Carbon Sequestration in a Global Energy Context

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Acknowledgments

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- BEES
Outline

• Global Energy Myths and Realities
• CO$_2$ Primer
• Your Questions
Tinker’s Top 10 Energy Myths

6. “Big Oil” controls the price of oil and gasoline and makes “obscene” profits.

7. Cutting oil imports will stabilize gasoline prices.

8. Global oil is “peaking” and we are running out of fossil energy.

9. All coal is dirty.

10. The cost of energy increasing.
Tinker’s Top 10 Energy Myths

1. The US can be energy independent in the next 25 years.

2. “Renewable energy” will reduce dependence on fossil fuels significantly in the next 25 years.

3. The economy will adapt easily to a rapid, federally imposed energy transition.

4. Energy efficiency and savings (alone) will solve the problem.

5. There is plenty of low cost (conventional) oil ready to be found.
We depend upon fossil fuels today.
We depend upon fossil fuels today.
Global Oil Supply and Demand

*Supply = world oil production & Demand = world oil consumption.

Data: Energy Information Administration (June 2007)
Global Conventional Oil Resource Forecasts

“Peakers” have yet to forecast a decline!

Each color represents a different forecaster

Economics, technology and ideas!

after Ahlbrandt et al., 2005
The Conventional Oil “Wedge”

If China and India grow from 1 B/P/Y today to 5 B/P/Y by 2030, it will create 48 MMBD of new demand.

35 MMBD new demand

Liquids Demand

Unconventionals Plus EOR

Canadian Oil Sands

NGL’s, OPEC Condensate, Other

Non-OPEC Crude + Condensate

Global Natural Gas Supply and Demand

*Supply = world natural gas production & Demand = world natural gas consumption.

Data: EIA, October 2007

Natural Gas (Tcf)

Year

Data: EIA, October 2007
US Dry Natural Gas Reserves

Source: Energy Information Administration (EIA)
U.S. Natural Gas Production

Global Energy Consumption

Global Energy Consumption New

- % Coal
- % Oil
- % Gas
- % Hydro
- % Nuclear
- % Geothermal, Biomass, Solar & Wind

Data: EIA October 2007
RATIO OF HYDROGEN (H) TO CARBON (C)
FOR GLOBAL PRIMARY ENERGY CONSUMPTION
SINCE 1860 & PROJECTIONS FOR THE FUTURE

- Methane: H/C = 4
- Oil: H/C = 2
- Coal: H/C = 1
- Wood: H/C = 0.1

1935 (midpoint of process)
\[ \Delta t = 300 \text{ years (length of process)} \]
We depend upon fossil fuels today.
Electricity will play an ever greater role in the energy end use mix.

After Huber and Mills, 2005.
US Cost of Energy

After Huber and Mills, 2005.
Electricity Options

- **Renewables and Efficiency**
  - Capacity impacts cost and reliability of renewables
  - *Efficiency creates increased use and demand in new areas*

- **Coal**
  - Abundant, reliable and dirty; need several new IGCC w/ CCS
  - *Sequestration is not just about geology*

- **Natural Gas**
  - Abundant and cleaner; need 15-20 LNG ports & intelligent access to existing resources
  - *Global deliverability*

- **Nuclear**
  - Abundant, reliable and clean; need several new plants
  - *Waste disposal, scale of disaster and public perception*
Future Global Trends

Historical Data: EIA October 2007
Forecasts: Tinker, 2008

Requirements for Success
- Environment and Access
- IGCC and Sequestration
- Access and LNG Terminals
- Land Use and Environment
- Permits and Waste Storage
- Storage, Transmission, Water

~75%
~25%
Outline

- Global Energy Myths and Realities
- $\text{CO}_2$ Primer
- Your Questions
What is CO$_2$?

- Carbon dioxide is the fourth most-abundant gas in the earth’s atmosphere.
- Animals exhale CO$_2$ and plants use photosynthesis to convert it to energy.
- CO$_2$ has thousands of commercial uses, such as carbonated drinks and dry ice.
- CO$_2$ is formed both naturally and by anthropogenic (man-made) processes.
- CO$_2$ is a greenhouse gas. Greenhouse gases keep heat in the atmosphere and sustain life on earth.
Is CO₂ Bad?

• Too much of a good thing can be a bad thing…
  – In large quantities, CO₂ is not good for you.

• The primary health dangers of carbon dioxide include asphyxiation, frostbite, pressure explosion, kidney damage, coma or death…
  – but CO₂ is required for life.

• Man's activities have increased the concentration of atmospheric CO₂.

• Although global warming and cooling cycles have happened throughout geologic time, anthropogenic CO₂ may accelerate the process.
  – Midland may want ocean front property, but…
Reducing Anthropogenic CO$_2$?

- Anthropogenic greenhouse gases are caused by emissions from fossil fuel combustion processes.
  - Mobile sources: planes, trains and automobiles.
  - Stationary (sitting duck) sources: fossil-fuel power plants, chemical plants, refineries, iron and steel plants, cement plants, and natural gas processing plants.
- There are many ways to reduce greenhouse gas emissions.
  - Conservation and energy efficiency
  - Fuel switching: e.g. natural gas for coal
  - Alternative energy: e.g. wind, solar, nuclear, etc.
  - Sequestration
What is Sequestration?

• Capture of emissions from stationary (sitting duck) sources and subsequent storage is called sequestration.

• Major sequestration options include:
  • Terrestrial: trees, plants, grasses
  • Oceans: carbonated salt water
  • Geologic: put in back into the rocks
    • We like rocks!
Is Sequestration Risky?

- Fossil fuels came from the earth; sequestration is “putting them back” in the form of CO$_2$.
- Because fossil fuel use is likely to decrease slowly over the next 50-100 years, CO$_2$ storage must be effective for several centuries.
- CO$_2$ emissions are going into the atmosphere today; anything we sequester is a net gain.
  - Small leaks are not a major problem.
  - Sudden CO$_2$ “burps” must be avoided.
  - Large volume contact with potable groundwater should be avoided.
Outline

- Global Energy Myths and Realities
- CO$_2$ Primer
- Your Questions
Coal Question

Is there adequate coal available to meet U.S. electricity demand?

- EIA has estimated 200 years supply at current usage.

- A major question is whether the US rail system can respond to increasing coal demand such that power plants can get the coal they need? This has coal power companies concerned.
Global Reserves

~ 33,000 Quads Reserves
Current Annual Consumption ~ 400 Quads

Recoverable Coal
(1.1 Trillion Short Tons)

Proved Conventional Oil
(1,317 Billion Barrels of Oil)

Proved Conventional Gas
(6,183 Trillion Cubic Ft)

Data: EIA June 2007
U.S. Coal Consumption

Coal Consumption (Quad BTUs)

- 0.0000
- 5.0000
- 10.0000
- 15.0000
- 20.0000
- 25.0000

- 1850
- 1875
- 1900
- 1925
- 1949
- 1954
- 1959
- 1964
- 1969
- 1974
- 1979
- 1984
- 1989
- 1994
- 1999
- 2004
Emissions Question

How would limits on carbon emissions alter the supply?

• Resources (supplies) are somewhat independent of carbon emissions limits. Limits are more likely to affect demand, presumably lowering demand for carbon intensive fuels as the price goes up.

• This presumes there are affordable, available alternatives, without which forced emissions limits could have a severely negative impact on energy availability and a resultant negative impact on the economy.
Life-Cycle Analysis

- Energy for Fuel Procurement and Transport
- Energy for Raw Material Mining, Milling and Fabrication
- Energy for Plant Construction
- Energy To Operate and Maintain Plant Equipment
- Energy To Decommission Plant and Reclaim Land
- Decommissioning
- Operation
- Fuel Cycle

After Gerald L. Kulcinski, 2004
US Economy and Oil Price

GDP Growth (Percentage points at annual rates)
Crude Oil Domestic Wellhead Price ($2000)

Data: EIA February 2007 and US department of Commerce
Is there adequate natural gas available to meet U.S. electricity demand?
• Yes. There are adequate global resources of natural gas. The issues are deliverability and price volatility. The gas exploration industry has shown it is capable of finding more gas from unconventional sources if prices remain high. Higher natural gas prices will translate into higher electricity prices.

How would limits on carbon emissions alter the supply?
• Limits on carbon emissions impact demand more than supply. In the case of natural gas, demand is likely to increase with carbon emission restrictions because the price of electricity from “clean coal” would go up, and the likelihood of large scale supply from nuclear, wind, hydro, solar or other sources is limited for several decades. LNG terminals are required to meet demand and stabilize price volatility.
US Natural Gas Resource Availability

1999 NPC Study (NPC, 1999b)
Recoverable Portion of In-Place US Gas Resource (Tcf)

- Cumulative Production (811)
- Reserves (157)
- Reserve Growth (305)
- Undiscovered, Unconventional Reserves (1,004)
- Unassessed Unconventional Reserves (400)
- Geopresseded Brine (Up to 24,000)
- Gas Hydrate (Up to 300,000)

Increasing development costs, technology needs, uncertainty, and decreasing concentration

Not Assessed by NPC
US Natural Gas
Resource Availability

North Sea Graben
(160.6 Tcf)

Volga-Ural Region
(99.2 Tcf)

West Siberian Basin
(1,271.8 Tcf)

N. Caspian Basin
(156.9 Tcf)

Amu-Darya Basin
(230.4 Tcf)

Western Gulf
(251.6 Tcf)

Gulf Cenozoic OCS
(140.3 Tcf)

East Venezuela Basin
(129.7 Tcf)

Northwest German Basin
(141.7 Tcf)

Grand Erg/ Ahnet Basin
(114.2 Tcf)

Zagros Fold Belt
(399.4 Tcf)

Mesopotamian Frdp. Bsn.
(298.3 Tcf)

Greater Ghawar Uplift
(248.6 Tcf)

Rub Al Khali Basin
(182.3 Tcf)

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USGS World Petroleum Assessment 2000 (Tcf)
US Natural Gas Resource Availability

~3870 Tcf in Major Basins
~13,000 Tcf Total Resources

Current annual global consumption is ~100 Tcf

Does not include unconventional gas (shale, coal, tight), brines, gas hydrates, or gasification of coal, heavy oil, tar.
Natural Gas Trade (2006)

Global natural gas demand growth ~ 2%

LNG ~ 20% of total traded gas

> 10% Growth LNG

> 5% Growth LNG

Tinker, NRC, 2008

BP Statistical Review of World Energy 2006
U.S. Natural Gas (Tcf)

**Consumption**

- Total Natural Gas
- Conventional Gas
- Unconventional Gas

**Pipelines**

- LNG

Technology Questions

What are the costs of conventional and unconventional oil and natural gas production technologies?

• There are financial, environmental, resource, and security costs.

• In grossly general terms, unconventional oil (shale, heavy, tar, coal liquefaction) take more energy and water to develop, have greater surface environmental impacts, and are more expensive on a per unit basis,

• Unconventional sources have lower security costs because tar sands, shale oil and coal are abundant NA resources.

• Increased price drives technology development and results in increased reserves.
## Options to Conventional Oil

<table>
<thead>
<tr>
<th>Option</th>
<th>Time to Initiate (Yrs)</th>
<th>Impact (+10 Yrs) (MM bpd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced Oil Recovery</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Heavy Oils / Oil Sands</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Shale Oil</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Coal Liquids</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Gas-To-Liquids</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Biofuels</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

*after Hirsch et.al, 2005*
# US Natural Gas Resource Base

<table>
<thead>
<tr>
<th>TCF</th>
<th>Current Technology</th>
<th>2015 Technology</th>
<th>2030 Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower 48 Onshore</td>
<td>764</td>
<td>839</td>
<td>1006</td>
</tr>
<tr>
<td>Lower 48 Offshore</td>
<td>384</td>
<td>415</td>
<td>486</td>
</tr>
<tr>
<td>Alaska</td>
<td>303</td>
<td>331</td>
<td>395</td>
</tr>
<tr>
<td>Total US</td>
<td>1451</td>
<td>1585</td>
<td>1,887</td>
</tr>
</tbody>
</table>

NPC, 2003
### Unconventional Natural Gas

<table>
<thead>
<tr>
<th>Potential Pathways</th>
<th>US In-place Resource</th>
<th>US Production Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Tight Sandstones</td>
<td>1,000s of trillions of cubic feet of gas</td>
<td>Expand economically recoverable resource by 350 Tcf by 2015</td>
</tr>
<tr>
<td>2 Unconventional Gas: Shale, Coal</td>
<td>1,000s of trillions of cubic feet</td>
<td>Approach annual production of &gt;7 TcF by 2015</td>
</tr>
<tr>
<td>3 LNG</td>
<td>1,000s of trillions of cubic feet</td>
<td>Annual production of &gt; 4 TcF by 2020</td>
</tr>
<tr>
<td>4 Deep Gas</td>
<td>1,000s of trillions of cubic feet of gas</td>
<td>By 2012 develop systems to enable economic recovery of 100 Tcf by 2020</td>
</tr>
<tr>
<td>5 Coal Gasification</td>
<td>1,000s of trillions of cubic feet (~7Tcf/ ton)</td>
<td>Approach annual production of &gt; 2 TcF equivalent by 2020</td>
</tr>
<tr>
<td>6 Methane Hydrates</td>
<td>10,000s of trillions of cubic feet of gas</td>
<td>Confirm safe, economical and environmentally sound at pilot scale by 2015</td>
</tr>
</tbody>
</table>

After 8/05 DOE Roundtable White Paper
Clean Coal and CCS Questions

What is the adequacy of current cost forecasts for IGCC and PC plants, both with and without CCS, and where do the costs come from?

• There are others better to answer this than me. My experience with FutureGen tells me the answer depends if you are buying or selling. Get several inputs on capital and operation costs. In terms of CCS, I don’t think we know the full costs yet. Reasonable estimates show a ~40-50% addition to the cost of electricity for IGCC and ~80-90% for PC. Still need CCS.

How much CCS will realistically be in place by 2020, from what sources, and at what costs?

• Crystal ball! Without a carbon tax or an aggressive cap and trade system passed in Congress in next few years, very little CCS will be online by 2020. Early entrants will be related to EOR.
Sensible Next Steps

- Geotechnical Progress
  - Performance
  - Risk
  - Monitoring
  - Injection Experiments
- Lessons from the FutureGen process
- Science and Policy
  - Sequestration experimental scale
  - Cap and Trade vs. Carbon Tax vs. Market
• There is field documentation of immiscible, non-wetting phase residual saturation
  – phase trapping
• Increased confidence in long-term trapping
  – Frio pilot
• Continued uncertainty about the significance of dissolution of CO₂ in brine
• Reduced expectation for mineral trapping in average sedimentary rocks
Geotechnical Progress
Risk

• Risks of brine displacement resulting from large scale CO₂ injection are being recognized (Area of Review issue)
  – BEG: Nicot/Hovorka model results

• Concerns about old well and long-term well performance have not been resolved
  – Celia Princeton, LANL, BP

• Risks to fresh water as a result of leakage of CO₂
  – reactive grain coats vs. bulk mineralogy
  – BEG/Kharaka USGS

GCCC, 2008
Geotechnical Progress Monitoring

• Increasing documentation of poor performance of soil gas methods for leakage monitoring
  – Weyburn, Otway, natural analogs; ZERT

• Increasing interest in feasibility of groundwater monitoring for leakage
  – SACROC, Cranfield, Otway, no results yet)

• Reduced expectations for seismic monitoring

• New method: deep above-zone monitoring
  – Favorable initial result (Frio),
  – larger-scale testing planned (Cranfield).

GCCC, 2008
Lessons from FutureGen

• Site matters
  • All products must be saleable to be economic: power, CO2, sulfur, slag, hydrogen, etc.
  • High power costs markets (coal on gas) are favorable

• CCS is not for everyone
  • NUMBY: Not Under My Back Yard

• Liability concerns are real and uninsurable at this early stage

• Compression and transportation are expensive

• Permitting and regulatory requirements are extensive and must be streamlined

• The cost of capture “ready” is less than capture “really”
Cap and Trade

Cap and trade is wasteful

- Constraints on the economy
- Unnecessary volatility of energy prices
- “Create a source of wealth to lobby for and to distribute politically (a wasteful activity)”
  - perhaps that is why it is so popular!
- Requires an international monitoring system

Feels voluntary approaches are working

If must do something, carbon tax is better

See also: Nicole Gelinas, WSJ, A Carbon Tax Would Be Cleaner, August 23, 2007
Carbon Tax

Who pays?

- Producers of carbon?
- Transporters of carbon?
- Industrial users of carbon?
- Small businesses?
- Everyone who uses energy?

There are reasons CEOs are standing in the “debate is over” line and it may have little to do with climate science...
What are the potential sites for geologic CO$_2$ storage, how do they match up with potential CO$_2$ sources, and on what time frames?

• There is an excellent match up in the Gulf Coast, and good match in some interior basins.

How did the recent EPRI study arrive at timing estimates for deployment of technologies for reducing CO$_2$ emissions from power generation?

• Good question for EPRI.

Is there adequate research support for innovative approaches to CCS?

• No

Are we adequately addressing carbon capture for natural gas combined cycle units?

• Europeans are looking at this (project underway in Norway).
Stacked Sinks

Very large volume of CO$_2$ storage potential in brine formations.

CO$_2$ will be used for EOR to offset development cost and speed implementation.
CO₂ Sources and Sinks

- Global ~ 26 Gt of CO₂ annually
- U.S. ~ 6 Gt of CO₂ annually
- Texas ~ 700 MMt of CO₂ annually
- Gulf Coast ~ 220 GT storage
Inventory of Sinks with Economic Offset (EOR)

Tinker, NRC, 2008

GCCC, 2004
EOR recovery in Texas outside of the Permian Basin is estimated at 4-6 bbo, using ~ 700 MT CO₂

At $60 oil, 5.7 bbo generates:
- wellhead value: $342 billion
- wellhead taxes: $30 billion
- other taxes: $22 billion
- economic activity: $498 billion

EOR helps finance the infrastructure!
Government Roles

- Incentivize and reward
- Assume ownership/ liability
- Streamline regulatory and permitting
- Intelligent access to resources
- Share infrastructure costs
- Property rights and IP
- Political boundary issues
Industry Roles

- Seek “Fit-for-purpose” sites
- Innovate and invent
- Invest in infrastructure and talent
- Invest in research
- Commercialize and compete
- This is a long-term challenge; try to ignore “The Street”
Thanks!