The Coal-Seq Project:

Key Results From Field, Laboratory, and Modeling Studies (2000-2004)

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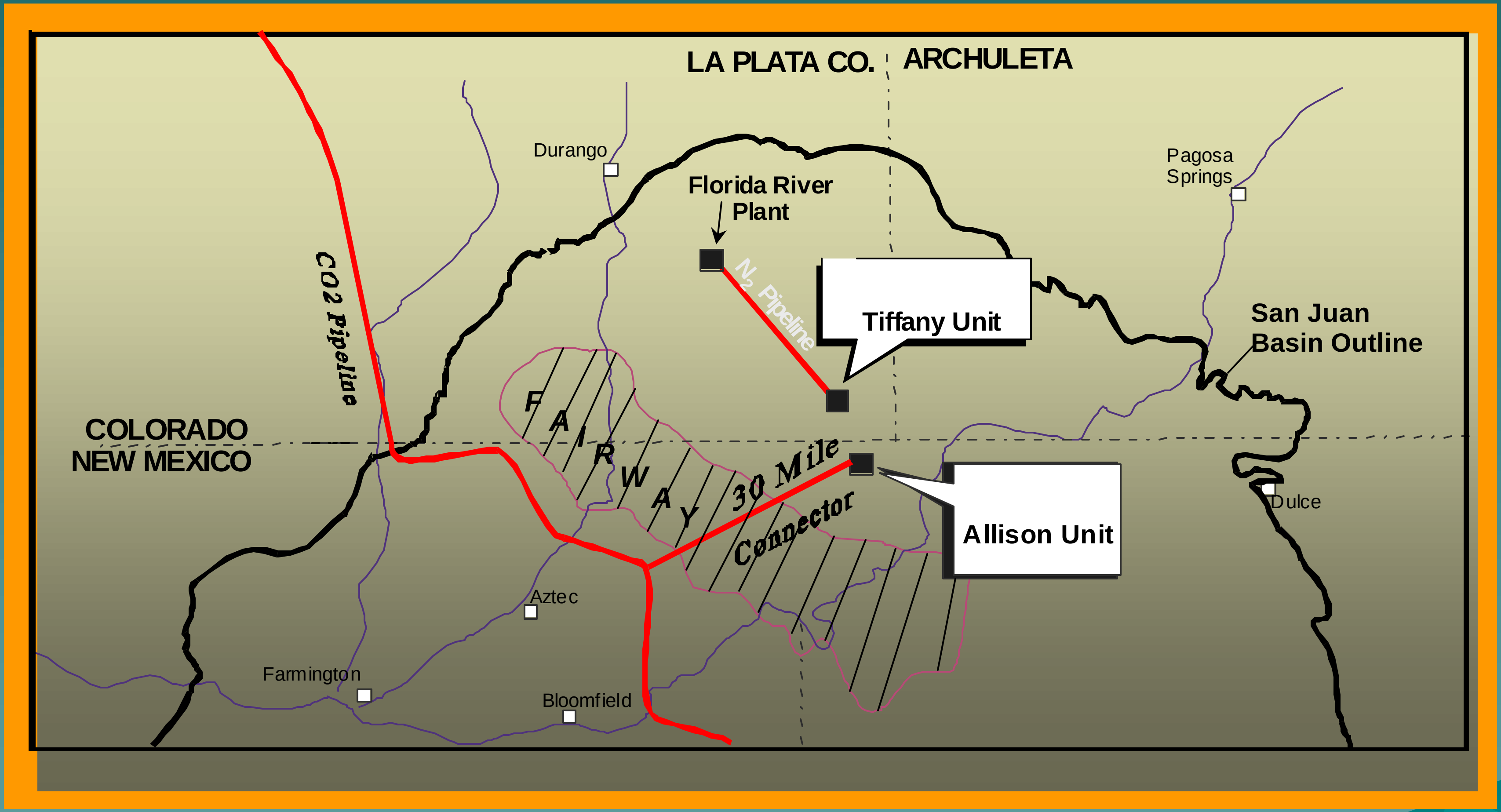
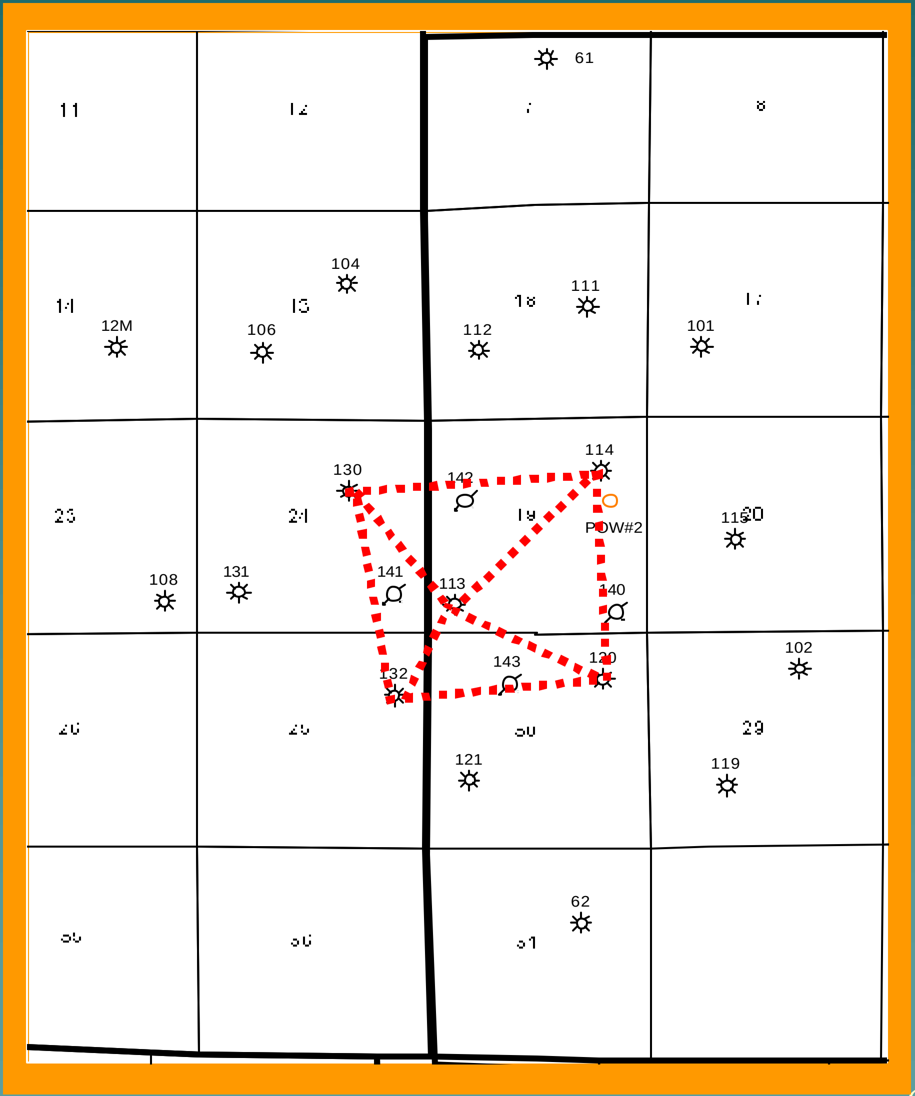
Coal-Seq Project Objectives

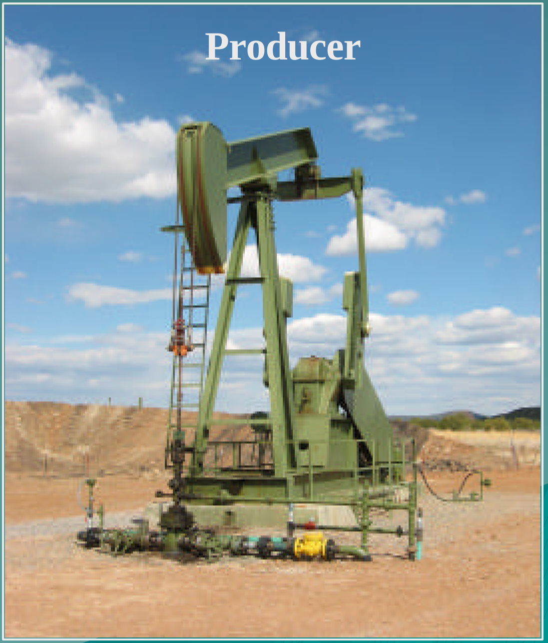
- Demonstrate Efficacy of Carbon Sequestration in Deep Unmineable Coals by Performing Detailed Field Studies of Existing CO_2/N_2-ECBM Projects
- Understand Critical CO_2 Sequestration Reservoir Mechanics (multi-component sorption, coal swelling)
- Demonstrate Utility/Validity of Reservoir Simulation Models
- Develop Techno-Economic Screening Model to Evaluate Potential Coalseam Sequestration Projects
- Identify Geologic Settings Most Amenable to Low-Cost Sequestration
- Assess Potential for Coalseam Sequestration across U.S.
- Disseminate Results to Industry

Field Sites, San Juan Basin



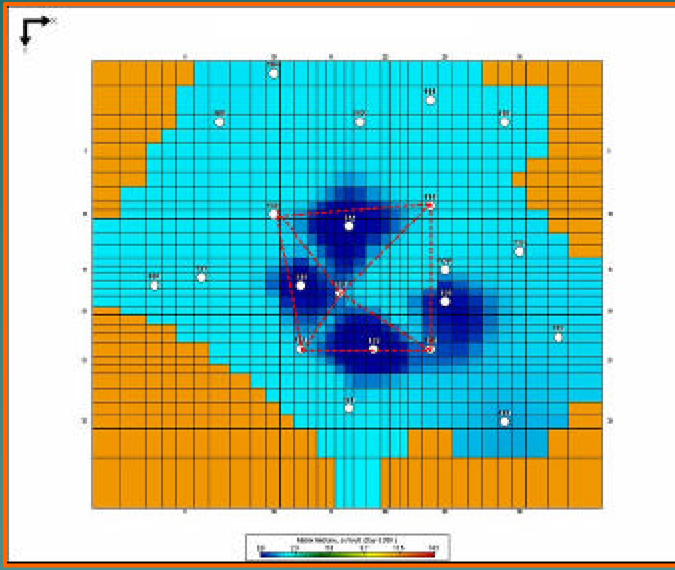
Allison Unit Well Pattern





Allison Modeling Results

- History-match achieved; overall quality very good. Difficulty matching injection pressures.
- CO_2 injection improved methane recovery from 77% to 95% of OGIP (central 5-spot area).
- 277,000 tons of CO_2 “sequestered”
- Ratio of injected CO_2 to produced CH_4 of 3:1 (@ abandonment and accounting for reproduced CO_2).
- Clear evidence of injectivity reduction with CO_2 injection.
- Reduced injectivity limited incremental CBM recovery and harmed economic performance.



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SP05032004

Allison Economic Performance

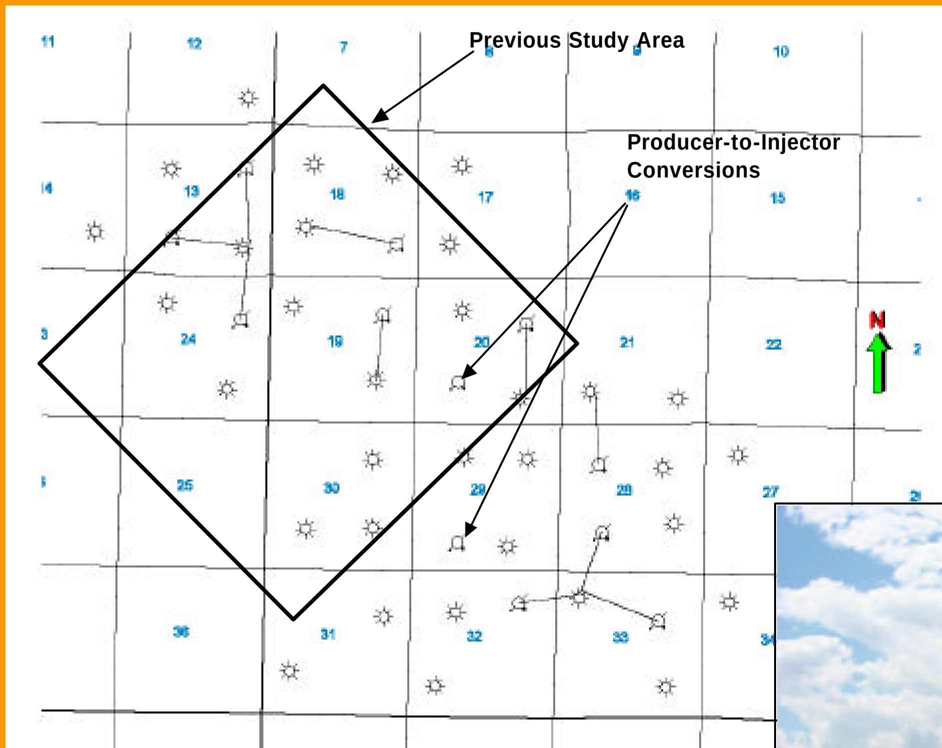
Assumptions

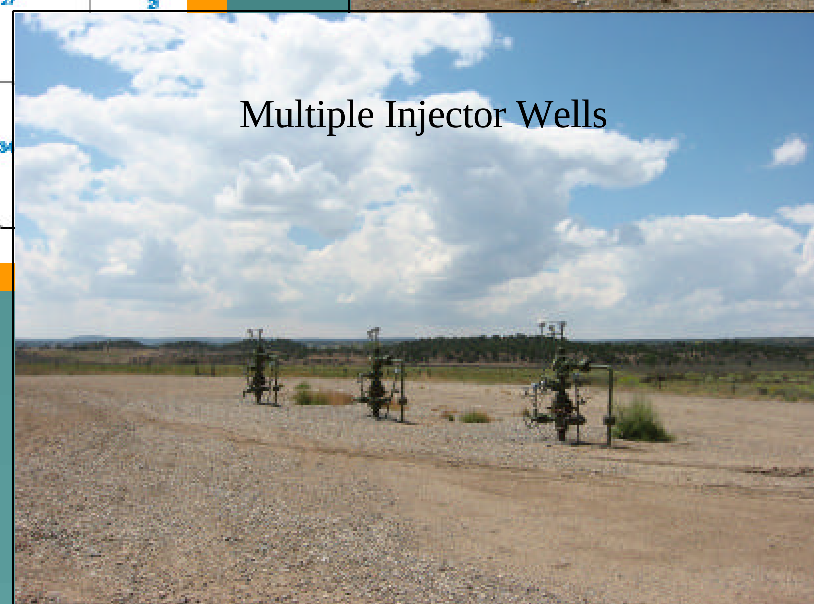
Capex:	$2.6 million (hot tap and 36 mi pipeline (allocated @ 25%), distribution lines, 4 new wells).
CO_2 Cost:	$0.30/Mcf ($5.19/ton)
Gas Processing:	$0.25/Mcf
Gas Price:	$2.20/MMBTU
Discount Rate:	12%

Results

	Same Injection Rate		Injection Rate X 4	
	$ 2.20/MMBTU	$4.00/MMBTU	$2.20/MMBTU	$4.00/MMBTU
Net Present Value:	($0.6 million)	$2.6 million	$3.6 million	$15.0 million
Breakeven Gas Price:	$2.57/MMBTU	$2.57/MMBTU	$1.63/MMTBU	$1.63/MMBTU
Breakeven CO_2 Cost:	$0.12/Mcf ($2/ton)	$1.06/Mcf ($18/ton)	$5.65 ($98/ton)	$19.38 ($335/ton)
Sequestration Cost:	$2.17/ton	($9.39/ton)	($13.00/ton)	($34.15/ton)

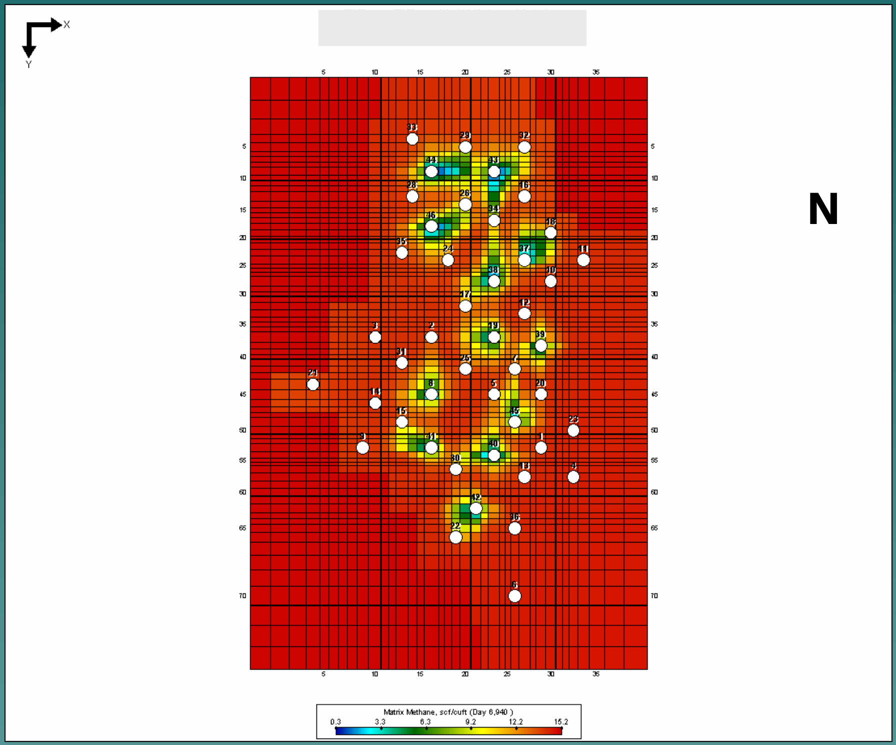
Tiffany Unit Well Pattern





Modeling Results

- History match achieved; overall quality very good. Difficulty matching producing pressures.
- N_2 injection provided incremental methane recovery of 18-21% of OGIP.
- Ratio of injected N_2 to produced CH_4 of 0.4:1
- Rapid N_2 breakthrough observed (as expected).



Tiffany Economic Performance

Assumptions

Capex:	$17.8 million (air separation plant, 16 mi. pipeline, distribution lines, 10 new wells).
N_2 Cost:	$0.40/Mcf
Gas Processing:	$0.50/Mcf
Gas Price:	$2.20/Mcf
Discount Rate:	12%

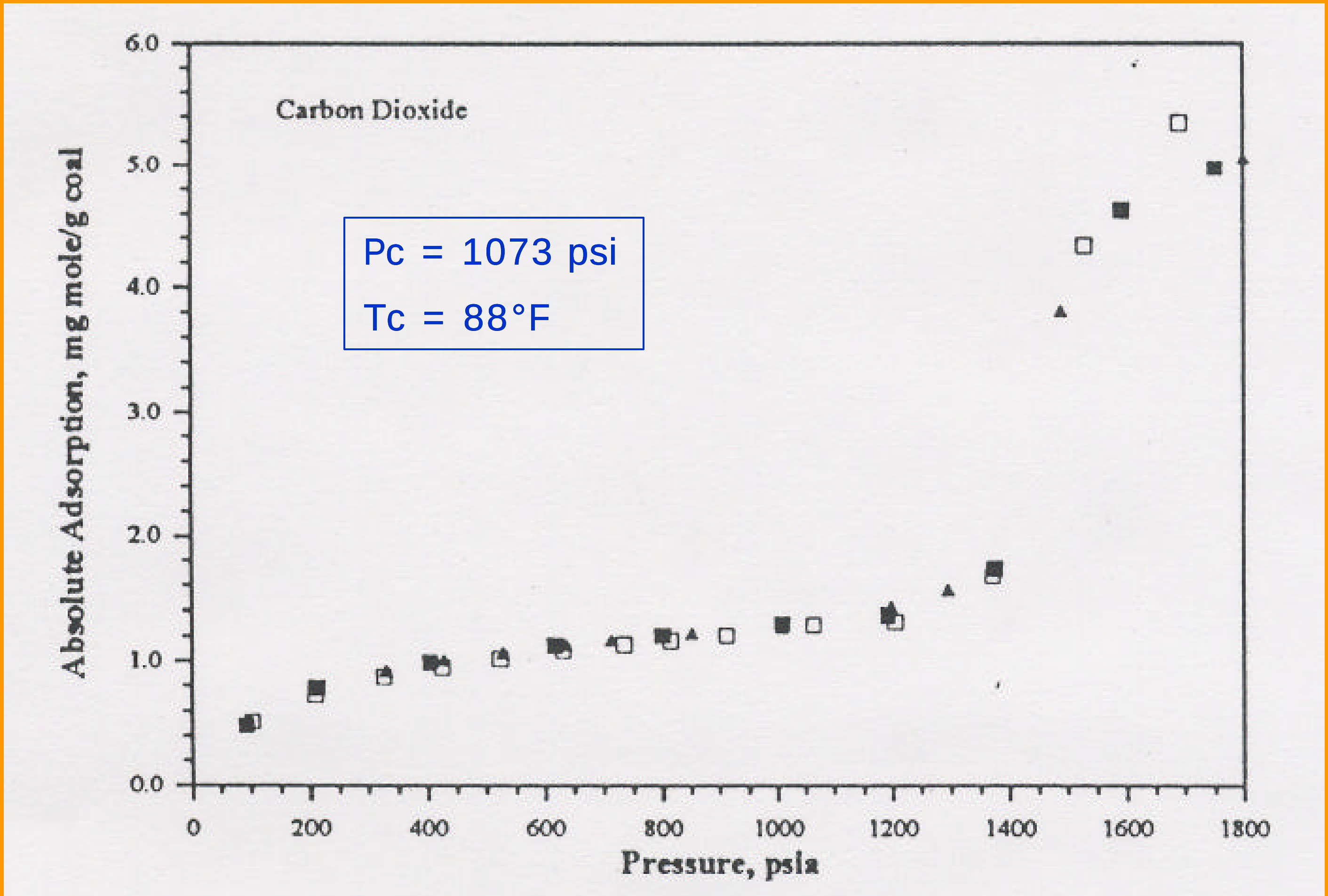
Results

	$ 2.20/Mcf	**$4.00/MMBTU**
Net Present Value:	($2.9 million)	$21.3 million
Breakeven Gas Price ($/Mcf):	$2.42	$2.42
Breakeven N_2 Cost ($/Mcf):	$0.15	$2.23

Reservoir Mechanics Studies

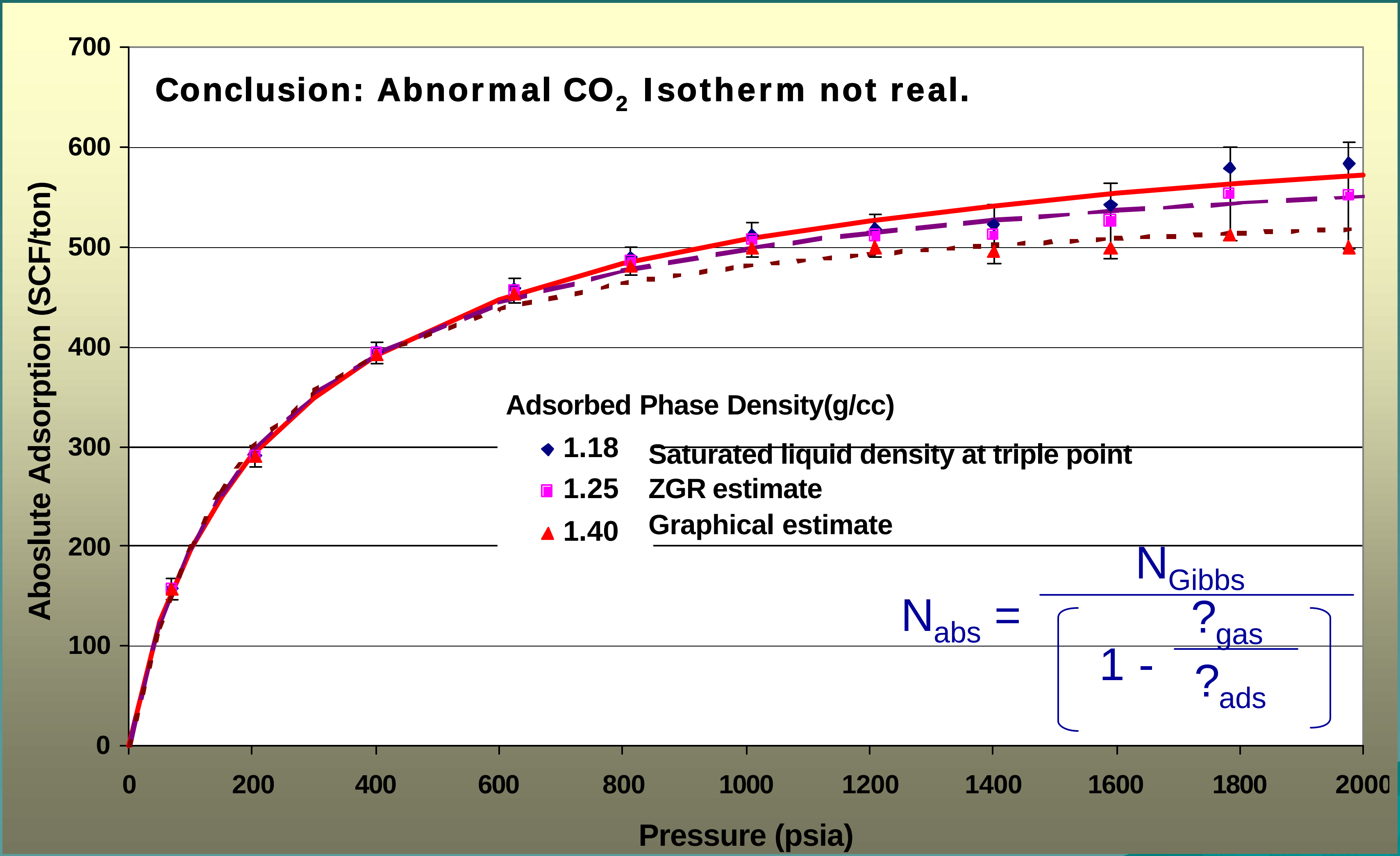
- Isotherm behavior
  - CO_2
  - Multi-component
- Coal swelling with CO_2 injection

Published CO_2 Sorption Isotherm, 1994



Source: SPE 29194: "Adsorption of Pure Methane, Nitrogen and Carbon Dioxide and their Binary Mixtures on Wet Fruitland Coal", 1994.

CO_2 Absolute Adsorption on Tiffany Coal Sample



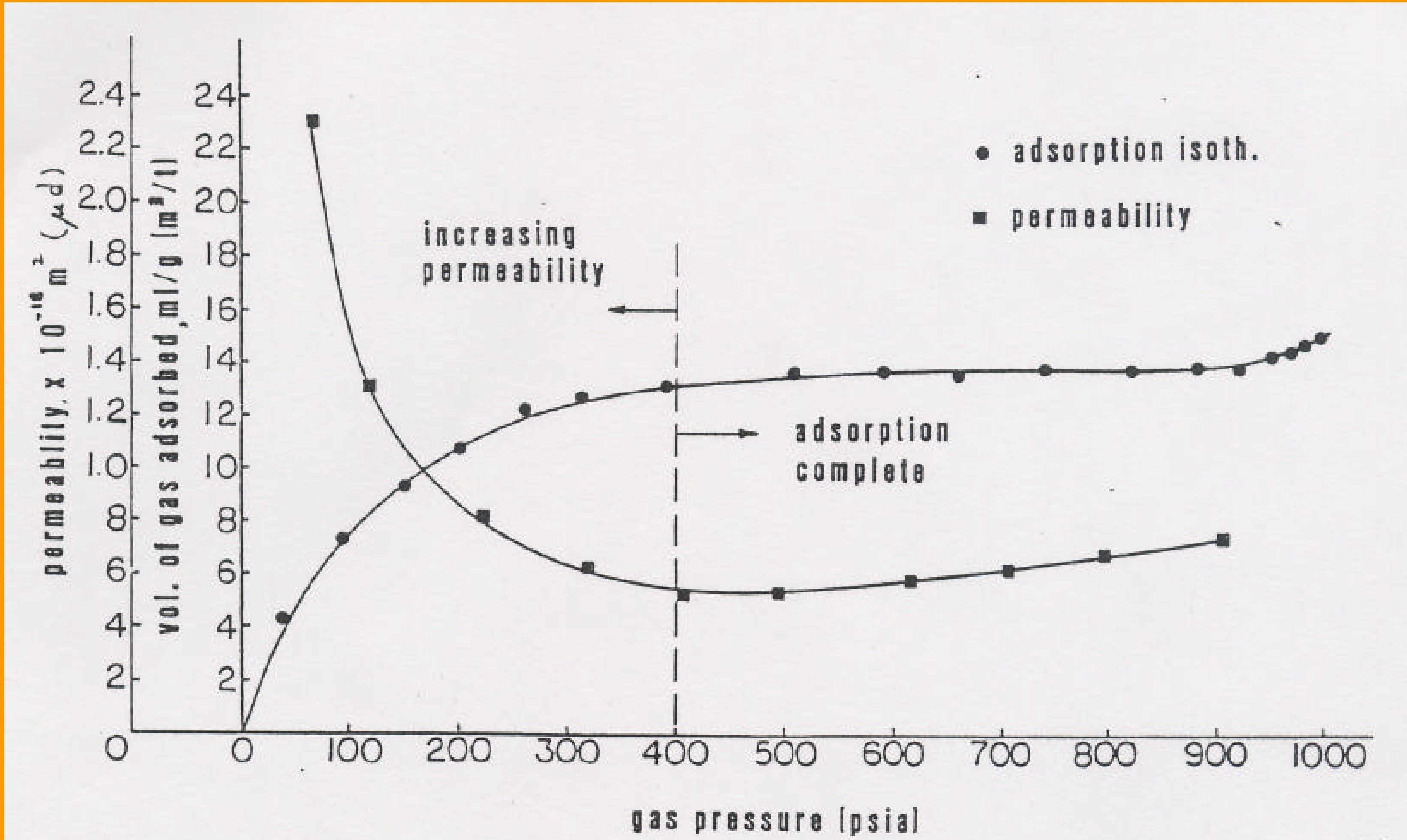
Accuracy of Model Predictions for Binary/Ternary Gas Adsorption

(based on pure-gas adsorption data)

Mixture, (Feed Mole %)	Langmuir % AAD	LRC (n=0.9) % AAD	ZGR-EOS % AAD	Experimental Error % AAD
CH_4 – N_2:				
CH_4 (50%)	15.8	12.0	11.9	7.0
N_2 (50%)	6.2	9.3	10.0	17.0
Total	12.2	8.2	11.5	7.0
CH_4 – CO_2:				
CH_4 (40%)	25.9	21.0	27.0	7.0
CO_2 (60%)	9.0	10.5	10.4	6.0
Total	1.2	2.2	1.4	4.0
N_2 – CO_2:				
N_2 (20%)	44.9	37.3	48.7	29.0
CO_2 (80%)	5.2	5.7	4.9	6.0
Total	3.5	3.8	3.5	5.0
N_2 – CH_4 - CO_2:				
N_2 (10%)	47.8	44.5	55.9	14.0
CH_4 (40%)	20.7	5.2	21.6	27.0
CO_2 (50%)	13.2	15.8	17.6	5.0
Total	2.9	5.4	4.3	5.0

Conclusion: Current isotherm models not adequate for multi-component behavior.

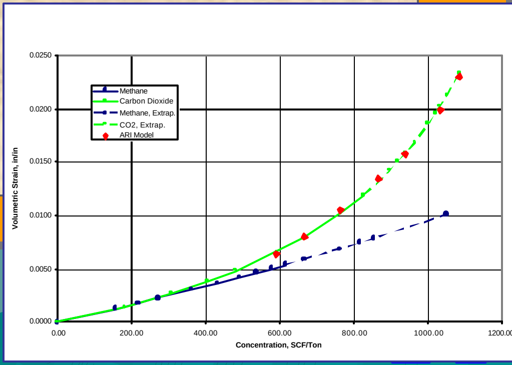
Matrix Shrinkage/Swelling



Source: "An Investigation of the Effect of Gas Desorption on Coal Permeability", paper 8923, 1989 Coalbed Methane Symposium.

New Formulation for Matrix Shrinkage/Swelling

	ARI (1990)	P&M (1996)
Description	Directly relates to sorbed gas volume	Based on coal mechanical properties
Advantage	Can handle under-saturated coal	Can model non-Langmuir behavior
Enhanced Features	Differential swelling (added under Coal-Seq project; Topical Report published)	n/a



Screening Model: Coal-Seq V 2.1

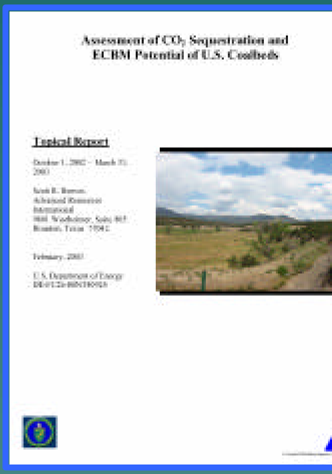
- Provide industry with a free tool to quickly screen potential CO_2-ECBM/sequestration projects.
- Consists of about 2,000 reservoir simulation cases in MS Access database with VB interface to view/compare results.
- Users can vary up to 7 input parameters (Perm, Area, Depth, Rank, Rate, Inj Gas, Inj Schedule), plus coal thickness.
- Economic calculations also performed.
- Available via project website.

Sensitivity Study Results

- N2-ECBM provides better/faster methane recovery than CO_2/ECBM.
- But, N_2 breakthrough can be rapid, particularly with high injection rates, and compromise sweep efficiency and incremental recovery. This is more pronounced where reservoir heterogeity exists. For CO_2, the higher the injection rate, the better.
- Model indicates that favorable <u>ECBM</u> economics can result if N_2 concentration in injectant is increased. However, net CO_2 sequestration volumes are less. Best sequestration economics are with 100% CO_2.
- Best economics are generally indicated for deep, low permeability, high rank coals. Also, greenfield projects are better than brownfield projects. Implication: New areas undeveloped for conventional CBM maybe best areas for ECBM/sequestration.

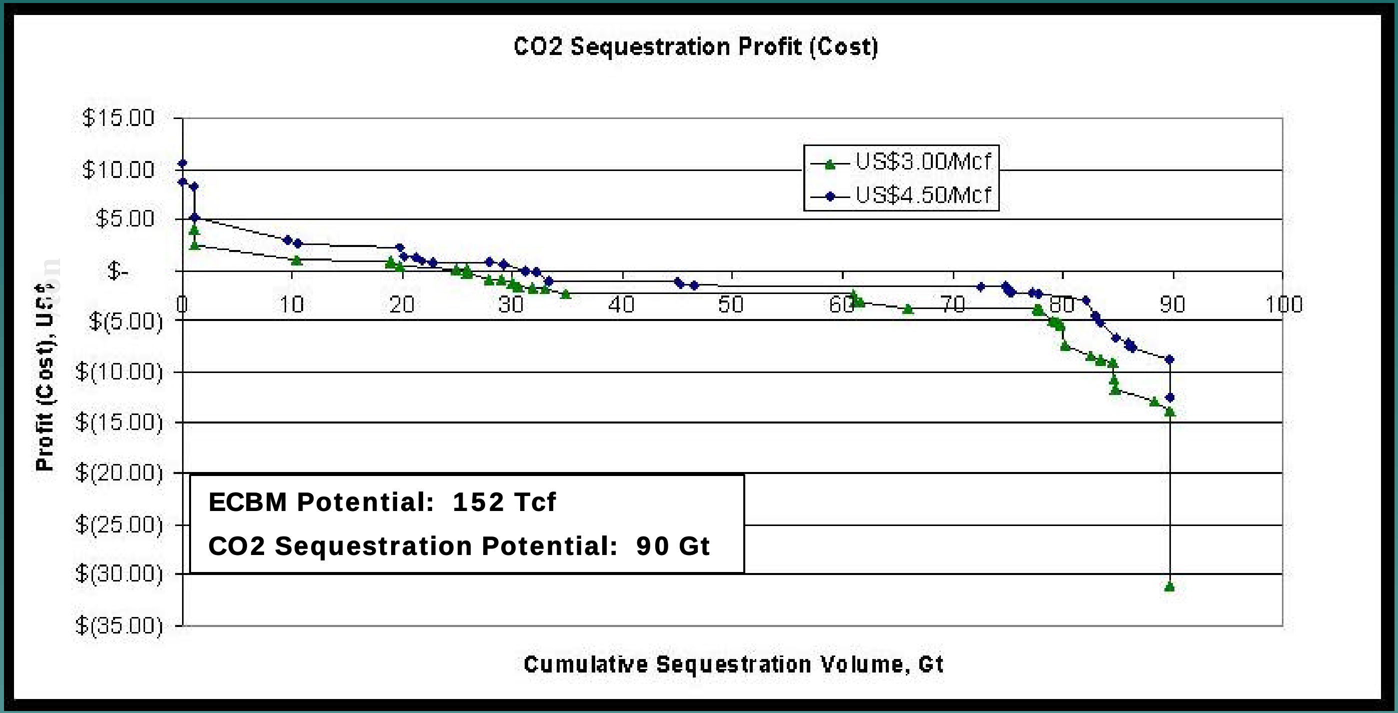
U.S. CO_2-ECBM/Sequestration Potential

- Expands/improves upon ARI's 1998 global assessment performed for IEA
- 17 basins/regions
- Three assessment "units"
  - Voidage-replacement in "commercial" area
  - ECBM in "commercial" area
  - ECBM in "non-commercial" area
- Imposed upper-limit boundaries to results
- Accounts for rank-dependent CO_2/CH_4 ratios
- Included economic performance


Assessment of CO_2 Sequestration and ECBM Potential of U.S. Coalbeds

Topical Report

Assessment Results



*Assumes "free" CO_2

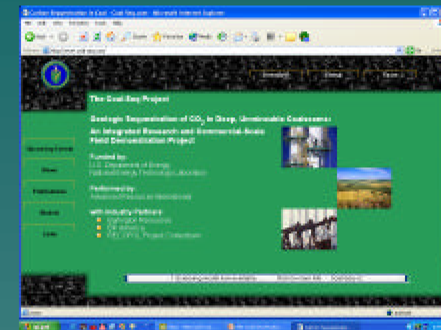
Best Basins: San Juan, Raton, Powder River and Uinta. Also Gulf Coast and Central Appalachian.

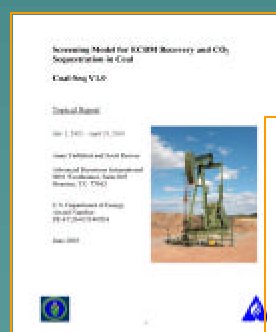
Best Areas: "Greenfield" – more ECBM recovery.

Does not account for high-injectivity technology.

Technology Transfer

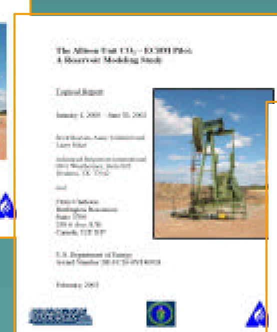
- www.coal-seq.com
- Coal-Seq forums
  - Coal-Seq I, March, ‘02, Houston
  - Coal-Seq II, March, ’03, Washington
  - Coal-Seq III, March, ’04, Baltimore
- Publications
  - Topical Reports
  - Technical Articles
  - Presentations
  - Etc.



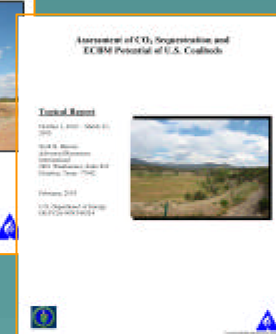

Screening Model for ECBM Recovery and CO_2 Sequestration in Coal

Coal-Seq V1.0

Topical Report


The Allison Unit CO_2 – ECBM Pilot: A Reservoir Modeling Study

Topical Report


Assessment of CO_2 Sequestration and ECBM Potential of U.S. Coalbeds

Topical Report

Key Accomplishments

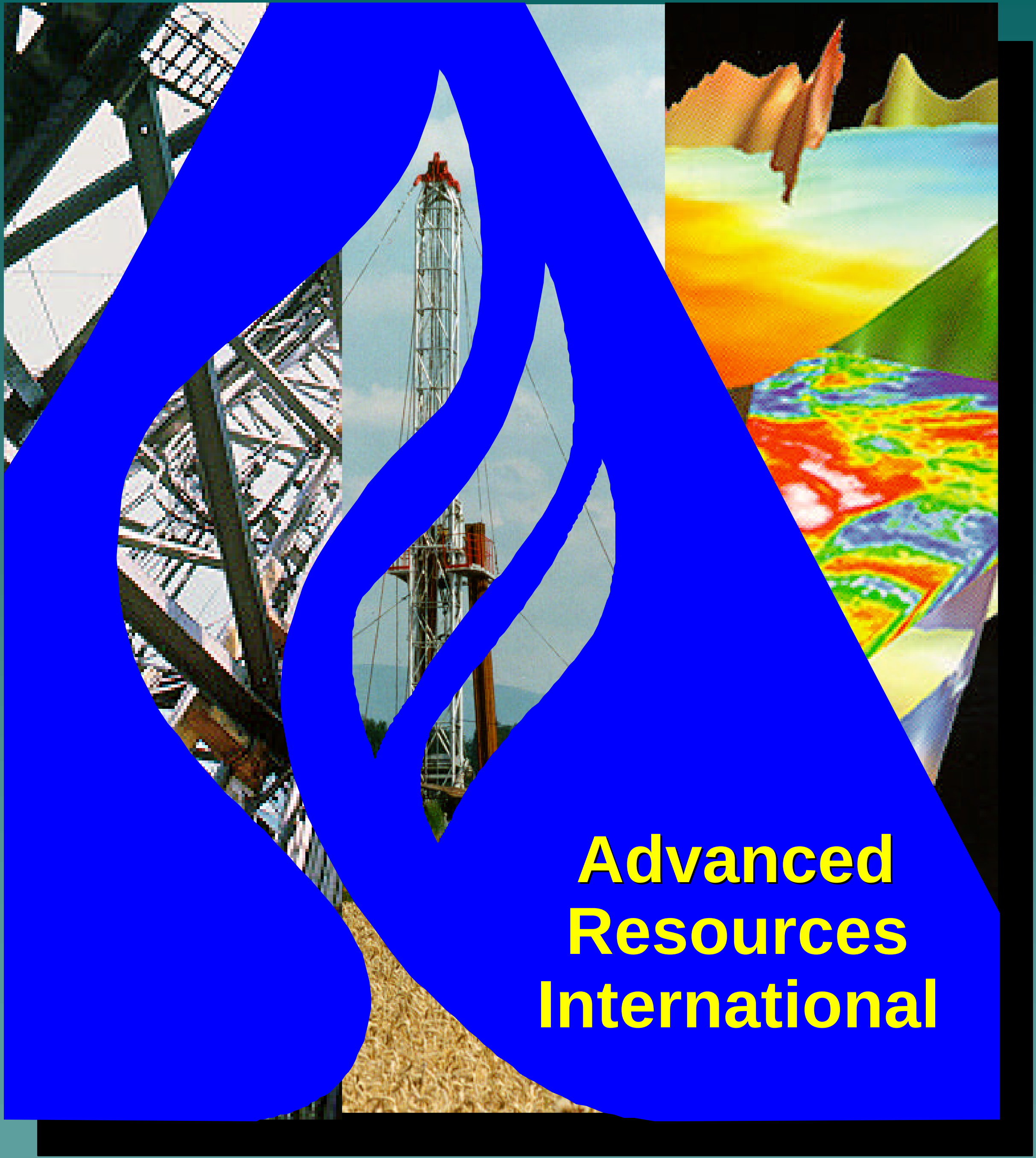
- CO_2–ECBM/sequestration documented at Allison
- N_2–ECBM documented at Tiffany
- Prepared field practices manual

Massive leveraging of industry investment.

- Demonstrated utility of existing reservoir models, and made improvements to coal swelling formulation
- Identified critical gaps in our understanding of reservoir mechanics
- Created techno-economic project screening model
- Performed technical/economic sensitivity of CO_2 sequestration in coal
- Assessed U.S. potential for CO_2-ECBM/sequestration
- Implemented successful technology transfer program
- Achieved integration and coordination with other projects: government, academia, industry, international
- Developed broad perspective on technology development
- Established Coal-Seq as a leading worldwide program in the area of carbon sequestration in deep, unmineable coal

Take-Aways

- Carbon sequestration in deep, unmineable coalseams is technically feasible.
- Incremental methane production with CO_2 and N_2 injection has been demonstrated.
- With today's gas prices, this sequestration option is economically attractive.
- Favorable environments are deeper, higher rank, lower permeability and undeveloped (for CBM) coals.
- Size of opportunity is substantial – 90 Gt CO_2 sequestration capacity and 150 Tcf ECBM resource.
- Technical hurdles remain:
  - Understand coal behavior (e.g., sorption, diffusion,swelling, PVT)
  - Enhance injectivity – with CO_2 injection (e.g., stimulation, horizontal wells)
  - More long-term, multi-well demonstrations required
  - Need SMV technology



Questions?