Using Industrial Sources of CO$_2$ for Value-Added Geologic Sequestration

Challenges & Approaches

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Perhaps integration of energy systems represents too many complexities for standard business approaches and regulatory regimes.
Kansas Approach

- Inventory & Evaluate Greenhouse Gas Resources
  - Multiple Scales (Nation – Regional – Local – Single Source)
- Inventory & Evaluate Sequestration Opportunities
  - Multiple Scales (Nation – Regional – Local – Wellbore)
- Guiding Principles
  - Economically Viable
  - Environmentally Sound
- Integrated Energy Systems
  - Ethanol Plants
  - Landfills
  - Cement Kilns
  - Fertilizer Plants
- Viewing CO₂ as a Resource
  - Path to the Future ⇒ IGCC ⇒ Carbon Management
January 5, 2006

Kansas State Seminar


total GHG Emissions 6,873 Million Metric Tons

Data: Year 2002 Energy Information Agency and Renewable Fuels Assos.

Kansas State Seminar

January 5, 2006
NatCarb – Inventory & Evaluate

Carbon Resources
NatCarb – Inventory & Evaluate

Sequestration Opportunities

Brine Data Selected

<table>
<thead>
<tr>
<th>Location Info</th>
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<tbody>
<tr>
<td>State: Nevada</td>
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<tr>
<td>County:</td>
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<tr>
<td>Location: TS, R, Sec.</td>
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<tr>
<td>Formation:</td>
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<tr>
<td>Depth: 5934</td>
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<tr>
<td>Data Source: NETL 26702</td>
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<td>Sample Date:</td>
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<table>
<thead>
<tr>
<th>General Analyses</th>
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<tbody>
<tr>
<td>PH: 7.69999981</td>
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<tr>
<td>Temperature: °F</td>
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<tr>
<td>Specific Gravity:</td>
</tr>
<tr>
<td>Resistivity (Rw):</td>
</tr>
<tr>
<td>Rw at 75 deg.:</td>
</tr>
<tr>
<td>Estimated Rw at 75 deg:</td>
</tr>
<tr>
<td>Total Dissolved Solids: mg/L</td>
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<table>
<thead>
<tr>
<th>Individual Chemical Analyses</th>
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<tbody>
<tr>
<td>Sodium/Potassium: mg/L</td>
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<tr>
<td>Sodium: 596 mg/L</td>
</tr>
<tr>
<td>Calcium: 18 mg/L</td>
</tr>
<tr>
<td>Magnesium: 8 mg/L</td>
</tr>
<tr>
<td>Iron: mg/L</td>
</tr>
<tr>
<td>Chloride: 142 mg/L</td>
</tr>
<tr>
<td>Sulfate: 180 mg/L</td>
</tr>
<tr>
<td>Bicarbonate: 1240 mg/L</td>
</tr>
<tr>
<td>Carbonate: mg/L</td>
</tr>
<tr>
<td>Bromine: mg/L</td>
</tr>
<tr>
<td>Iodine: mg/L</td>
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<tr>
<td>Hydrogen Sulfide: mg/L</td>
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This server is run by the Kansas Geological Survey for NatCarb, a project funded by the U.S. Dept. of Energy’s National Energy Technology Laboratory. Programs Updated Nov. 11, 2004. The URL for this page is http://www.natcarb.org/Group/index.html. Comments to webadmin@ku.edu
Russell, Kansas Project

First Sequestration of Agricultural CO₂

Russell is centered in oil, grain and cattle region
Integrated Energy Systems

Raw Materials
- 9.5 million bushels milo
- Wheat gluten plant
- Gas fired co-generation

Ethanol Plant
- 2.7 BCF (145k metric tons)
- 7.5 mmcf/d
- CO₂ Pipeline

Products
- 500 MBO
- (68.5*10^3 tonnes)
- 48 million gallons ethanol
- 182 million liters
- Feed Pellets for 192,000 head

1 metric ton CO₂ = 19 mcf

- One Bushel Milo
- Heat
- Water

Fermentation
- 10 liters Ethanol
- 8.4 kg Carbon Dioxide
- 8.2 kg Cattle Feed (DDG)
CO2 Miscible Flood Demonstration

- 10+ acre, three-spot
- 1 CO₂ injector
- 2 Producers
- 1 Monitoring
- 2 Containment Water Injectors
- 0.29 BCF (15,263 tonnes) CO₂ Injected-WAG
- 6 year operating life
- 18,000 BO (2466 tonnes) estimated recovery

www.kgs.ku.edu/ERC/CO2Pilot
Boevau Canyon, NE
Field-Scale Demonstration

- 14 CO2 injection Wells - 16 Producers
- Ethanol 36 → 45 MGY (136 → 170 M liters)
  - Corn & Milo 17 Million Bushels
    - (432 Million kg)
  - 137 metric tons (Mt) DDG
    - 172,000 Head of Cattle
- 300 → 375 Mt/day (5.6 → 7.0 mmcf/d)
- Verification and Carbon Credits
• InSAR Coverage
  – Coverage, 1992 to present
  – Green Frame shows areas with >20 scenes
  – Monitor mm-scale deformation
Major Kansas GHG Sources

Russell Project

Deffenbaugh

Fredonia

Coffeyville

Oil and Gas Fields
- CBM
- Oil
- Oil & Gas
- Gas

Industry
- Cement
- Power
- Ethanol
- Ammonia
- Refinery
- Landfills
Landfill Gas

Landfill Gas (LFG)
- 9.3% US Greenhouse Gas Emissions
- 8.1 Million Metric Tons CH₄
  - 4.9 Million Captured
  - 2.4 Million Flared
- Subsidy $1.09 mcf ($0.04 m³)

Capture Costs
- 12-15 Cents/Kwh (3600 kJ)
  Assuming 33% efficiency

Deffenbaugh Facility
- LFG 4.5 mmcf/day (236 t/d)
  CO₂ equiv.
  54 mmcf (2842 t/d)
- CH₄ sold 1.8 mmcf/d (95 t/d)
- 116 tonnes CO₂ and NMVOC vented per day
Deffenbaugh Facility

- 18 Mt of Waste in Place
- Additional 1.5 Mt per Year Received
- LFG 4.5 mmcf/day (236t/d)
  - 150 Wells
  - Gathering System
    - 7 miles of 22” pipe under 45” of water vacuum
- CO₂ (GHG equiv.) 54 mmcf/d (2842 t/d)
- CH₄ recovery 2.5 mmcf/d (132 t/d)
- CH₄ sold 1.8 mmcf/d (95t/d)
- 116 tonnes CO₂ and NMVOC vented per day
Trash Cell (ready to take waste)
Landfill Gas Well
Landfill Panorama
(showing gas plant & drill rig)
Landfill Gas
Adsorption Isotherms

- Nitrogen
- Methane
- CO₂

Graph showing adsorption isotherms for Nitrogen, Methane, and CO₂ under varying pressures (psia). The graph includes data points and lines representing different models such as LRC and ZGR.
Landfill Gas

Landfill Gas (LFG)
CH₄, CO₂, NMVOC

Pipeline

Unmineable Coals

CH₄

CO₂
Landfill Gas & CBM Basins

COAL BASINS and COALBED GAS RESOURCES OF THE U.S.A.

- **Yellow**: lignite
- **Orange**: sub-bituminous coal
- **Dark Brown**: bituminous coal
- **Red**: anthracite

**Basins and Resources**
- **Greater Green River**: 314 TCF
- **Wind River**: 6 TCF
- **Big Horn**: 3 TCF
- **Powder River**: 39 TCF
- **North Central Coal Region**: 4 TCF
- **Hanna/Carbon**: 15 TCF
- **Illinois**: 21 TCF
- **Denver**: 1 TCF
- **Forest City**: 1 TCF
- **Raton**: 10 TCF
- **Uinta**: 10 TCF
- **Piceance**: 10 TCF
- **San Juan**: 84 TCF
- **Fort Worth**: 7 TCF
- **Arkoma**: 4 TCF
- **Warrior**: 20 TCF
- **Arkoma**: 4 TCF
- **Cahaba/Coosa**: 1 TCF
- **Richmond/Deep River**: 1 TCF
- **Valley coal fields**: ? TCF
- **Pennsylvania anthracite fields**: ? TCF

**Additional Resources**
- **Northern Appalachian**: 61 TCF
- **Michigan**: 15 TCF
- **Arkoma**: 4 TCF
- **Northern Appalachian**: ? TCF
- **San Juan**: 84 TCF
- **Ft. Worth**: 7 TCF
- **Gulf Coast**: 7 TCF
- **Arkoma**: 4 TCF
- **Warrior**: 20 TCF
- **Cahaba/Coosa**: 1 TCF
- **Richmond/Deep River**: 1 TCF
- **Valley coal fields**: ? TCF
- **Pennsylvania anthracite fields**: ? TCF

**Notes**
- CBM stands for Coal Bed Methane
- **Deffensaugh Landfill**
Major Kansas GHG Sources

- Oil and Gas Fields
- Industry
- CBM
- Oil
- Oil & Gas
- Gas
- Cement
- Power
- Refinery
- Ethanol
- Ammonia
- Landfills

Locations:
- Russell Project
- Deffenbaugh
- Fredonia
- Coffeyville
Southeast Kansas

Partially miscible and immiscible CO₂ EOR

- El Dorado
- Salyards Trend,

Enhanced Coalbed Methane (N₂ and CO₂)

Cement plant gas stream may be best suited for ECBM
Cement Production

Dry Kiln Portland Cement Process

Calcination Process
CaCO₃ > CaO + CO₂
0.51 tonnes CO2 / tonne cement

CO₂ and N₂ kiln gas mix may be suitable for ECBM with little processing
Fredonia Flue Gas and Potential SE Kansas Markets

**Present Composition**

<table>
<thead>
<tr>
<th>% Weight</th>
<th>% Dry Weight</th>
<th>Volume</th>
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<tbody>
<tr>
<td>N₂ 47.3%</td>
<td>N₂ 61%</td>
<td>69%</td>
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<tr>
<td>H₂O 22.6%</td>
<td>CO₂ 25%</td>
<td>18%</td>
</tr>
<tr>
<td>CO₂ 19.3%</td>
<td>O₂ 14%</td>
<td>13%</td>
</tr>
<tr>
<td>O₂ 10.6%</td>
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<td></td>
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<tr>
<td>99.8%</td>
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682 tons/day at 332° F (167° C)

**Enhanced Coalbed Methane (ECBM)**

<table>
<thead>
<tr>
<th>% Dry Weight</th>
<th>Volume</th>
<th>Annual Vol.</th>
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<tbody>
<tr>
<td>N₂ 46%</td>
<td>57%</td>
<td>8.1 BCF</td>
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<tr>
<td>CO₂ 50%</td>
<td>39%</td>
<td>5.7 BCF</td>
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<tr>
<td>O₂ 4%</td>
<td>4%</td>
<td>0.6 BCF</td>
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Dehydrate

Reduce 

Direct or Modified Co-generation

400°C

Kiln Gas CO₂, N₂, ?

CH₄ Pipeline

Kiln Gas CH₄, CO₂, N₂, ?

Pipeline
Cement Plants and Coal Basins

Modified from Portland Cement Association 12/98 map
Coffeyville Resources
Coke to $H_2$ Gasification Plant for Ammonia & $CO_2$
Coffeyville Coke Gasification to Ammonia Project

Air Separation Unit

Ammonia Synthesis

Ammonia

UAN Plant

NH3 Product

UAN Product

1000 t/d

1650 t/d

CO2 Purification

CO2 Vent

2100 t/d

CO2

PSA

75 mmscf/d

630 t/d

Raw H2

Raw CO2

Syngas Scrubbing

Tail Gas

CO Shift / Gas Cooling

SELEXOL

Acid Gas

Sulfur Recovery

Coke Grinding / Slurry Prep

Petroleum Coke

1000 t/d

Metric tons
Southeast Kansas

Miscible, partially miscible and immiscible CO₂ EOR
- El Dorado
- Salyards Trend
- Oklahoma

Enhanced Coalbed Methane (N₂ and CO₂)

Oil and Gas Fields

Oil & Gas

Industry

Ethanol
Ammonia
Power
Refinery
Oil & Gas Fields Plus Coal Basins
**Greenhouse Gas Resource**

- **Ethanol** – 10.3
- **Land Fill Gas** – 182
- **Energy Methane** – 252
- **Electric Generation** – 2250
- **Non-Power Industrial Commercial & Residential** – 1,565
- **Transportation** – 1850
- **Industrial Processes** – 114
  - **Cement** - 43
  - **Fertilizer** – 39
- **Agricultural Methane** – 183
- **Nitrous Oxides** – 333
- **HFC, PFC, SF₆, etc.** – 121

**Total GHG Emissions 6,873 Million Metric Tons**

Data: Year 2002 Energy Information Agency and Renewable Fuels Assos.
FutureGen
Challenges

Size and Scope of Sequestration

1 Million Metric Tons Per Year

- 50 MMCF/Day (2650 tonnes/day)
- 124 kWh/tonne to compress and deliver (1,500psi or 10,000 kPa) (446,000 kJ/tonne)
- $300K per mile (1.6km) of pipeline

Approximately 200 Injectors

- 3.5 Producers per Injector
- Capital Costs $60 MM
- Additional 3.8 Million BO/D (520,000 tonnes/D)
Potential Energy Systems

Opportunities and Challenges

U.S. Ethanol Facilities

Russell Plant

ETH A N O L Industry Outlook 2001

Modified from Portland Cement Association 12/98 map

Cement Plants
- Lafarge
- Other

Coal Basins
- ECBM Projects
Approach

- Expand the number and type of carbon sequestration opportunities in Kansas
- Lower the cost and optimize the value-added benefits associated with CO$_2$ storage
- Develop field and carbon management practices to minimize seepage and promote permanence
- Develop capability to assess capacity for carbon storage