Assessing Economics for Sequestering CO_2 in Coal Seams with Horizontal Wells

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3rd Annual Sequestration Conference
May 3-6, 2004
Alexandria, VA

Problem: How do economics change the optimal design of coal seam sequestration in Eastern coal seams?

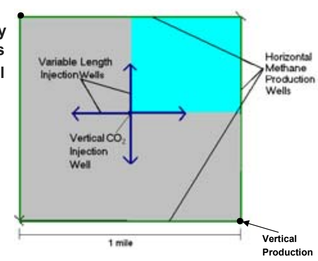
- Eastern coal seams tend to be thin with relatively high methane content and sequestration capacity per mass of coal.
- Horizontal wells have shown promise for improved methane recovery and CO_2 injectivity.
- Many studies have been performed to optimize design for total volume of CO_2 sequestered, but economics have not been included.

Approach: Combine coal seam simulations with economic analyses.

- Use PSU-COALCOMP, a state-of-the-art enhanced coalbed methane simulator
- Simulate several scenarios of sequestration with horizontal wells
- Collect data for start-up and operational costs
- Use "net present value" (NPV) analysis to compare multiple-year scenarios at different rates of return

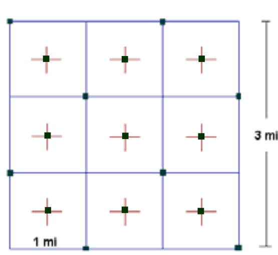
The physical model is based on a recent project in an Appalachian coal.

- Square pattern bordered by horizontal production wells
- Four central horizontal well bores that serve as either producers or injectors
- Well patterns 1 mi x 1 mi square (640 acres)
- Injector length and injection pressure variables
- Coal seam anisotropy varied



A 3-mile x 3-mile repeated pattern was used for the purpose of scaling the economics.

- Wells for single pattern:
  - Three vertical wells
  - Four horizontal wells
- Wells needed for the repeated pattern:
  - Seventeen vertical wells
  - Twenty-four horizontal wells
- Nine full 1 mi sq patterns



Reservoir properties are for Pittsburgh coal, a typical eastern coal seam.

Reservoir Thickness	5ft	Critical Gas Saturation	0.0 %
Coal-cleat Porosity	0.10%	Critical Water Saturation	10.0%
Lateral Permeability	8md	Initial Water Saturation	40%
Initial Reservoir Pressure	700 psia	Reservoir Temperature	113°F
Sorption Volume constant (CH_4, CO_2)	600 SCF/ton, 1500 SCF/ton	Initial Mole Fraction of Gas (CH_4, CO_2)	100%, 0%
Sorption Pressure constant (CH_4, CO_2)	700 psia, 300 psia	Reservoir Drainage Area	1 mile x 1 mile (640 acres)
Rock Density	1.4 g/cm^3	Wellbore Radius	0.1 ft
Skin	0.0	Coalface Pressure at Producers	100 psia

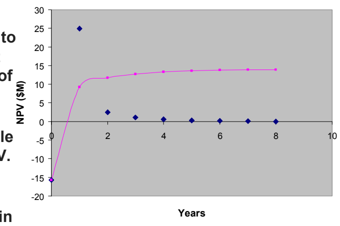
- Coal seam 5ft thick, 1400' deep
- Modeled as a homogeneous coal seam
- Injector lengths (515, 915, 1315ft)
- Injection pressures (300, 500, 700psi)
- Anisotropy ratios (1:1, 2:1, 4:1)

Cost estimates were gathered from several industry sources.

Cost Types	Amounts ($k)	Cost Types	Amounts ($k)
Start-up Costs		**Yearly Costs**	
Drilling		**Operation and Maintenance**	1,224
Producers	6,000	**SMV maintenance costs (@20%)**	245
Injectors	5,400	**Total Yearly Costs**	**1,469**
Well Completion +			
Injectors	720		
Producers	160		
CO_2 Supply Line			
10 mile pipeline	150	**Gas Prices**	
Surface Costs (piping, etc.)	680	Wellhead Price of CH_4 ($/Mcf)	3, 4, 5
SMV capital costs (@20%)	2,600	Cost of CO_2 ($/Mcf); (($/ton))	1, 1.75, 2.9 (17.2, 30, 50)
Total Start-up Costs	**15,710**	CO_2 "credits" ($/MCF); (($/ton))	0, 1.17, 2.33 (0, 20, 40)

Net present value (NPV) analysis was used for the economic analysis.

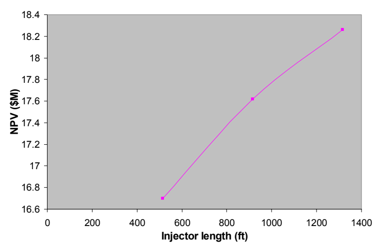
- Each year, costs are subtracted from revenues.
- Profits are discounted to year zero (project start year) using given rate of return.
- NPV for all years is summed to give a single cumulative project NPV.
- NPV helps compare projects that have different dollar values in the future and different project lengths.



Blue diamonds are yearly NPV values; pink line is cumulative NPV

Primary production is profitable.

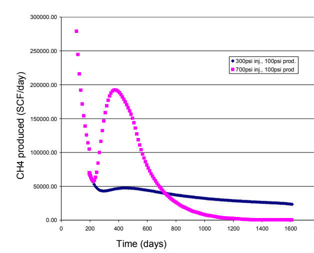
Primary Production
Perm ratio=2
ROR=10%
CH4 price=$4/MCF



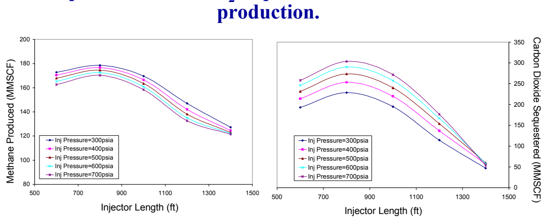
- Profitability increases with increasing well length.

Injecting CO_2 enhances the production of methane from the coal seam.

- Methane and water are produced from all wells
- Once coal is sufficiently dewatered, internal wells are converted to injectors
- Carbon dioxide is injected until:
  - the percentage of CO_2 in the production stream is greater than 10%, OR
  - the costs for the year are greater than the revenues



Previous work* has given insights into engineering optimization of CO_2 sequestration and methane production.

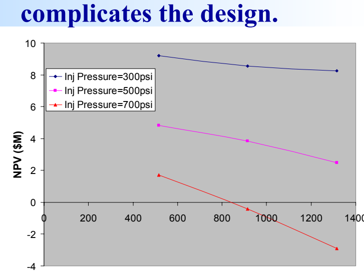


- There is an optimum well length that is less than half of the length of the pattern.
- Higher injection pressures sequester more CO_2.
- Lower injection pressures produce more methane.

* Sams et al, ICBM Symposium, Tuscaloosa, AL, May 2003; Sams et al, SPE National Meeting,

Adding economic considerations complicates the design.

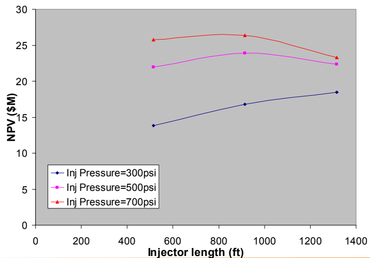
ECBM CASE
Perm ratio=2
ROR=10%
CO2 credit=NONE
CO2 cost=$30/ton
CH4 price=$4/MCF



- Shorter well lengths yield better results.
- Lower pressures give the best economic return.

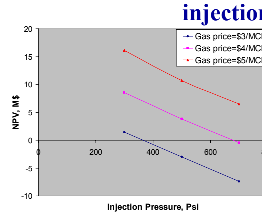
With CO_2 credits, the results change.

Perm ratio=2
ROR=10%
CO2 credit=$2.9/MCF
CO2 cost=$2.33/MCF
CH4 price=$4/MCF



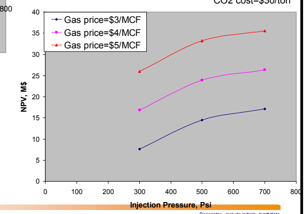
- As in the technical studies, there is an optimum well length.
- Higher pressures give the best economic return.

Gas price doesn't change the effects of injection pressure.



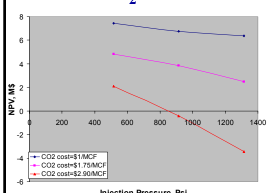
Well length=915ft
Perm ratio=2
ROR=10%
CO2 credit=$0/ton
CO2 cost=$30/ton

Well length=915ft
Perm ratio=2
ROR=10%
CO2 credit=$40/ton
CO2 cost=$30/ton



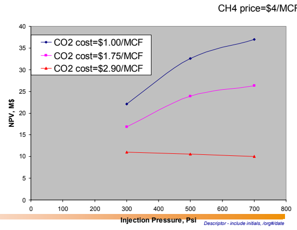
- Higher injection pressures are better for sequestration, but worse for ECBM.

CO_2 cost has a more significant effect.



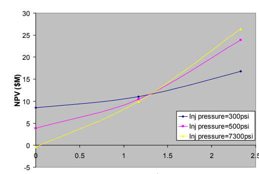
Well length=915ft
Perm ratio=2
ROR=10%
CO2 credit=$0/ton
CH4 price=$4/MCF

Well length=915ft
Perm ratio=2
ROR=10%
CO2 credit=$40/ton
CH4 price=$4/MCF



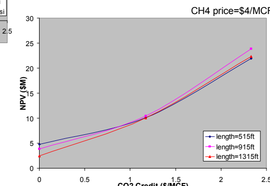
- At high enough CO_2 cost, the sequestration scenario behaves like ECBM.

The amount of a CO_2 credit will have a significant effect on operational design.



Well length=915ft
Perm ratio=2
ROR=10%
CO2 cost=$30/ton
CH4 price=$4/MCF

Inj press=500psi
Perm ratio=2
ROR=10%
CO2 cost=$30/ton
CH4 price=$4/MCF

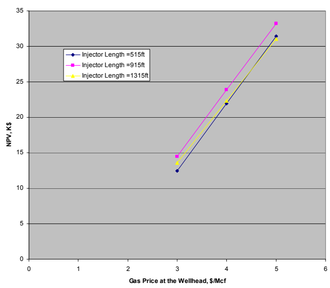


Conclusions: Economic considerations can have a significant effect on optimal design.

- Optimizing the design of a sequestration project will depend heavily on the value of credits.
- The best injection pressures (high) for sequestration give the worst results for the no credit case.
- Shorter injectors are better for enhanced production, but not for sequestration.
- Gas price is important for profitability but has relatively little effect on optimal design for the cases studied.

Other things to consider:

- Every coal seam is different!!!
- Multiple coal seams provide greater economic incentive.
- Different well patterns can be used to optimize sequestration.
- Coal swelling may reduce effectiveness.
- Horizontal wells vs. vertical wells.
- Rising natural gas prices raise possibilities.
- Monte Carlo analysis may provide further insight.



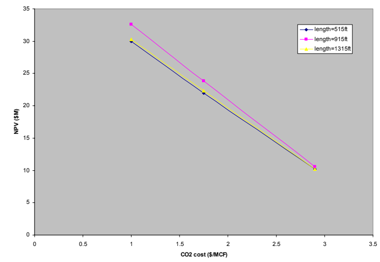
Inj press=500psi

Perm ratio=2

ROR=10%

CO_2 credit=$40/ton

CO_2 cost=$30/ton



Well length=915ft

Inj press=500psi

Perm ratio=2

ROR=10%

CO_2 credit=$40/ton

CH_4 price=$4/MCF

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