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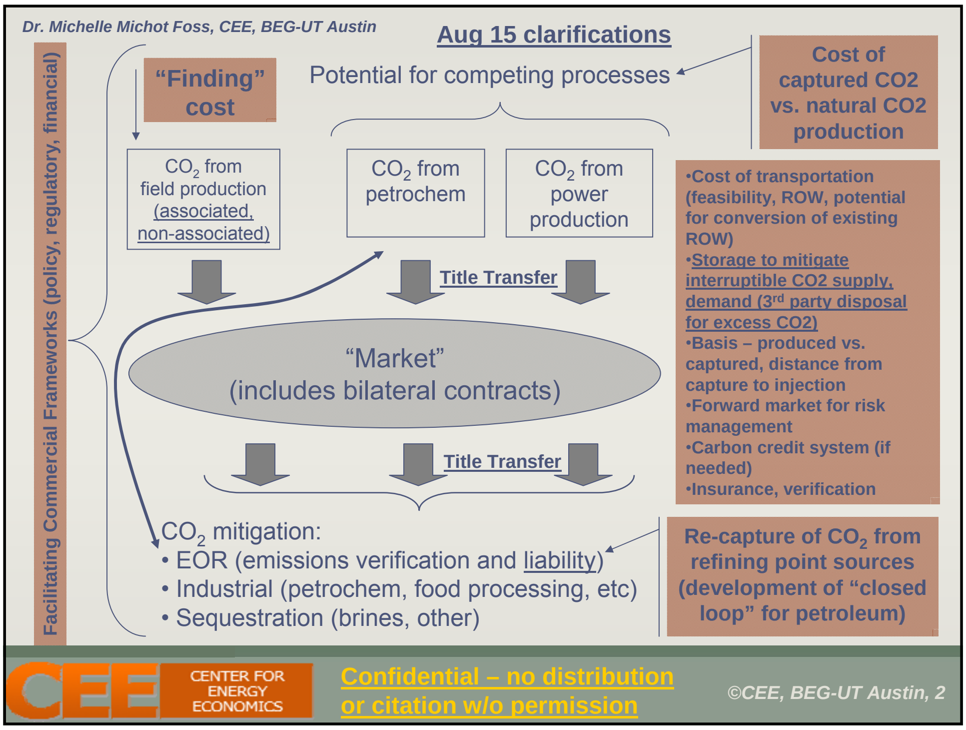
Bureau of Economic Geology, The University of Texas at Austin

CEE CO2 Road Mapping
August 15, 2006



Integrated CO2-EOR Project Economics

Cost Models

Capture cost = f(amount of CO_2, utility costs, concentration, pressure, stability, etc.)

Storage cost = f(capacity, materials, compression, liquefaction, etc.)

Transport cost = f(diameter, length, compression, etc.)

EOR cost = f(CO2 effectiveness, recycle ratio, injection, depth, etc.)

➔ **DCF model**

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Some preliminary numbers

	Cost of CCS ($/bbl)				Cost of Oil Production ($/bbl)		
	Capture	Transport*	Storage†	**Total**	O&M	EOR	**Total**
Low	6.67	0.13	0.03	**6.83**	5	3.5	**8.5**
Medium	15.00	0.60	1.33	**16.93**	10	4	**14**
High	23.33	1.07	2.67	**27.07**	15	4.5	**19.5**

Sources: IPCC for CCS, EPRI for EOR costs

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Some preliminary numbers II

	Cost of CCS ($ / bbl)				Cost of Oil Production ($ / bbl)		
	Capture	Transport*	Storage†	**Total**	O&M	EOR	**Total**
Low	2	0.47	0.33	**2.80**	5	3.5	**8.5**
Medium	12	1.40	2.83	**16.23**	10	4	**14**
High	22	2.33	5.33	**29.67**	15	4.5	**19.5**

Sources: *Can Geological Carbon Storage Be Competitive?* Steffen Kallbekken & Asbjørn Torvanger, Center for International Climate and Environmental Research (CICERO), Norway, May 2004 for CCS, and EPRI for EOR costs

Integrated CO2-EOR Project Economics, II (Aug 15)

Policy approaches drive scenarios

CO2 mitigation NPV>0 w/ higher oil price

CO2 mitigation NPV>0 w/ credit/offset

CO2 is a waste (designation as hazardous waste?)

CO2 is a commodity

Selection Process - Oil Fields

- Short listed first 31 large oil fields **(NOTE from Aug 15 – where can units be formed? Can units be formed at the most prospective fields?)**
  - ❖ Starting with Conroe in Montgomery County
    - Cumulative production to date -710 mmSTB
    - Oil recoverable through EOR – 213 mmSTB
    - CO_2 required for EOR – 28 million tons
    - Storage potential after EOR – 78 million tons
  - ❖ Ending with Refugio-Fox in Refugio County
    - Cumulative production to date - 44 mmSTB
    - Oil recoverable through EOR – ~13 mmSTB
    - CO_2 required for EOR – ~2 million tons
    - Storage potential after EOR – ~4 million tons

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Selected oil fields

	Min	Max
Total recoverable oil recoverable in billion stock barrels (STB)	1.48	1.51
CO_2 required for EOR in million tons	191	196
Total oil field CO_2 storage potential after EOR in	615	635
Total CO_2 required for both EOR and storage after EOR	806	831
Annual CO_2 required for EOR and sequestration assuming a 20 yr economic operation of a capture technology	40 – 42 million tons	

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Selection process – CO_2 sources

- **Limited selection only to power plants located in the Gulf Coast Region**
- Potential CO_2 supply -
    - **131 million tons annually** *when gas plants operate at average Capacity factors (less than 50% CF) as today*
    - **190 million tons annually** *when gas plants operate at their optimal average Capacity factors (above 70% CF).*
  - ❖ Coal power plants alone: 212 million tons annually
- CO_2 Demand for EOR and sequestration
  - ❖ Total ***796 million tons***
  - ❖ Annual: ***40 million tons/yr for 20 years***
- Excess supply: ***91–150 million tons annually***

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Storing the Excess CO2 supply

RRC District	Depleted fields in billion tons	CO2 storage billion tons/ yr
District 1	5.8	0.29
District 2	44.8	2.24
District 3	125.0	6.25
District 4	190.0	9.25
District 5	6.0	0.30
District 6	8.0	0.40
Total	**380.0**	**19.00**

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3[rd] Step – Downsized to Match CO2 Demand

- Selected 11 power plants to match CO_2 demand of 31 major oil fields.
  - ❖ 5 coal power plants total emission = 29.4 million tons
  - ❖ 6 gas fired plants total emission = 12.3 – 25.5 million tons
  - ❖ Total potential CO_2 supply = ***41.7 – 55 million tons***
- CO_2 Demand for EOR and sequestration
  - ❖ Total ***806-831 million tons***
  - ❖ Annual: ***40-42 million tons/yr for 20 years***

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Capture Technology

- Post combustion capture
  - ❖ capture of CO2 from flue gas produced by combustion.
- Relatively low CO2 concentration in power plants make chemical absorption systems the dominant technology of interest for capture.
- Absorption process based on chemical solvents is currently the most commercially viable option for post-combustion technologies.
  - ❖ Offers high capture efficiency
  - ❖ Lowest energy use

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Capture Cost Assumptions

	Coal Retrofit		Gas Retrofit	
	Min	*Max*	*Min*	*Max*
Capital cost: CC ($/kW) IPCC study (2005)	647	1,600	355	550
Other investments (land, etc.) % of capital cost	50%	50%	25%	30%
Economic life time (yr)	20	20	20	20
ROI (%)	8	10	8	10
Fuel costs $/mmBTU	2	2	6	7
Fixed O&M cost (% of CC)	10%	10%	10%	10%
Interest during construction	15%	15%	10%	10%

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CO_2 Capture Chemicals: Cost Assumptions

	Min	Max
MEA – Amine $/ton IPCC study (2005)	1,250	1,800
Alkaline (NaOH) $/ton *Wider price swings depending on demand; can fall to as low as $30* Varied sources internet such	200	500
Activated Carbon $/ton *Wider price swings depending on demand* Varied sources internet such	500	5,000

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Existing Coal Power plants in Gulf Coast Region, Texas

Annual incremental expenses Power plant section	
Ave. Availability	0.85
Total capacity	6,571
Avg. electric efficiency.	35%
Total CO_2 emissions	~77 million tons/yr
Incremental fixed O & M cost	$43-45 million
Incremental variable O&M cost	$4.4-9.8 million
Incremental fuel cost	$213-236 million

CO_2 capture equipment	
Assumed CO_2 capture fraction	90%
Total capital cost	$1.1-3.1 billion
Tot. fixed O&M cost	$111-306 million
Tot. variable O&M	$21-248 million
Total cost of capture	$17-37/ton

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Existing Gas Power Plants in Gulf Coast Region, Texas

Annual incremental expenses Power plant section	
Avg. availability	0.37
Total capacity	20,193
Ave. electric efficiency	35%
Total CO_2 emissions	~55 million tons/yr
Incremental fixed O & M cost	$65-75 million
Incremental variable O&M cost	$16-43 million
Incremental fuel cost	$676-796 million

CO_2 capture equipment	
Assumed CO_2 capture fraction	85%
Total capital cost	$1.78-3.25 billion
Tot. fixed O&M cost	$178-325 million
Tot. variable O&M	$13-154 million
Total cost of capture	$31-51/ton (CF≤40%) $21-32/ton (CF≥70%)

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Cost comparisons

- Cost tilts to the low-side depending on
  - Land availability for retrofit
  - Rehabilitation of existing plant to cope with retrofit.
  - Capture efficiency envisioned; higher capture higher cost
  - Cost of CO_2 solvent
  - Cost of other chemicals
    - NaOH, activated charcoal, etc.
- Cost of capture is generally lower for coal plants than for gas plants.
- Cost of capture of retrofits are about 1½ times lower than cost of capture of complete new power plants with capture.
  - *The assumption is that the cost of the existing power plants is largely a sunk cost, if not already fully or partly recovered.*

Selecting CO_2 Pipeline Parameters

- Pipe parameters
  - Size (diameter); Wall thickness; Length, Grade (class); Material; Roughness; Drag factor
- Fluid parameters
  - Density of gas, Molecular weight, Viscosity, Compressibility
- Heat transfer parameters
  - Inlet temp.; Soil temp.; Burial depth; Soil conductivity; Heat transfer coefficient
- Compressor parameters
  - Unit/type; fuel type; Compression ratio; Efficiency; Ambient temp.; Heat rate; Heat constant; Flow rate; Gas composition; Gas temperature
- System parameters
  - Supply and demand forecast; Sources and Delivery locations; Maximum and Minimum operating pressures; Operating temperature; (temperature profiles); Elevation changes.

Pipeline estimates

- Average expected initial compression pressure (from the capture point): **1533 psi (13 MPa)**
- Expected average final pressure arriving at the delivery point: **1189 psi (8.13 MPa)**
- Threshold (critical pressure) 1071 psi (7.38 MPa)
- Estimated final total pipeline network cost
  - **$515 – 783 million (**984-1,291 miles, 18-20 inches)
  - **$531,300 – 607,000 per mile**

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Summary: Status of Input Data

BEG

- Cost of Capture $/t$CO_2$
  - Existing coal fired: **17-37** *(fuel price of $1.89/GJ)*
  - Existing gas fired: **48-72 (cf<40%)**
    38-52 (cf>70%)
    (Gas price $6.63/Gj)

CO_2 pipeline network

- Cost per km
  - **$323,000 – 377,000 per km**
- Transportation $/tonne CO_2 per 250 km
  - **$2**

International

- Cost of capture $/t$CO_2$
  - Existing Coal fired **31-56 (***fuel price of $1 - 3.2/GJ)*
  - Gas fired **33-57 (***Gas price of $3.13 - 5.0/GJ)*
- CO2 pipeline network
- Cost per km
  - **$330,000**
  (Great Plains, N. Dakota to Weyburn EOR project, 1997)
- Transportation $/tonne CO_2 per 250 km
  - **$1-8**
  (IPCC findings, 2005)

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