Some Thoughts on CCS, EOR and UCG.

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Clean Air Task Force, Boston, MA
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This Presentation:

• Carbon capture technology quick overview
• Potential for rapid development of technology in China
• Development of CO2 pipelines—realistic?
• Why anthropogenic CO2 will be critical to meet next generation EOR needs.
• UCG as a game changer
About Clean Air Task Force (CATF)

CATF is a nonprofit organization dedicated to reducing atmospheric pollution through research, advocacy, and private sector collaboration.

CATF staff consists of senior engineers, MBAs, scientists, attorneys, and communications specialists.

Headquartered in Boston, we operate additional offices in Washington, DC, Ohio, Illinois, Maine, and New Hampshire, as well as in Beijing, China.

CATF has been called “a well-respected public health and environment advocacy group” by Science Insider, a publication of the American Association for the Advancement of Science.
Key Points

- **EOR can play an important role in providing CO2-ready sequestration sites**; next generation EOR (ROZs etc) will need anthropogenic EOR so CCS development must move forward now to ensure future supplies

  - Capture technology, like EOR, has been around for a while and is available. Dozens of operational carbon capture projects (including coal boilers and gas turbines) for chemical production, EOR, and food production. 77 large-scale CCS projects are under active development and 234 active or planned worldwide. Challenge: to fund/ build commercial large scale projects and reducing cost.

  - Technology is rapidly developing outside US (e.g China)

  - Sequestration technology was developed in US EOR and is proven. Miscible CO2 floods have been underway for decades: approximately a billion tons of CO2 have been injected for EOR, in the Permian Basin alone, since 1982.

  - **UCG can be a game changer** for coal power and provide CO2 for EOR
Three Components: Capture, Transport and Sequestration

Image Courtesy of: CRC for Greenhouse Gas Technologies (CO2CRC)
CO2 Capture

Image Courtesy of: CRC for Greenhouse Gas Technologies (CO2CRC)
Two Capture Approaches

Pre-Combustion Capture
(Through Gasification)

Post-Combustion Capture
(PCC)
In an “IGCC”, the natural gas supply is replaced with a system to convert coal to “syngas” – mostly hydrogen.
Underground coal gasification with CCS

- With UCG, the coal mine, coal prep, and gasifier are replaced with a suitable coal seam itself, leading to considerable cost savings.
### Pre-Combustion Capture - Commercially Gigawatts of Collective Experience

<table>
<thead>
<tr>
<th>Plant Owner</th>
<th>Country</th>
<th>Start-up Date</th>
<th>Feedstock</th>
<th>Process</th>
<th>AGR Process</th>
<th>Application</th>
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<td>Lurgi Dry Ash</td>
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<td>Quimigas Adobos</td>
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<td>GS/Moell</td>
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<td>IGCC-C &amp; methanol</td>
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<td>coal &amp; I&amp;I coke</td>
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<td>EPCOS SA</td>
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<td>IGCC/Cogén, H2</td>
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<td>Total Fina Elf/Texaco</td>
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<td>Total SCA</td>
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<td>2005</td>
<td>vacuum residue</td>
<td>Texaco</td>
<td>Selsec</td>
<td>IGCC</td>
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</tbody>
</table>

*Note: AGR Process refers to the Absorption, Gasiﬁcation, Reformation (AGR) process, a type of chemical process used in the production of hydrogen from coal or natural gas.*
Example: Beulah, ND Coal Gasification

- Dakota Gasification, Beulah, ND
  - Built as part of US Synfuels program;
  - 18,500 tons per day of lignite converted to substitute natural gas (SNG)
  - 3 million tons of CO₂ per year captured and transported by pipeline to Weyburn for EOR (equivalent to a new 460 MW plant)
Summit Power Group’s Texas Clean Energy Project
• 245MW commercial output power
• 90% CO2 removal (~2.7 million tons/yr)
  ▪ Captured CO2 will be used for EOR in the West Permian Basin
• Set to start construction in 2011 and begin operation in 2014.
Southern Co. Kemper Plant: 50%-65% Capture + EOR
(Roughly equivalent to a natural gas plant)

Plant Ratcliffe, Kemper County, MS

- Under Construction
  Groundbreaking- Dec 2010
- 65% capture, to be used for EOR
- 582 MW
- Plant Cost: $2.4 billion
Tampa Polk Station: 18%-30% Capture + Saline

Tampa Electric's Polk Power Station
• 250MW integrated gasification combined cycle (IGCC) unit
• Began operation in 1996
• CCS
  ▪ Slip stream is being developed to capture CO2 from a 30 percent side stream of the plant's syngas.
  ▪ Expected to sequester approximately 300,000 tons of CO₂ in a saline formation more than 5,000 feet below the Polk power station.
  ▪ Construction set to finish in 2013.

Image Courtesy of: TECO Energy
Examples of Post-Combustion Capture Plants

Plant Barry, Southern Company, Alabama

- 25 MW carbon capture and storage plant
- Successfully started capturing CO₂ in June 2011 using KM CDR process technology.
- Will capture 0.15MT/Yr CO₂ with a 90% capture rate.
- Captured CO₂ will be used for EOR in the Citronelle Oil Field

Mountaineer, AEP, West Virginia

- Phase 1: (2009) 30 MW slide slip from the 1,300 MW Mountaineer Plant (1.5% of power plant).
  - 0.1 MT CO₂/Yr. Planned operation from 1-5 years.
- Phase 2: (2016) 235 MW. 90% (suspended)
- Sequestration into the Mount Simon Sandstone
Post-Combustion Capture on New Plants

Tenaska Trailblazer, Sweetwater, TX

- 600 MW (net) carbon capture and storage plant
- Super critical pulverized coal technology Fluor Corporation Econamine FG plus capture technology.
- 85-90% capture rate 5.75MTY CO₂
- Captured CO₂ will be used for EOR in Permian oil fields.
- Commercial operation set to start in 2015
China

• Projects in China may dramatically lower CCS costs globally in the next decade.

• Chinese projects are driving innovation
In the last three years, China has built enough new coal plants to rival the size of the entire US coal fleet. By 2015, China will have 900 GW of coal plants, three times the size of the current US coal fleet.
China’s Manufacturing Infrastructure

China adds one new coal plant per week and one new gasification plant per month, resulting in huge EPC manufacturing and engineering capacity.

Fast construction speed
(more than twice US)

Low-cost manufacturing

Rapid Innovation

Result:
- Pulverized coal and IGCC plants cost ¼ of US costs.
- Chinese gasifier technology is superior to West.
- US firms going to China to commercialize new technology.
China Innovation Examples

Shidongkou Post Combustion Capture Plant
- CO₂ capture: $35/ton
- 120,000 tons/CO₂
- Construction time: 4 months

GreenGen IGCC with CCS
- In operation starting this summer
- Capture at 0-90% (phased approach)
  - Stage I: 250 MW,
  - Stage II: 400 MW
- Construction time: less than 2 years
CO₂ Transport

Image Courtesy of: CRC for Greenhouse Gas Technologies (CO2CRC)
Currently: 4000 Miles of CO₂ Pipelines

- IOGCC study (2010): “Growth is occurring in CO2 -driven EOR through the use of anthropogenic, or man-made, CO2 along with the pipeline infrastructure necessary to meet that demand.”
- 50 MMT/y throughput.
- Largely naturally mined CO2 supply at present (Jackson Dome, McElmo Dome, Sheep Mtn, LaBarge etc)
- Denbury and Partner Anthropogenic Source Development:
  - 320 mile/ 24” Green Pipeline completed in 2010 with half dozen contracts for anthropogenic CO₂. 800 mcfd capacity, cost: $825 million.
  - Proposed Midwest CO₂ Pipeline: 17 mmt/yr from IL, IN, KY to MS, LA, TX.
  - Medicine Bow, WY CTL; Southern Co. Kemper County, Mississippi Power CCS plant.

Denbury Green pipeline under construction in 2009
Pipeline Growth Not an Obstacle to CCS.

- Dooley et al (Batelle) analysis (2009)
- Between 11,000 and 23,000 additional miles of dedicated CO2 pipeline could be needed in the United States before 2050 under 2 standard climate mitigation cases examined.
- Demand for additional CO₂ pipeline capacity will unfold relatively slowly and in a geographically dispersed manner as CCS-plants come online.
- Realistic 2010–2030 growth: a few hundred to less than 1000 miles per year.
- Analogy: 1950–2000, the U.S. natural gas pipeline distribution system grew at rates that far exceed these growth projections.
- “the need to increase the size of the existing dedicated CO2 pipeline system should not be seen as a major obstacle for the commercial deployment of CCS technologies in the United States.”
Modeled CO$_2$ Pipeline Corridors
The “Horseshoe” Pipeline Concept
Interconnecting anthropogenic and natural sources with EOR basins

Source: MITei
ARI: Three 800-mi Pipelines could store 30 Years of OH River Valley Coal Plant CO₂

With three long distance (800 mile), large capacity (5 Bcf/d) pipelines, plus shorter distance CO₂ distribution lines, CO₂-EOR could store all of the CO₂ captured in 30 years from Ohio River Valley (ECAR) coal-fired power plants.

Total and captured CO₂ emissions* from coal-fired power plants in 30 years (Gt).

CO₂ storage capacity provided by “traditional” CO₂-EOR (Gt) in each market region.

CO₂ storage capacity (Gt) provided by EOR in the Residual Oil Zone in the Permian Basin.

*Captured CO₂ assumes retirement of inefficient coal-fired capacity equal to 1/3 of today’s CO₂ emissions and 90% CO₂ capture from the remaining coal-fired plants.

Source: Advanced Resources Int’l (2010).
480,000 Miles of Natural Gas and HL Pipelines.
CO$_2$ Sequestration

Image Courtesy of: CRC for Greenhouse Gas Technologies (CO2CRC)
Sequestration Potential: Hundreds of Years. Coal Plants and Sequestration Sites Overlay.

**Figure 4-1 Map of US Coal Plants and Sequestration Sites**

US Storage Potential from DOE Carbon Storage Atlas, 2010 (Billions of tons)
Several Large-scale Integrated Projects are Operating or Under Construction

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Capture</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleipner CO₂ Injection</td>
<td>Norway</td>
<td>Gas processing</td>
<td>Deep saline formation</td>
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<tr>
<td>Snøhvit CO₂ Injection</td>
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<td>In Salah CO₂ Injection</td>
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<td>Pre-combustion (syngas)</td>
<td>EOR with MMV</td>
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<td>Gorgon Carbon Dioxide Injection Project</td>
<td>Australia</td>
<td>Gas processing</td>
<td>Deep saline formation</td>
</tr>
</tbody>
</table>

Sleipner, North Sea

- Norwegian Statoil, BP, others, initiated 1996 to avoid $55/t CO2 tax.
- Separation and reinjection of CO2 produced w/ NG.
- 1 MMT/yr
- 11 MMT to date (2008)

Modeling of Sleipner field suggests that CO2 would not begin to migrate into the North Sea for 100,000 years and then at a rate of $10^{-6}$ (a 0.0001% a year) after a million years (Lindberg and Bergmo, 2003.)
**Snohvit**

- Norwegian Statoil.
- Separation and reinjection of CO2 produced with NG.
- Injection into sandstone at 2500m depth.
- 0.7 MMT/yr since 4-2008.


In Salah natural gas, Algeria

- Injection began 2004 (1.2 MMTT/y)
- Separation and reinjection of CO2 produced with NG
- 30 Year Project: 17 MMT CO2
- Storage in Saline water leg of structure

From Wright, 2010
DOE Phase III Cranfield, MS Storage and Monitoring Test (Denbury/ TX BEG)

- Nearly 3 MMT stored since 2008 in saline water leg of producing structure-- a saline test in an EOR site.
- CO2 Source: Denbury/Jackson Dome.
- Advantage: existing CO2 infrastructure.
- Research Center for GS monitoring development: e.g. satellite uplinked pressure monitoring.
Enhanced Oil Recovery:
A foundation for carbon sequestration.

- Began in the 1970s; CO2 miscible flooding with supercritical CO2 found more effective than water flooding.
- In the US, 2008, 105 EOR projects, 6,121 wells, injected 51 million metric tons of CO2 (Oil and Gas Journal 2009). 6% of US Crude Oil Production (EIA).
- Historically CO2 is 33-68% of the cost of CO2 EOR operations (EPRI 1999), so CO2 losses are tracked and minimized by recapture and reinjection.
- EOR can accommodate 100% of the volumes of CO2 forecasted to be captured in the next 20 to 30 years.
EOR Advantages-

- Has capacity for large volumes of CO2
- Infrastructure in place
- CO2 plume management via production wells
- Provides redundancy via pipeline or stacked storage
- Cost offset by oil production
EOR GS w/ anthropogenic CO2: Weyburn-Midale.

- Injection of anthropogenic CO2 from Dakota gasification (2.9 MMT/yr). IEA goal: understanding CO2 behavior & monitoring.
- 19 MMT anthropogenic CO2 from 205 mile pipeline injected into oil and gas fields (Canadian Williston Basin) at 5,000 feet depth. 300 injector/700 producer wells.
- EnCana/Cenovus/Weyburn: 2.4 MMT/yr, 17 MMT (as of 12/10) Projected net sequestered: 26 MMT after 30 yrs.
- Apache/Midale: 0.46 MMT/yr; 2.1 MMT (as of 4/10); projected net sequestered: 8.5 MMT after 30 yrs.
- 2/3 net CO2 from oil production as w/o GS (IEA GHG).
- GS potentials: ~30 MMT EOR, 55MMT post EOR.

US CCS-EOR GS Development

• Rio Tinto HECA Oxy combustion plant to Occidental’s Elk Hills EOR Field in CA: 2-4 MMT/yr.

• Summit Energy TX to Permian Basin EOR via pipeline: 3.1 MMT/yr.

• Southern CO. Kemper County MS, CO2 to Denbury EOR via pipeline: 3.1 MMT/yr.

• Tenaska Trailblazer, TX, to Permian Basin EOR via pipeline: 5.75 MMT/yr.
Retention is Key Issue to Clarify for Policymakers

- Geologic sequestration inherently results from tertiary EOR CO$_2$ “retention”. CO$_2$ is lost to injected formations via a variety of mechanisms (e.g. capillary, solution trapping) as it flushes out the oil. Retention, the CO$_2$ left behind in the formation after a single cycle—the purchased CO$_2$ less the produced CO$_2$—commonly considered to be on the order of half. But remaining CO$_2$ is recycled and progressively all CO$_2$ remains trapped in the reservoir. Loss to atmosphere is an incorrect presumption implied by older concept of retention.

- For GS purposes, “permanent retention” is sum of injected/purchased CO$_2$ – sum of vented, flared, fugitive CO$_2$ which, from available data, appears to be in the low single digits.
CO$_2$ EOR Capacity by Region

Saline vs. EOR Geologic Carbon Sequestration: Opportunities & Challenges

- **EOR** has sequestered CO₂ as part of the injection and flooding process for 30 years, and so provides large and important near-term opportunity for sequestration of anthropogenic CO₂.
  - Long track record of CO₂ injection. SACROC 1 BCF/day of CO₂ is injected (~20 MT, or ~4 large power plants equivalent!)
  - Oil and water production allows recycling & more efficient use of storage space and plume control through production. Existing infrastructure
  - Wells allow tracking of CO₂ plumes.
  - Costs offset by oil production.
  - Challenge include addressing old wells and CO₂ recycle and accounting.

- **Saline** GCS is needed to meet future volumetric needs for CO₂ sequestration and in basins with power plants and other sources but minimal or no petroleum production.
  - Advantage is that saline storage can be located near power source.
  - Understanding of subsurface geology may not be as well developed
  - Challenge is cost-effective MVA with fewer wells.
  - Less opportunity for plume tracking/direction management unless water production wells and separation plants are utilized.
The Residual Oil Zone (ROZ) Frontier: Substantial New CO2 Required.

With ROZs and Advanced flooding, demand could be as high as 19.5 billion tons of CO2 (ARI report – in review)
The Residual Oil Zone (ROZ) Frontier:

- “State of the art” next-generation EOR in naturally waterflooded zones below the oil/water contact with significant remaining (~30%?) residual oil saturation.
- “The current levels of oil prices could support a very robust future for PB CO2 EOR in the ROZ for the coming 30-50 years.” –Ming, Melzer (2010).
- By a recent estimate, next generation EOR (including ROZ) may produce as much as 135 billion barrels of oil in the PB; 12% of new CO2 is likely to come from existing sources. (Melzer, 2011, after ARI).
Anthropogenic CO2 needed to meet future EOR demand.
Underground Coal Gasification (UCG)

UCG could be a climate game-changer. Including CCS costs, UCG costs about the same as uncontrolled gas or coal.

China’s 12th Five-year plan envisions creating new UCG industry.
Why UCG?

- Could increase usable coal in the U.S. by 300-400%.
- Capital costs for UCG plants are substantially less than the equivalent plant using surface gasifiers.
- Reduces air and water pollution and local water demands for the production of power.
- Reduces the cost of deployed carbon capture and sequestration.
- UCG is a proven technology. Commercial-scale tests are underway in the U.S. (WY, AK), Canada, Australia, New Zealand, India, China, and South Africa.
## Trends

### Some noteworthy UCG efforts

<table>
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<tr>
<th>Region/Trial</th>
<th>Length (days)</th>
<th>Gasified (tonnes)</th>
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