CO_2 Capture Project

REVIEW AND EVALUATION OF THE CO_2 CAPTURE PROJECT BY THE TECHNICAL ADVISORY BOARD

Prepared by:

Vello A. Kuuskraa

Chairman, CCP Technical Advisory Board

President, Advanced Resources International, Inc.

March 24, 2004

OUTLINE

1. Introduction to the Technical Advisory Board (TAB).
2. Evaluating the Impacts of CCP's Accomplishments in CO_2 Capture and Storage.
3. TAB's Recommended Next Steps.

CCP TECHNICAL ADVISORY BOARD

The Technical Advisory Board (TAB) is an international panel of six private sector/research organization technology experts and seven funding agency representatives.

As part of its responsibilities and charter, the TAB provides technical oversight, performance evaluation and peer review for the CO_2 Capture Project (CCP).

CCP TECHNICAL ADVISORY BOARD

TECHNOLOGY REPRESENTATIVES

Vello Kuuskraa	TAB Chairman, Advanced Resources International
Sally Benson	Lawrence Berkeley National Laboratory
Pierpaolo Garibaldi	Independent Consultant
Arnie Godin	Arnie Godin Consulting Ltd.
Dale Simbeck	SFA Pacific
Maarten van der Burgt	Independent Consultant

FUNDING AGENCIES REPRESENTATIVES

David Beecy Jay Braitch	U.S. Department of Energy (HQ)
David Hyman Scott Klara	U.S. DOE/NETL
Vassilios Kougionas	European Union DG Energy and Transportation
Denis O'Brien	European Union DG Research
Hans-Roar Sorheim	KLIMATEK – Norway

SUMMARY OF TAB AND CCP INTERACTIONS

The TAB has been most pleased with its role and interaction with the CCP. It received detailed presentations from the technical teams and was provided considerable time for in-depth questioning and discussion.

The TAB believes it was given the opportunity to provide technical advice that was seriously considered and incorporated in the project. At no time did it find that it was merely serving as "window dressing", as is often the case with advisory boards.

SUMMARY OF TAB REVIEW AND GUIDANCE

1. Give additional emphasis to post-combustion capture, particularly for advanced amine and solvent systems and innovative design and integration.
2. Maintain emphasis on promising pre-combustion membrane technologies, even though research may entail longer lead times than CCP's "stage gate" criteria.
3. Undertake "breakthrough" technologies for air separation for oxyfuel technologies.

SUMMARY OF TAB REVIEW AND GUIDANCE (Cont'd)

4. Expand CCP's efforts in geologic storage.
5. Assure transparency and access for the Common Economic Model.
6. Pursue new and novel ("radical ideas") for capture technologies.
7. Move the technology transfer phase to year 2004 to assure adequate time and emphasis on communicating accomplishments.
8. Assign high priorities to technologies that are consistent with a "hydrogen future."

TAB'S ASSESSMENT OF CCP ACCOMPLISHMENTS

The CO_2 Capture Project (CCP) has made major contribution toward lower-cost, safe options for reducing greenhouse gas emissions from energy industries. As so well summarized by one of the TAB members, *"The CCP has met its promises."* Specifically:

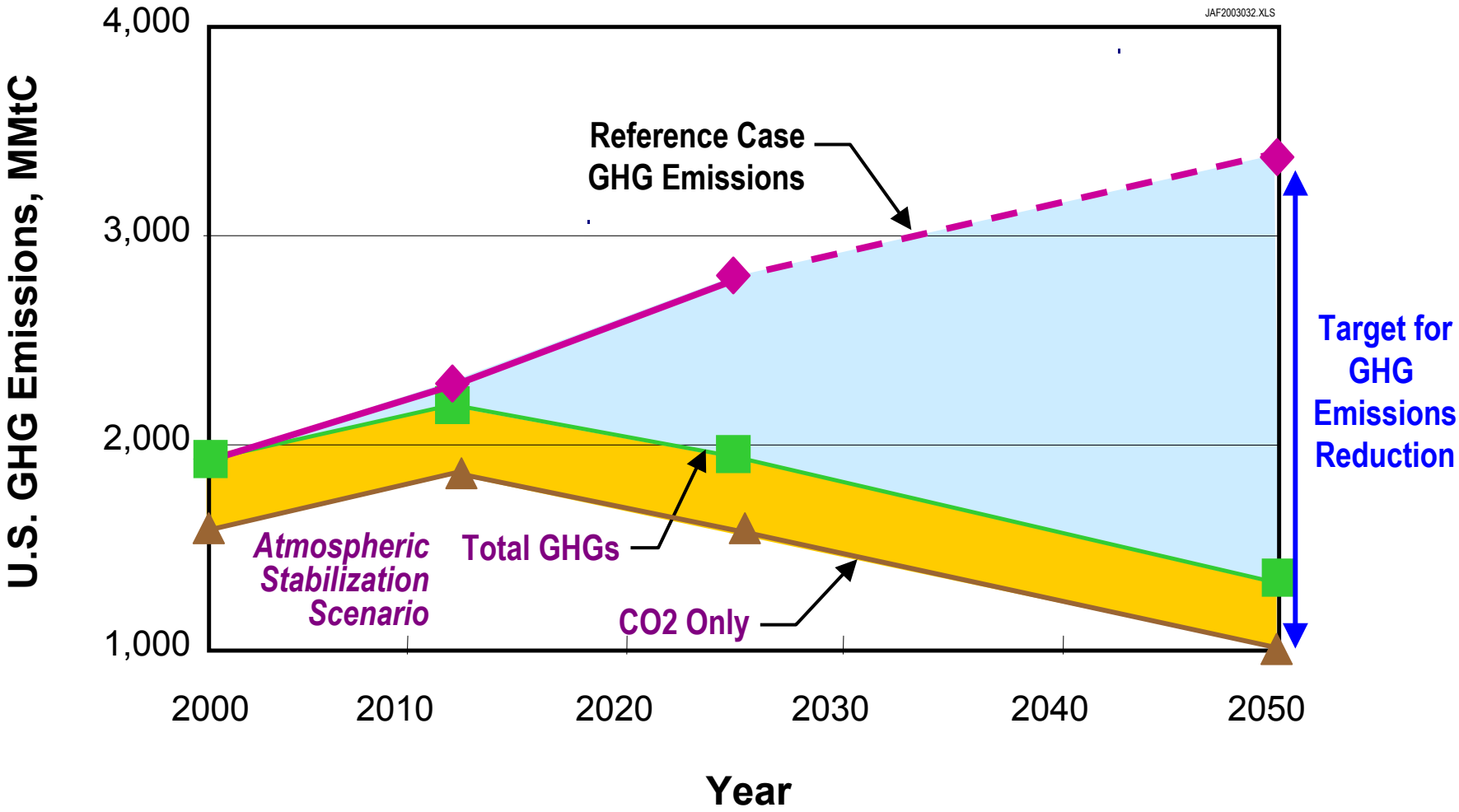
- The CCP has identified and developed a suite of advanced technologies that have the potential to reduce the costs of CO_2 capture by a third to over a half, with further work offering promise of additional cost reductions.
- It has made major contributions to the knowledge base and monitoring technology for assuring safe, reliable geologic storage of CO_2.
- It has developed a "Common Economic Model (CEM)" that is usable by a wide variety of policy, research and technology managers.
- Finally, the work by the CO_2 Capture Project is forging a significantly lower-cost, zero-emissions pathway toward introducing hydrogen as the "fuel of the future".

TAB'S ESTIMATE OF THE IMPACTS AND BENEFITS OF CCP ACCOMPLISHMENTS

The domestic and international economic benefits of the knowledge and technology on CO_2 capture and storage developed by the CCP will be measured in the hundreds of billions of dollars.

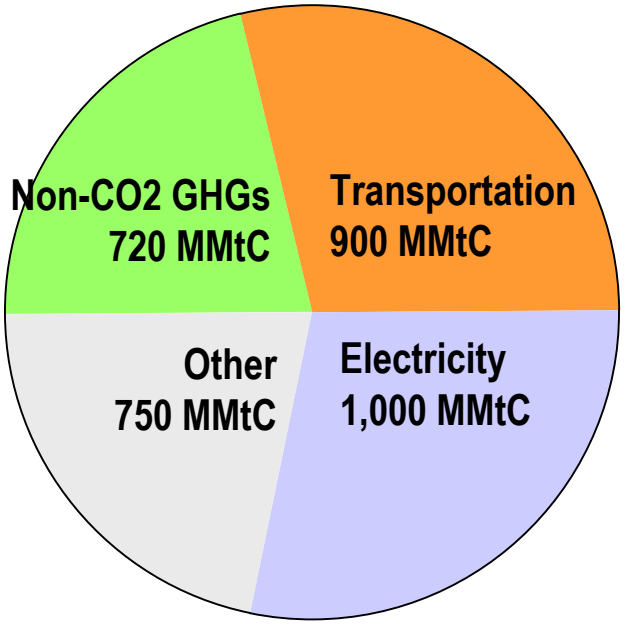
- For the U.S., the lower-cost CO_2 capture technologies could save the economy $5 billion per year in 2025 and $20 billion per year in 2050, should the U.S. pursue a pathway toward atmospheric stabilization of greenhouse gas concentrations.
- For the European Union and Norway, the other two governmental sponsors of the CCP, the economic benefits could be comparable.

REFERENCE CASE AND ATMOSPHERIC STABILIZATION, U.S. GHG EMISSIONS



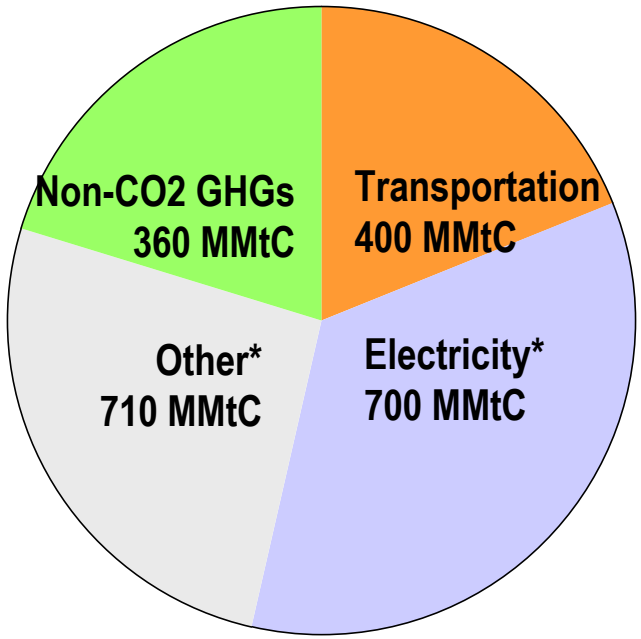
HOW TO ACHIEVE STABILIZATION GOAL?

Reference Case GHG Emissions Year 2050



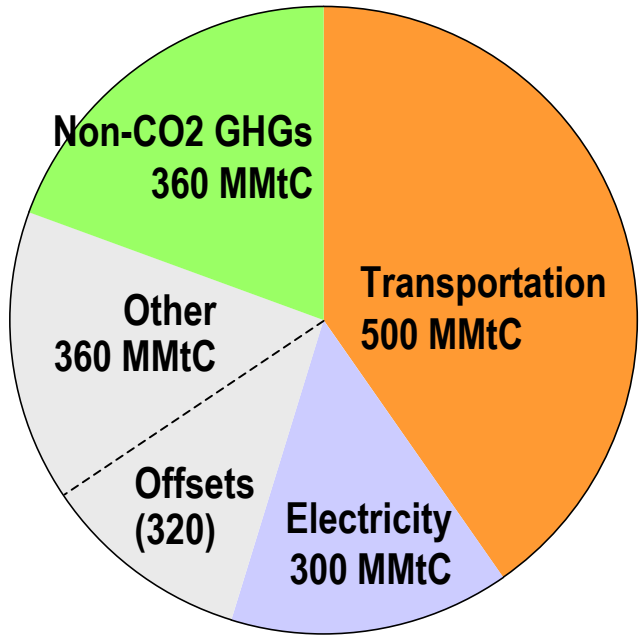
3,370 MMtC

Required Reductions Year 2050



2,170 MMtC

Atmospheric Stabilization Year 2050



1,200 MMtC

**Involves CO2 Sequestration*

Note: Offsets include Terrestrial (70/MMtC) and H2 (250 MMtC)

KEY ASSUMPTIONS FOR ESTIMATING BENEFITS

1. The CCP identified cost reductions for CO_2 capture are realized and implemented.
2. Carbon capture is applied to 60% of new power plants built by 2025 and 90% of new power plants built after 2025, providing over 100 MMtC of reductions in 2025 and over 400 MMtC in 2050.
3. Capture of CO_2 from the production of hydrogen for transportation and other energy applications provides 250 MMtC of reductions in 2050.
4. CO_2 capture from high concentration CO_2 vents and storage with EOR/EGR builds the essential infrastructure.
5. Carbon sequestration accounts for over a third of the GHG emissions reduction requirements, with efficiency, renewables and reductions in non-CO_2 GHGs providing the balance.

TABULATION OF CCP's COST REDUCTIONS

	U.K. Refinery (Heaters and Boilers)	Norway Natural Gas Power Plant	Canada Oil Sands Coke Gasification	Alaska Oil Field (Compressor Operations)
I. "Normalized" Cost of Baseline CO2 Capture Technology*	1.0	1.0	1.0**	1.0
II. Selected Advanced CO2 Capture Technologies				
A. Pre-Combustion Technologies				
(1) Membrane Water-Gas Shift (WGS)	(33%)			
(2) Sorption Enhanced WGS		(34%)		(21%)****
(3) Hydrogen Membrane Reformer		(55%)		
(4) CO2 LDSEP (Fluor)			(17%)	
B. Oxyfuels Technologies				
(1) Flue Gas Recycle w/Ionic Transport Membrane	(64%)			
(2) Integration of Air Separation Membranes in Gas Turbines/Boilers (TBD)				
(3) Chemical Looping (TBD)				
C. Post-Combustion Technologies				
(1) MHI-Kverner (non-integrated)		(20%)		
(2) MHI-Kverner/CCP Integrated Post-Combustion Technology		(55%)		

**All scenarios and capture technologies were evaluated using generic fuel and power prices and Gulf Coast construction costs; cost reductions are on a CO2 avoided basis.*
***Baseline technology already represents a relatively advanced technology case involving production of multiple products, such as hydrogen, steam and power.*
****Cost reductions are -44% under the actual higher natural gas and lower electricity sales prices in Norway.*
*****Cost reductions are -37% under the actual lower natural gas prices in Alaska.*

APPLICABILITY OF CCP TECHNOLOGIES TO COAL-FIRED POWER

Over 100,000 MW of new coal-fired power is expected between now and 2025, in addition to 300,000 MW of existing capacity.

Significant cost savings would accrue to operators of these new and existing plans should the CCP's technologies be integrated into new plant or re-powering designs. Specifically:

- *Improved amine systems/CO_2 scrubbers with integrated and optimized post-combustion capture.*
- *Advanced air separation (e.g., ITM oxygen system) for oxygen-fired coal boilers plus chemical looping combustion.*
- *Advanced coal gasifcation systems using sorption enhanced and membrane water-gas shift technology.*

Finally, essentially all of the CCP's SMV work is applicable, assuming geological storage of CO_2 becomes a preferred option.

NEXT STEPS: TAB's RECOMMENDATIONS FOR CCP PHASE II

Importantly, the work is not yet finished and the costs of CO_2 capture and storage are still too high:

- The CO_2 capture technologies identified and developed by the CCP need to be pilot tested and demonstrated to assure their commercial availability in the next ten years.
- Further research, process optimization and innovative engineering by the CCP, its participating companies and its technology providers offer promise that additional cost reductions and technology advances can be expected.
- And, full public understanding and acceptance of CO_2 storage is yet to be achieved, placing a high priority on this essential aspect of CO_2 sequestration.

NEXT STEPS: TAB's RECOMMENDATIONS FOR CCP PHASE II

The TAB recommends the following priorities for the next phase of the CCP:

1. ***Maintain the vision and organization structure***. The CCP is a unique and successful example of a joint industry-government partnership and of international cooperation.
2. ***Expand the membership, particularly to include traditional electric power companies.*** While the CCP sought to recruit electric power companies, with unsuccessful results when it was first formed, the landscape has changed.
3. ***Further develop, test and optimize the most promising CO_2 capture technologies***. Detailed engineering-based energy and pressure integration plus optimization, the classic "learning by learning" approach, has enabled the CCP to lower the costs of CO_2 capture, even for "mature" such as post-combustion. Similar gains are likely in the other CO_2 capture areas.

NEXT STEPS: TAB's RECOMMENDATIONS FOR CCP PHASE II

4. ***Address the technologies and benefits of joint capture and storage of CO_2, SO_X, NO_X and other power plant emissions***. Many of the technologies offer lower volumes of NO_X as well as the joint capture of CO_2, SO_X and other emissions. The CCP is in a unique position to address this issue.

5. ***Examine and demonstrate the potential of using CO_2-based enhanced oil and gas recovery as a transition step toward "permanent" storage of CO_2.*** CO2-EOR projects can provide a platform for testing advanced SMV technology and practices, while providing additional oil and gas production and near-term reductions of CO_2 emissions.

6. ***Sponsor a series of world class, transparent demonstrations of the safety and reliability of geologic storage of CO_2***. Monitoring and verification technologies, plus the development of advanced "early warning" and mitigation technologies, need to be tested and shown to be reliable, safe and verifiable, helping build the essential public trust in this important greenhouse gas management option.