Enhanced Gas Recovery and CO_2 Storage in Coal Bed Methane Reservoirs: Optimized Injected Gas Composition for Mature Basins of Various Coal Rank*

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Abstract

Nitrogen (N_2) and carbon dioxide (CO_2) injection has been a subject of enhanced coal bed methane (ECBM) and carbon capture and storage (CCS) research during the past decade. N_2 and CO_2 injection produce substantially different recovery processes. Coal has a higher affinity for CO_2 as compared to methane (CH_4), making it an ideal candidate for CCS and address environmental issues related to green house gas emissions. However, preferential adsorption of CO_2, a larger molecule than CH_4, onto the coal surface results in a dramatic decrease in cleat permeability due to coal swelling. This ultimately induces a loss of injectivity creating a significant technical hurdle for CCS operations in coal. In contrast, N_2 increases cleat permeability because of its lower coal storage capacity relative to CH_4. As a result, injectivity increases during N_2-ECBM. Theoretically, the injection of a mixture of CO_2 and N_2 will result in ECBM and CCS without a loss of injectivity. This study presents an investigation of that concept.

Based on the lessons learned from several actual large-scale and small-scale field demonstrations to date, this paper will focus on the improvement of CO_2 sequestration and associated ECBM by optimization of gas composition and injection designs for different coal ranks. To characterize resources and identify key geological and reservoir parameters driving ECBM and sequestration processes in deep unminable coal seams, a Monte Carlo probabilistic approach was implemented for coal seams of different rank. To perform the study, a matrix of simulation scenarios consisting of multiple coal types (taken from mature coal basins such as San Juan, Black Warrior, Central Appalachian and Powder River), permeability values, pattern sizes and injected gas mixtures (from 100% CO_2 to 100% N_2,) was established. First results show that, for a specific coal rank, ECBM and CCS can drastically improve by increasing N_2 content in the injected gas stream.

ENHANCED GAS RECOVERY AND CO_2 STORAGE IN COAL BED METHANE RESERVOIRS: OPTIMIZED INJECTED GAS COMPOSITION FOR MATURE BASINS OF VARIOUS COAL RANK – PART 2

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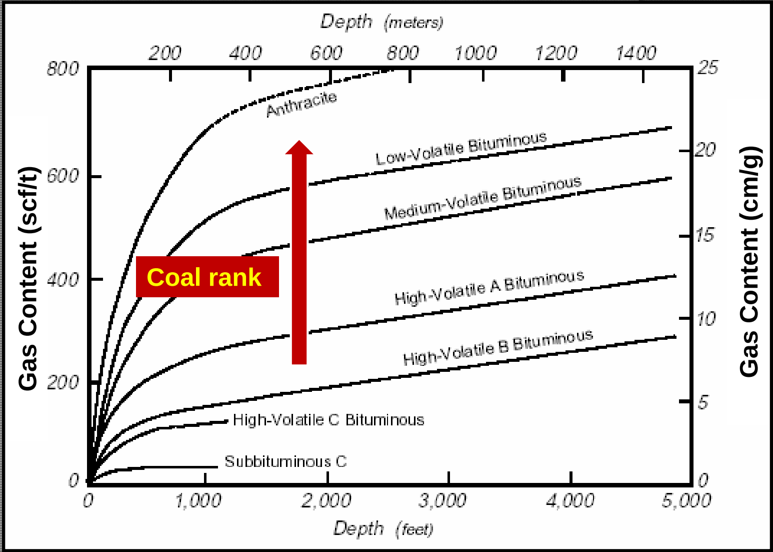
OBJECTIVES

- Identify key parameters driving ECBM and sequestration processes in deep unminable coal seams.
- Better understand cleat permeability changes in response to injected gas composition during ECBM process, by coal rank.
- Optimize injected gas composition to maintain injectivity while sequestering carbon dioxide.

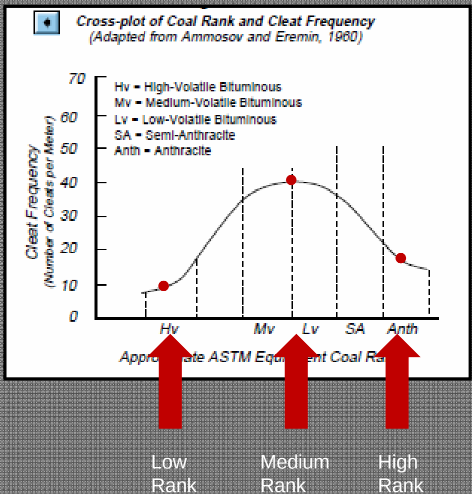
OUTLINES

- Objectives
- Key reservoir parameters driving CBM and CO_2 sequestration
- Cleat permeability changes during ECBM
- Optimizing enhanced gas recovery while sequestering carbon dioxide
- Summary and Conclusions

GAS STORAGE VS. COAL RANK

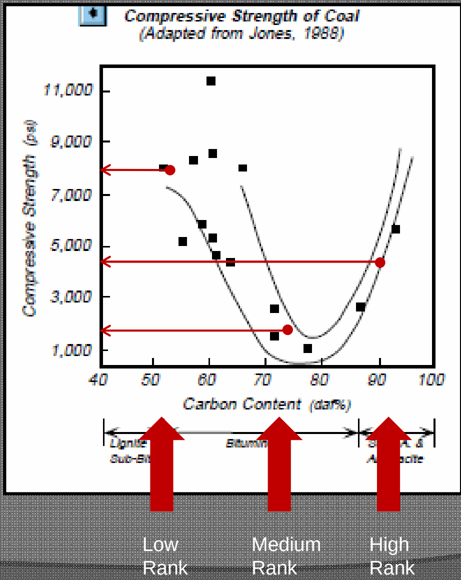


CLEAT PERMEABILITY VS. COAL RANK



- Fracture permeability directly related to cleat frequency:
  - The higher cleat intensity, the higher permeability
  - Low permeability for low rank coal (early coalification) and high rank coal (metamorphism)
  - Highest permeability for Medium to Low-Volatile bituminous

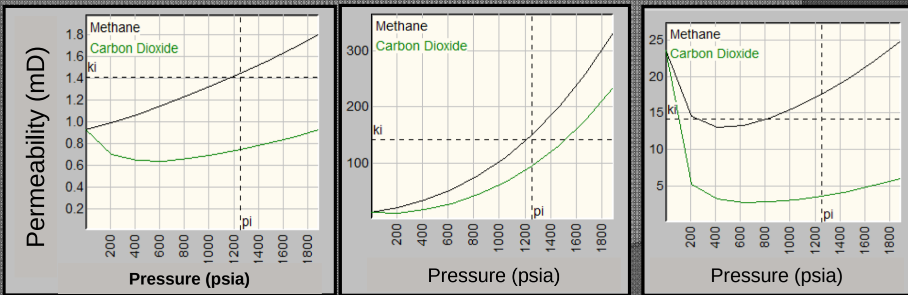
PORE COMPRESSIBILITY VS. COAL RANK



- Compressive strength :
  - Capacity of a material to withstand axially-directed pushing forces
  - Minimum where cleats are most developed: medium rank
- Opposite to pore compressibility (1/psi)
  - Maximum where cleats are most developed: medium rank
    - $Cp=500*10^{-6}$ psi^{-1} (1/2,000)
  - Minimum for low and high rank:
    - High rank $Cp=250*10^{-6}$ psi^{-1}
    - Low rank $Cp=125*10^{-6}$ psi^{-1}

CLEAT PERMEABILITY VS. COAL RANK

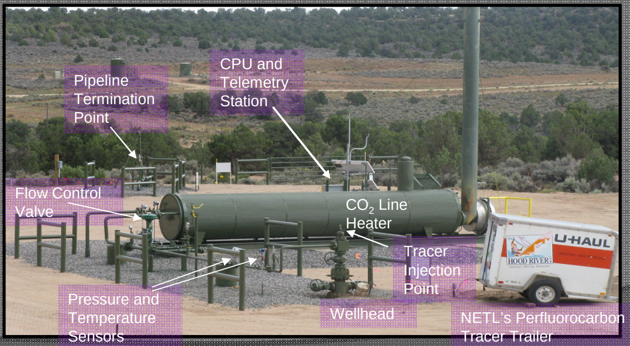
- Matrix shrinkage:
  - Low rank with early stage coalification, lower gas content, matrix less likely to swell or shrink: lower matrix compressibility -> minimum fracture permeability improvement



a) Low Rank Coals b) Medium Rank Coals c) High Rank Coals

MOST COMMERCIAL CBM PROJECTS ARE MEDIUM RANK COALS

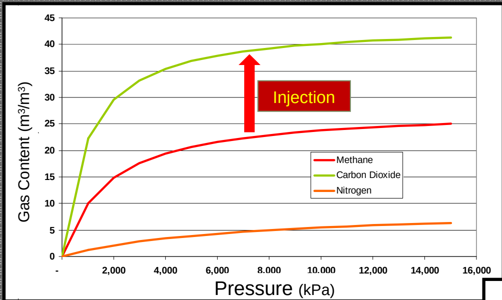
- High Rank Coal: high gas content but low injectivity
- Low Rank Coal: low gas content but high injectivity
- Good compromise are medium rank coals with average gas content and initial permeability



SWP – CO_2 Injection in Fruitland coal

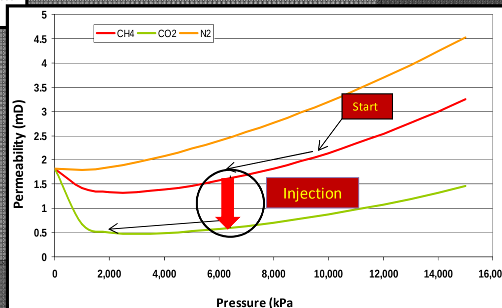
SECARB Appalachian – CO_2 Pilot in Pratt coal

CLEAT PERMEABILITY DURING CO_2-ECBM

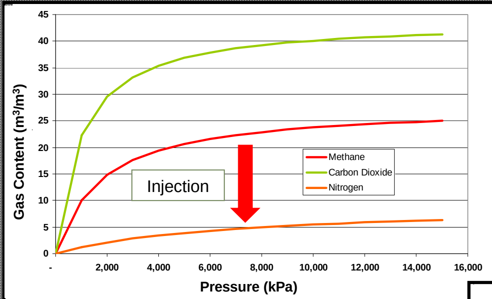


Preferential adsorption of CO_2, high storage capacity

Preferential adsorption of CO_2 induces coal swelling resulting in an **injectivity loss**



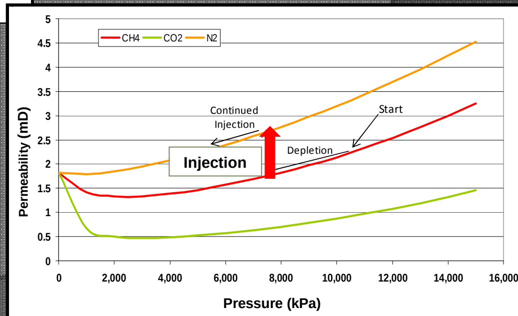
CLEAT PERMEABILITY DURING N_2-ECBM



Lower adsorptivity of N_2 :

- N_2 stays in fractures while CH_4 is stripped out of matrix sites
- Rapid N_2 breakthrough

Preferential adsorption of CH_4 induces coal matrix shrinkage resulting in **injectivity improvement**

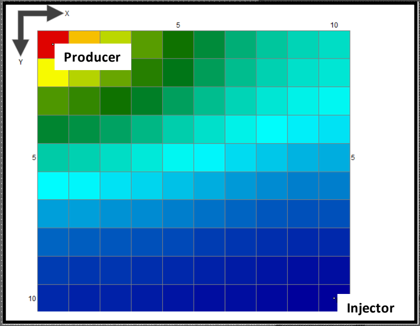


ECBM OPTIMIZATION PROCESS

- How can injected gas composition be optimized to maintain injectivity while sequestering CO_2 for different coal ranks?

MODEL CONSTRUCTION

- Simulation performed using *COMET3.*
- 5-spot injection pattern, vertical wells.
- 10 years of primary production followed by 15 years of injection.
- Well spacing determined based on CO_2 breakthrough occurring after 8 to 10 years of 100% CO_2 injection.



PARAMETRIC STUDY: POROSITY AND PERMEABILITY PER COAL RANK

Parameters	Low Rank	Medium Rank	High Rank	Units
Average Fracture Permeability	1	100	10	mD
Fracture Permeability Anisotropy	1:2	1:2	1:2	
Fracture Porosity	0.25	1.50	0.50	%
Pore Compressibility	1.25E-04	5.00E-04	2.50E-04	1/psia
Permeability Exponent (S&P)	3	3	3	
Matrix Shrinkage	5.00E-07	1.00E-06	2.00E-06	1/psia
CO2/CH4 Differential Swelling Factor	1.25	2	3	
N2/CH4 Differential Swelling Factor	0.5	0.5	0.5	

Note: CO_2 swelling factor will be referred as Ck

Presenter's notes: Example of high rank coal: Illinois basin coal where tectonics (semi-anthracite) and low-vol. bituminous in Arkoma Basin or Arkansas; medium coal: San Juan Basin outside fairway (medium volatile). Low rank coal: Powder River basin (low C-bituminous)

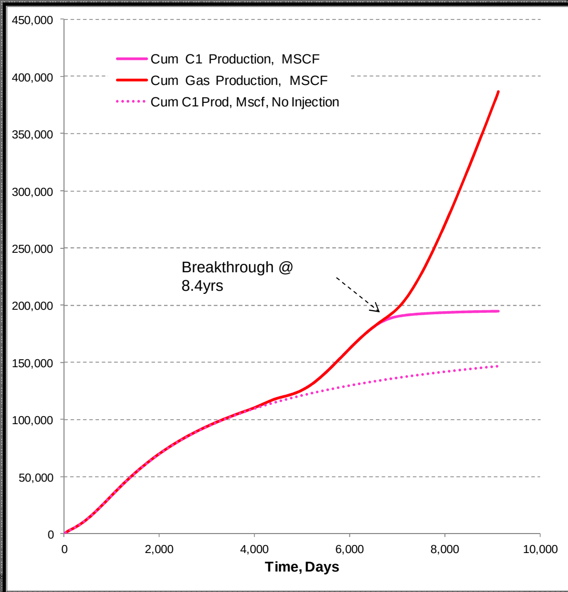
INJECTION SCENARIOS

- Gas mixtures
  - 100% CO_2
  - 75% CO_2/25% N_2
  - 50% CO_2/50% N_2
  - 25% CO_2/75% N_2
  - 100% N_2
- Injection rate constraint: 5 MMcfd max.
- Injection pressure constraint: 0.6 psia/ft maximum bottom-hole pressure.

LOW RANK COALS

- 35 acres spacing to reach CO_2 breakthrough after 8.5 years of injection
- At end of primary production, permeability was down from 1 mD to 0.7 mD: moderate loss due to low pore compressibility.
- *Can we maintain or improve this permeability?*

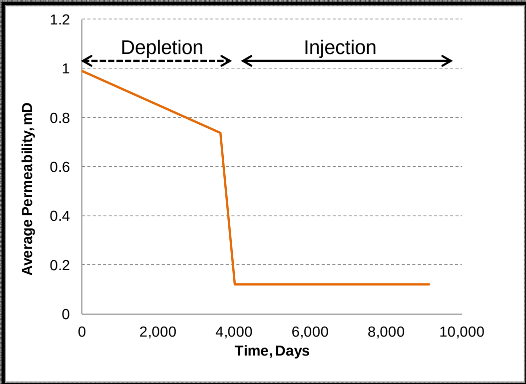
LOW RANK COALS – 100% CO_2 INJECTION

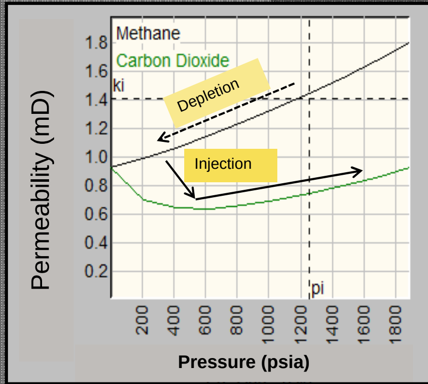


Presenter's notes: Delayed breakthrough

LOW RANK COALS – 100% CO_2 INJECTION

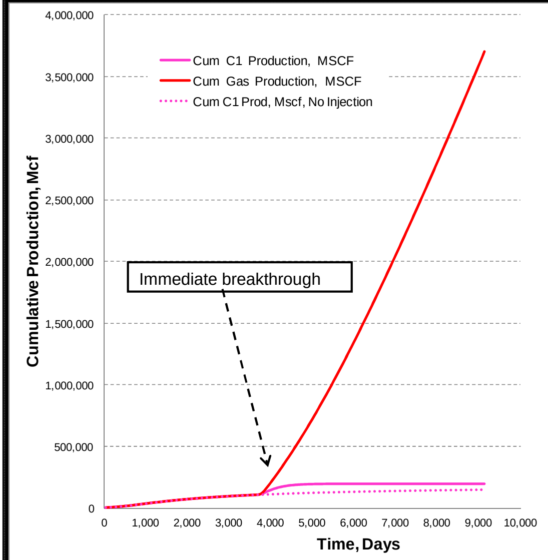
Injectivity loss due to coal swelling under CO_2 injection



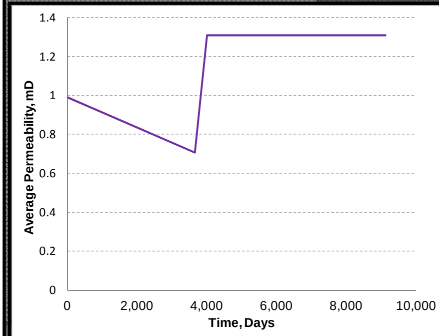


Presenter's notes: Depletion from 1800 to 307 psia. Then injection and repressurization until 1600psia

LOW RANK COALS – 100% N_2 INJECTION



Injectivity increase due to coal shrinking under N_2 injection



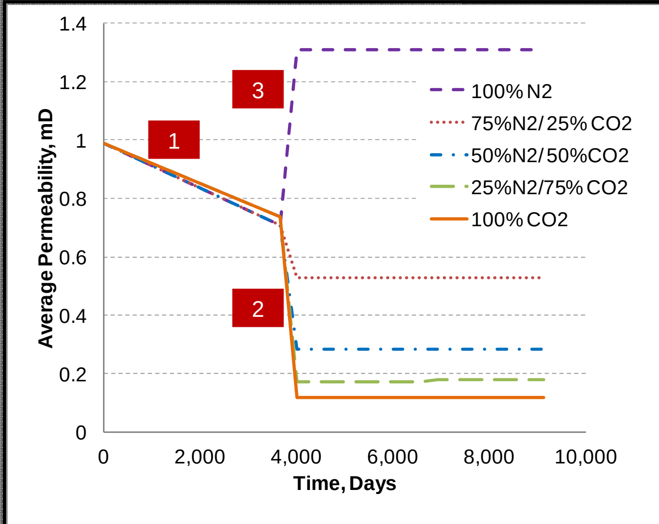
Presenter's notes: At 4,015 days, reservoir pressure higher than initial pressure. Also 0.5 diff. swelling for N2+CH4 stripping: matrix shrinks and fractures open.

LOW RANK COALS - MIXTURES

1 Moderate permeability loss (-30%) during depletion (low C_p)

2 Drastic permeability loss (-90% from initial value) once injection starts due to coal swelling (high C_k), even with N_2 mixture

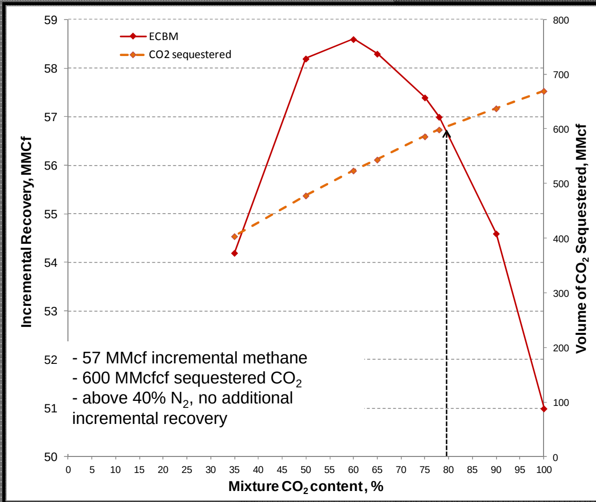
3 Permeability increase of 35% when 100% N_2 injection starts, as matrix shrinks



Presenter's notes: Higher the N2 content, faster the reservoir pressurization too

LOW RANK COALS - SUMMARY

- CO_2 sequestration optimum with 100% CO_2 but lowest incremental CH_4
- Best mixture at 20% N_2/ 80% CO_2
  - ECBM increase of 69% (from 100% CO_2 injection)
  - Minimal sequestration capacity loss of 27%



MEDIUM RANK COALS

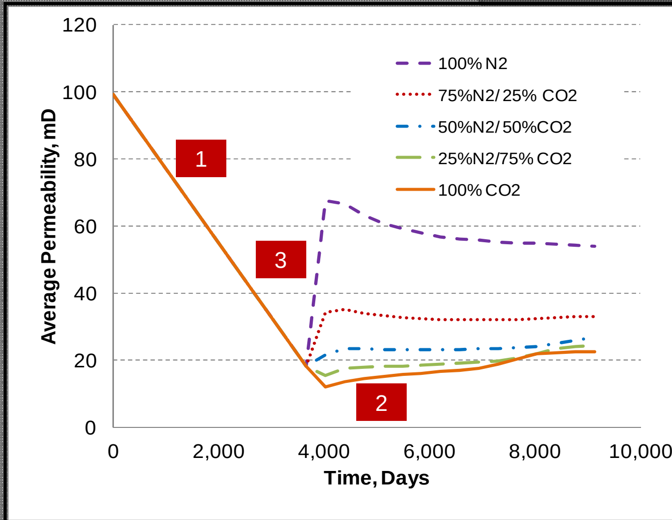
- 640 acres spacing necessary to achieve breakthrough after 9.4 years of injection
- At end of primary production, permeability reduction of 82% due to highest C_p
- *Can we maintain or improve this permeability?*

MEDIUM RANK COALS

1 Drastic permeability loss (-80%) during depletion (high C_p)

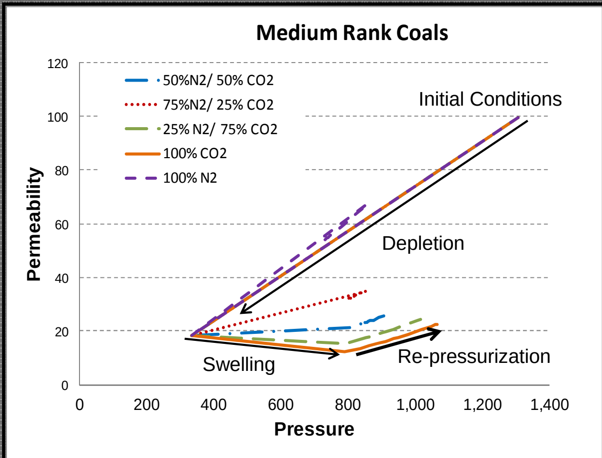
2 Moderate permeability loss of 10% once injection starts due to coal swelling (average C_k), followed by permeability increase (10%) due to re-pressurization and C_p

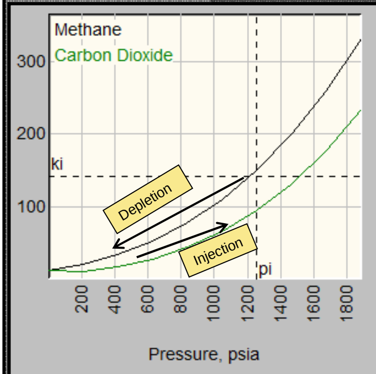
3 Permeability increase of 50% when N_2 injection starts, as matrix shrinks



Presenter's notes: For 100% N2, pressure above initial pressure, hence permeability higher than initial

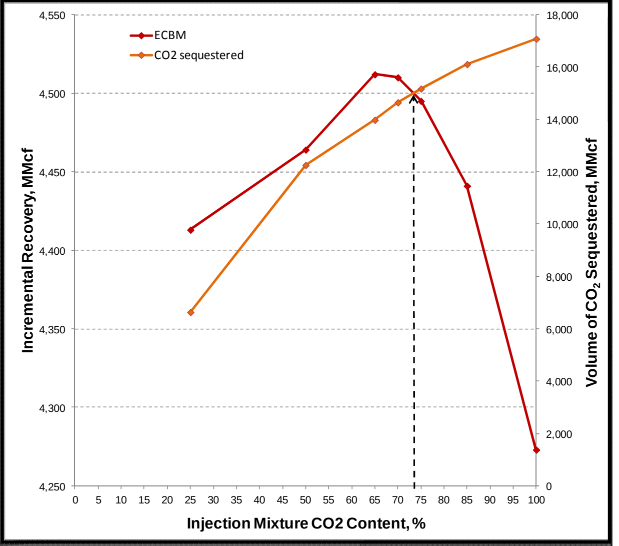
MEDIUM RANK COALS





MEDIUM RANKS COALS OPTIMIZATION

- Best mixture at 30% N_2/ 70% CO_2
  - ECBM increase of 95% (from 100% CO_2 injection)
  - Minimal sequestration capacity loss of 20%

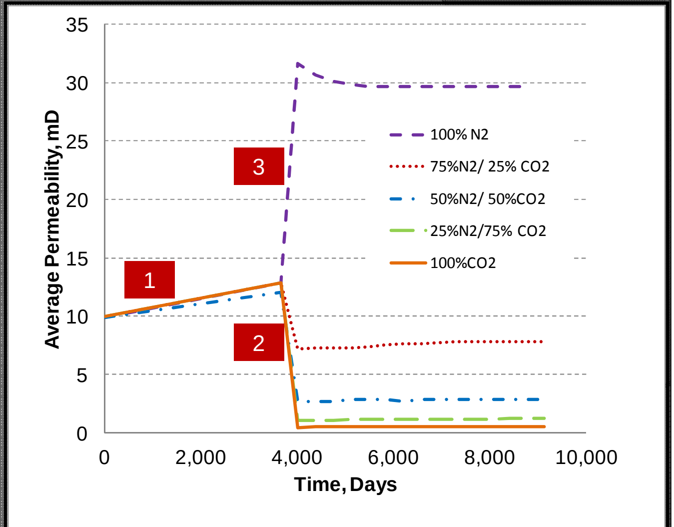


HIGH RANK COALS

1 Permeability gain of 20% during depletion (high C_m)

2 Drastic permeability loss of 90% once injection starts due to coal swelling (average C_k)

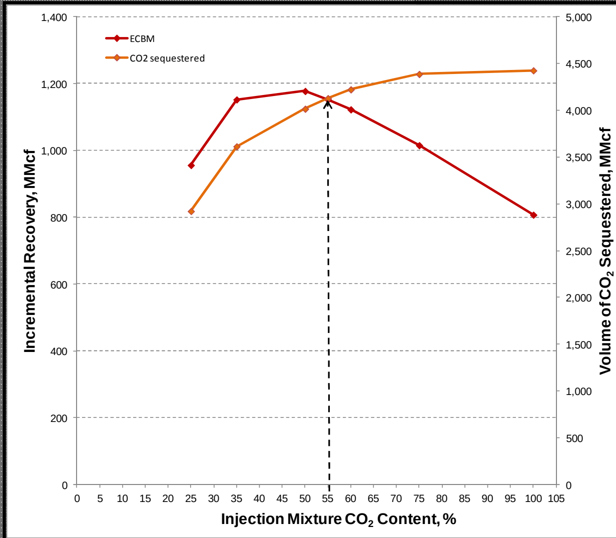
3 Permeability increase of 300% when pure N_2 injection starts, as matrix shrinks (highest C_m)



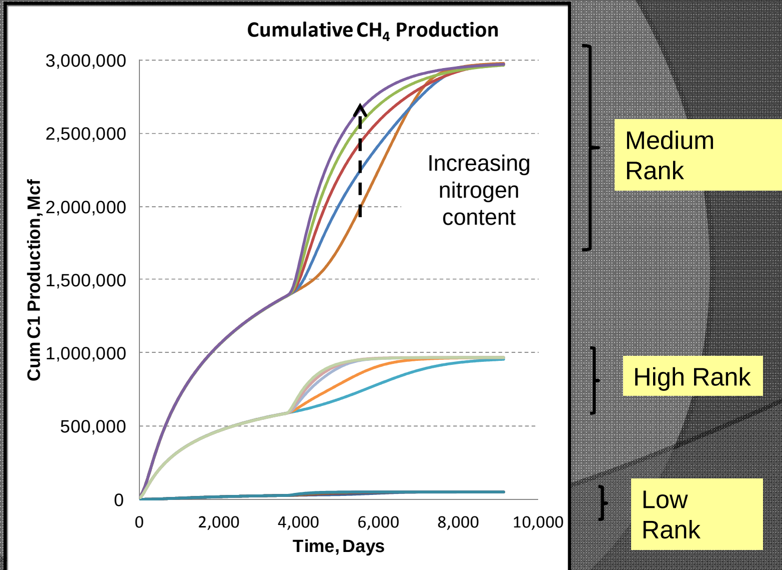
Presenter's notes: For 100% N2, pressure above initial pressure, hence permeability higher than initial

HIGH RANKS COALS OPTIMIZATION

- Best mixture at 45% N_2/ 65% CO_2
  - ECBM increase of 93% (from 100% CO_2 injection)
  - Minimal sequestration capacity loss of 20%



CONCLUSIONS: INCREMENTAL RECOVERY DUE TO N_2 INJECTION



CONCLUSIONS

Low Rank Coal

	100% CO2	80%CO2/20%N2	75%CO2/25%N2	50%CO2/50%N2	25%CO2/75%N2	100%N2
Incremental CH4, MMcf	[illegible]	**57**	57	58	48	48
Breakthrough time, years	8[illegible]	**8.8**	8.7	9.1	Not reached (25%@15years)	N/A
Sequestered CO2 volume @ breakthrough time, MMcf	670[illegible]	**599**	586	478	330	N/A

Medium Rank Coal

Increasing N_2 content with coal rank to achieve optimum ECBM and CO_2 sequestration.

	75[illegible]2/25%N2	70%CO2/30%N2	50%CO2/50%N2	25%CO2/75%N2	100%N2
[illegible]	[illegible]95	**4,510**	4,464	4,413	4,413
[illegible]	[illegible]3	**11.6**	14	Not reached (25%@15years)	N/A
[illegible]	15[illegible]	**14,648**	12,255	6,638	N/A

High Rank Coal

	100% CO2	75%CO2/25%N2	55%CO2/45%N2	50%CO2/50%N2	25%CO2/75%N2	100%N2
Incremental CH4, MMcf	807	1,015	**1,152**	1,177	956	956
Breakthrough time, years	10	7.3	**5.8**	5.5	Not reached (25%@15years)	N/A
Sequestered CO2 volume @ breakthrough time, MMcf	4,424	4,386	**4,127**	4,014	2,921	N/A

CONCLUSIONS

- By injecting a 100% nitrogen mixture in high rank coals, cleat permeability is improved beyond initial conditions due to reservoir pressurization. Laboratory research would be helpful to better illustrate this phenomenon.
- Results presented here are specific to samples and their reservoir properties – optimized mixture content might vary for different coal samples of similar rank.

QUESTIONS?

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