) to remove carbon from the atmosphere by various means and store it.

From *Carbon Sequestration Research and Development* (USDOE, 1999)

Sequestration Options



STORAGE UNDERGROUND	ADVANTAGES	DISADVANTAGES
Coal Beds	Potentially low costs	Immature technology
Mined Salt Domes	Custom designs	High costs
Deep Saline Aquifers	Large capacity	Unknown storage integrity
Depleted Oil or Gas Reservoirs	Proven storage integrity	Limited capacity

STORAGE IN OCEAN	ADVANTAGES	DISADVANTAGES
Droplet Plume	Minimal environmental effects	Some leakage
Towed Pipe	Minimal environmental effects	Some leakage
Dry Ice	Simple technology	High costs
Carbon Dioxide Lake	Carbon will remain in ocean for thousands of years	Immature technology

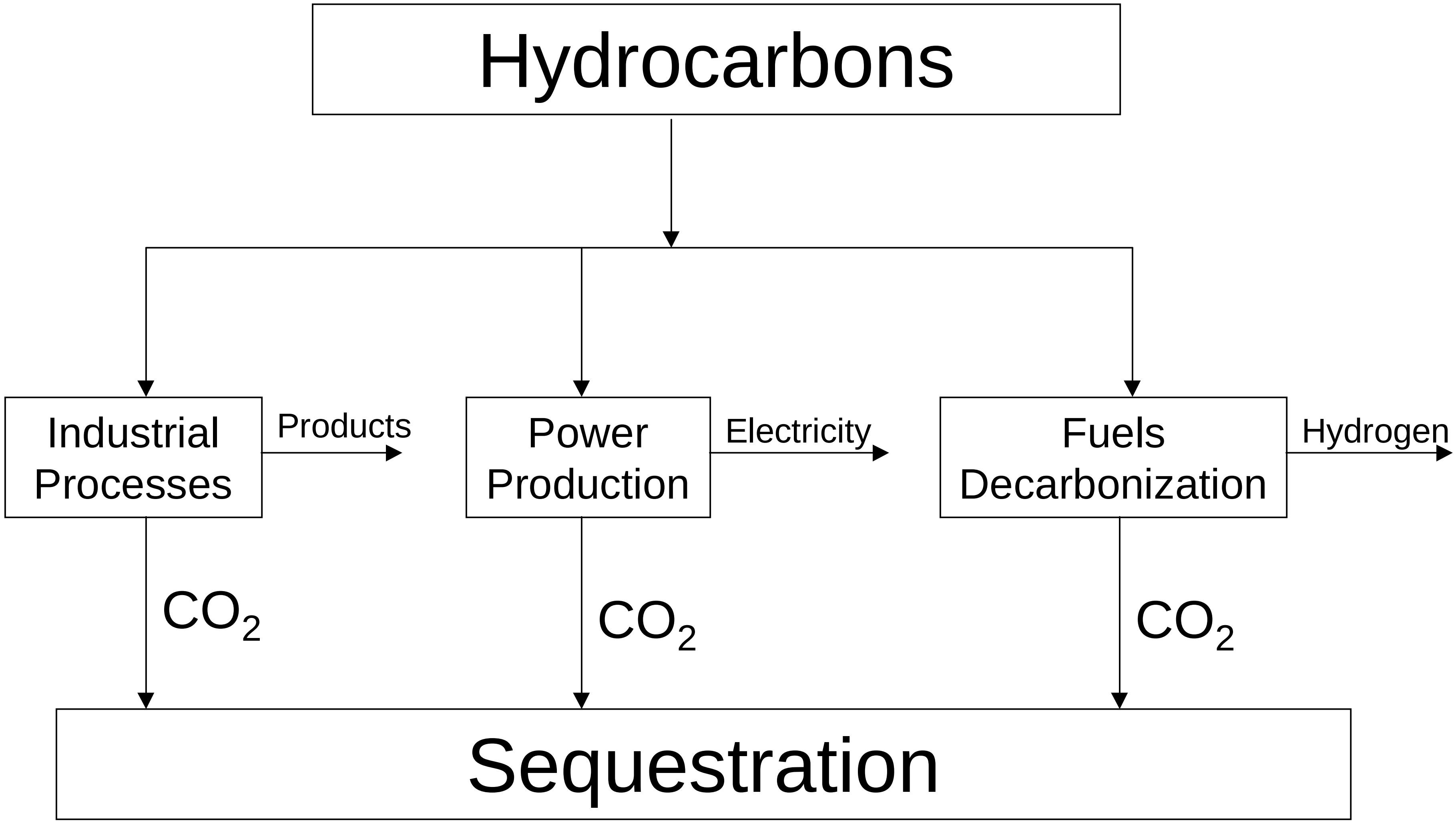
Sinks

Sink	**Opportunities**	**Barriers**
Geologic	Ubiquitous	Storage Integrity
Oceanic	Large Potential	Environmental Concerns
Terrestrial	Inexpensive ?	Measurement Verification
Conversion	Sell Products	Small Markets Thermodynamics

Sink Capacity

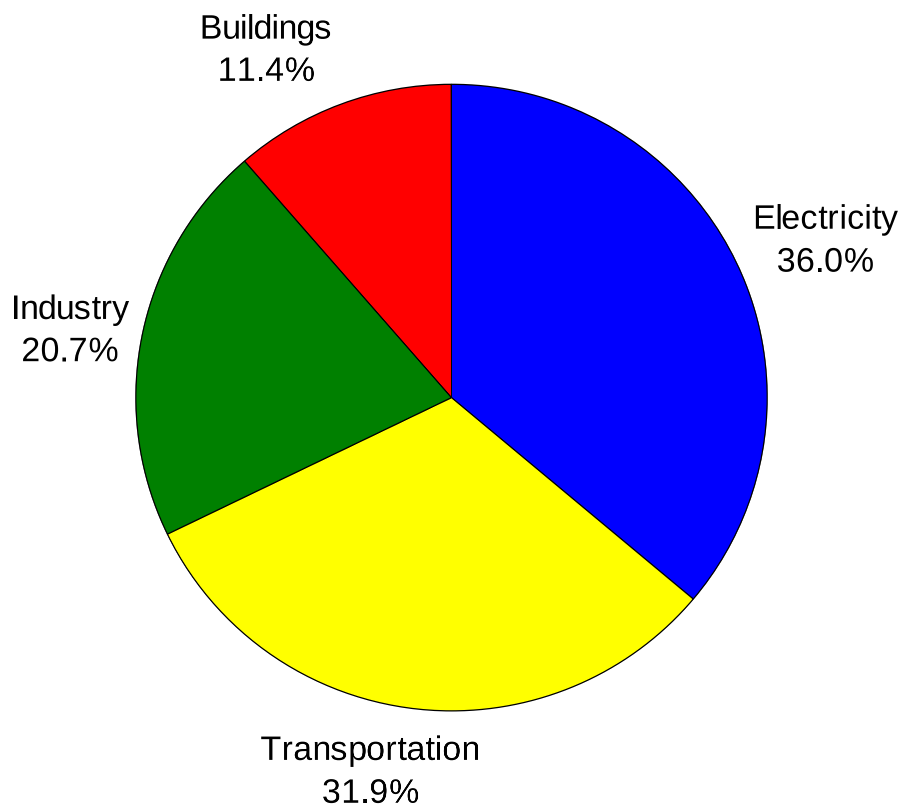
Sequestration Option	**Worldwide Capacity (Order of Magnitude)**
Ocean	1000s GtC
Aquifers	100s – 1000s GtC
Depleted Oil and Gas	100s GtC
Coal Seams	10s – 100s GtC
Terrestrial	10s GtC
Utilization	< 1 GtC per year

Large Stationary Sources



US Carbon Emissions, 1997

Total = 1483 Mt C



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

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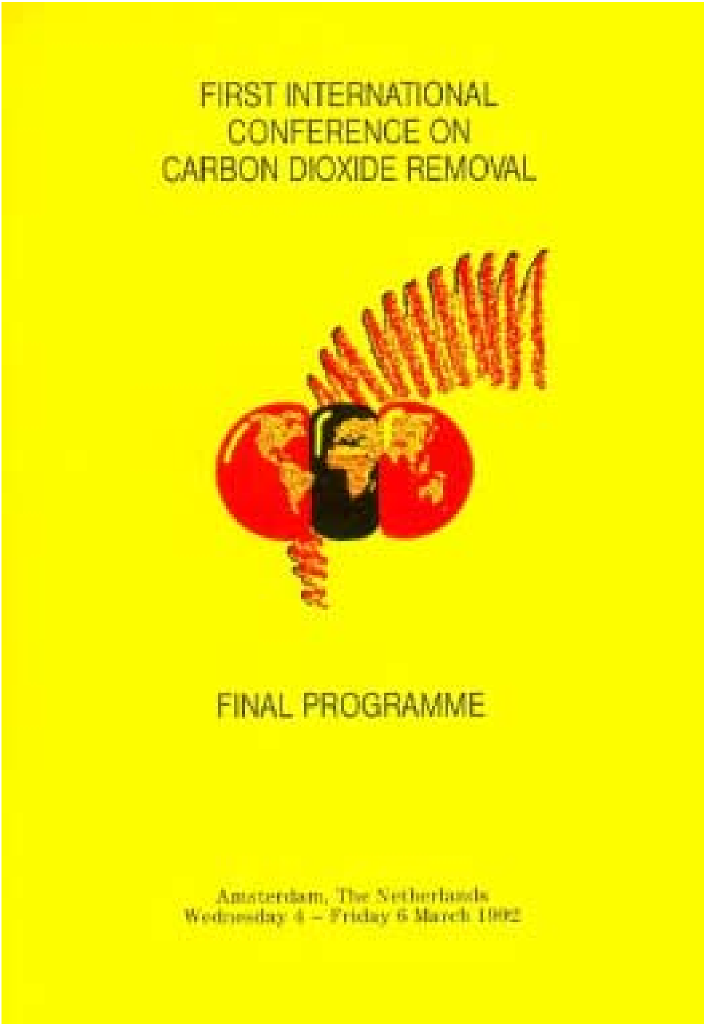
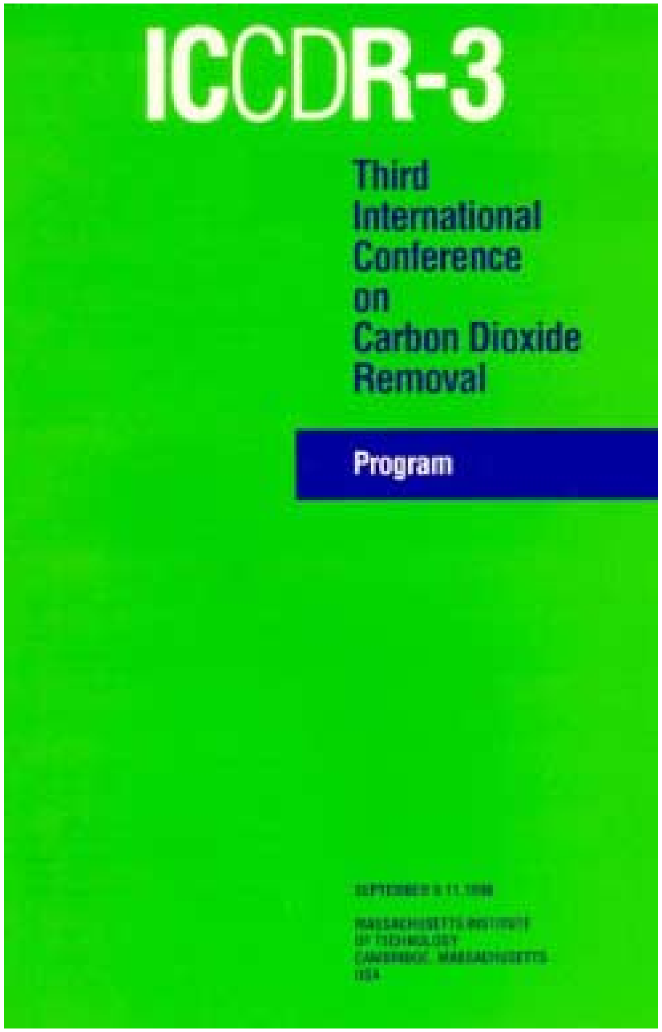
A Decade of Progress

- The Forming of a Community
- Establishment of R&D Programs
- Commercial Successes
- Industrial Leadership
- Stakeholder Outreach

The Forming of a Community





The Forming of a Community

Meeting	Date	Location	Organizer	Attendees
ICCDR-1	March 1992	Amsterdam Netherlands	University of Utrecht	250
ICCDR-2	October 1994	Kyoto Japan	RITE	400 (300 from Japan)
ICCDR-3	September 1996	Cambridge USA	MIT	250
GHGT-4	August 1998	Interlaken Switzerland	ABB, PSI	500
GHGT-5	August 2000	Cairns Australia	CSIRO	350 - 400
GHGT-6	October 2002	Kyoto Japan	RITE	???

Establishing R&D Programs

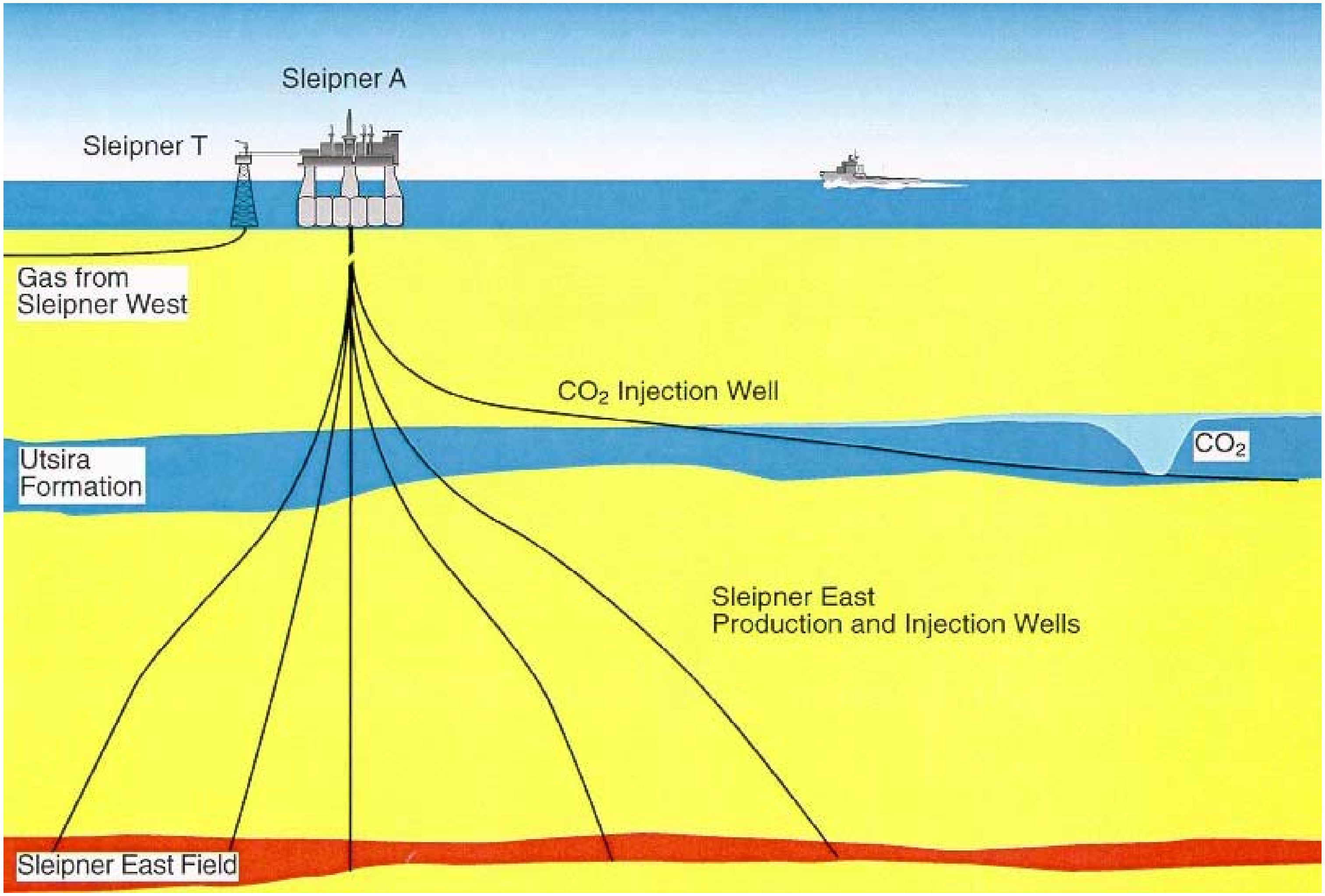
- Japan
  - RITE (Research Institute of Innovative Technology for the Earth) established in July 1990
  - About $50 million USD per year in direct expenses
- IEA Greenhouse Gas R&D Programme
  - Established 1991
  - Currently has 17 members plus 7 sponsors
- US
  - Pre-1998, only about $1.5 million per year
  - Budgets show significant growth starting in 1998

DOE Budgets (in Millions of USD)

DOE Organization	FY 1999 Actual	FY 2000 Actual	FY 2001 Actual	FY 2002 OMB
Science	$6.8	$19.5	$19.2	
Fossil Energy	$5.9	$9.2	$18.8	$20.7
Total	$12.7	$28.7	$38.0	

The Sleipner CO_2-Injection Project

The Sleipner CO_2-Injection Project



CO_2 Capture Project

- Aims to reduce cost of carbon capture
- Is developing methods for safely storing CO_2 underground
- Is a joint project of 7 companies
- Is working together with other stakeholders

Advice from an NGO on Carbon Sequestration

- Reduce the energy penalty
- Address concerns about leaks
- Complement, not compete, with renewables and efficiency
- Make part of a broad-based portfolio
- Stay away from oceans
- Keep out of Kyoto debate
- Use as a bridge (as opposed to a wedge) to a low/no-carbon future

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Reducing Costs

- Separation and capture costs prime target right now
- Efficient power plants critical starting point
- Essential to reduce energy penalty
- How to judge?
  - Relative to other alternatives
  - Relative to status quo

Developing Sinks

- Need to be safe and environmentally acceptable
- Need to be effective – issue of permanence
- Economical
  - Development costs
  - Monitoring costs
  - Location relative to emissions source

Educating Stakeholders

- A program of education and outreach is essential
- Goals are primarily to inform
- Stakeholders include the general public, NGOs, and policy-makers

Final Thoughts

- 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

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Workshop Leaders

- Howard Herzog, MIT
- Harry Audus,IEA GHG R&D Programme
- Gary Rochelle, University of Texas
- Bill Gunter, Alberta Research Council
- Vello Kuuskraa, Advanced Resources International
- Chunshan Song, Pennsylvania State University
- David Keith, Carnegie Mellon University

Capture and Sequestration

- 8:30-9:30 Workshop Overview (HH)
- 9:30-10:30 Separation & Capture Overview (HA)
- 10:45-11:45 Capture Processes – (HA)
- 12:30-2:30 Separation Technologies (GR)
- 2:45-3:45 Economics – (HH)
- 3:45-4:45 Novel Approaches – (HA)
- 4:45-5:30 Informal discussions

Geologic Sequestration

- 8:30-9:30 Overview (BG)
- 9:30-10:30 Geochemistry (BG)
- 10:45-11:45 Oil & Gas Reservoirs/EOR (VK)
- 12:30-1:30 Oil & Gas Reservoirs, EOR (con't)
- 1:45-3:15 Aquifers (BG)
- 3:15-4:45 Coal Beds (BG/ VK)
- 4:45-5:30 Informal discussions

Other Topics

- 8:30-10:30 Ocean Sequestration (HH)
- 10:30-10:45 Break
- 10:45-11:45 Chemical Conversion and Utilization (CS)
- 12:30-1:30 Chemical Conversion and Utilization (con’t)
- 1:45-2:45 Modeling and Integrated Assessment (HH)
- 2:45-3:45 Public Perception (DK)
- 3:45-4:45 Workshop Summary (HH)

Further Information

- Carbon Sequestration Initiative web site:

  http://sequestration.mit.edu/

- My home page:

  http://web.mit.edu/energylab/www/hjherzog