CO_2 Sequestration in Deep "Unmineable" Coal Seams

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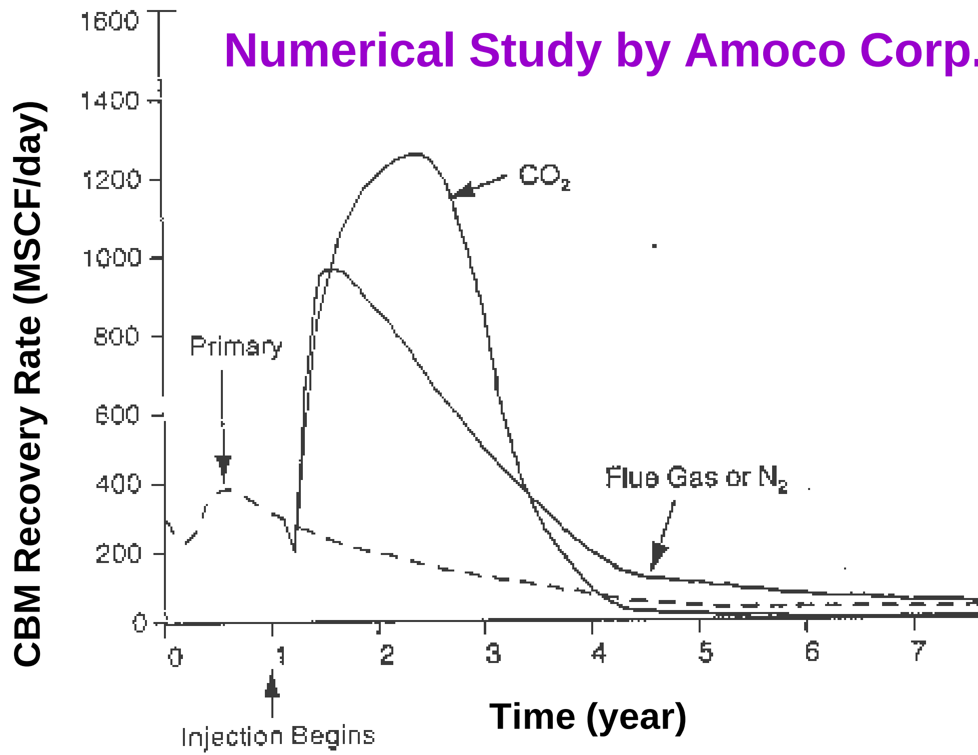
CO_2-Enhanced Coalbed Methane (CO_2-ECBM) Recovery

- Amoco Corp. studies on U.S. coalbeds (patents issued)
- Burlington Resources field operation in San Juan Basin in New Mexico, U.S.A.
- Alberta Research Council single well field test in Fenn-Big Valley, Alberta, Canada



Chaback et al., "Method for Treating A Mixtures of Gaseous Fluids Within A Solid Carbonaceous Subterranean Formation", U.S. Patent No. 5,439,054 (1995)

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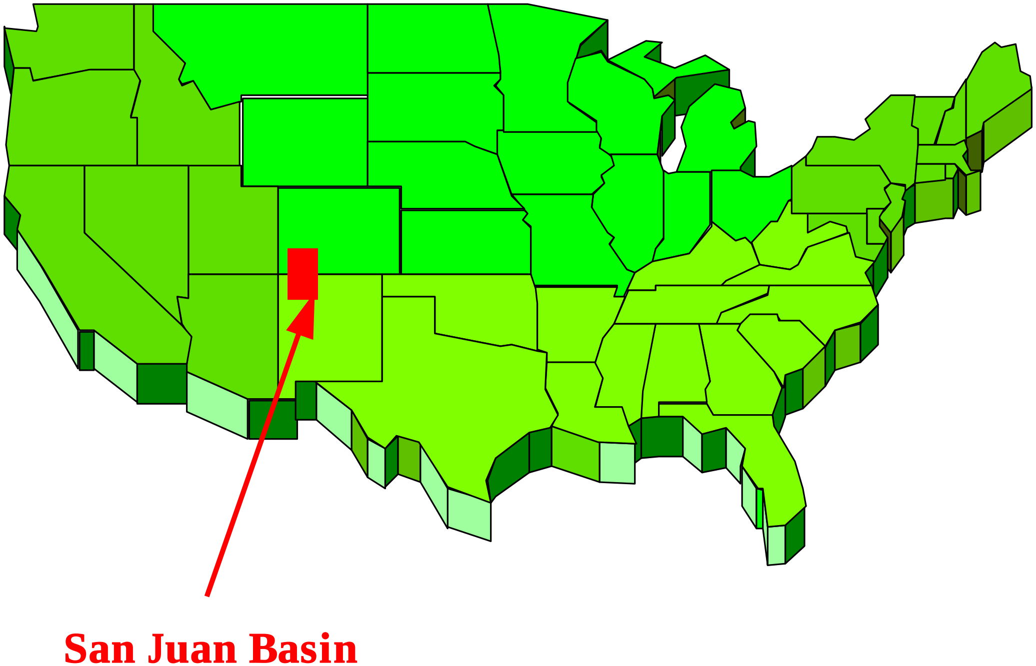
ECBM Field Pilots in United States



- Amoco N_2-ECBM pilots
- Burlington CO_2-ECBM pilot

CBM-CO_2 Project

General Objectives

- To enhance, by injection of carbon dioxide, CBM recovery factors and production rates to an economic rate in Alberta, Canada.
- To reduce greenhouse gas emissions by subsurface injection (storage) of carbon dioxide into coalbeds with production of coalbed methane (CBM).

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Questions to be Answered

- How effective is coal in soaking up CO_2?

↓

- Can you enhance CH_4 production from coalbeds at the same time as the CO_2 is being sequestered?

↓

- Is there an advantage gained by coupling power plants to coalbed methane production?

Linear Process

Generation of power by burning surface mined coal.

↓

Injection of flue gases from coal-burning into deep unmineab
coal beds where the gases are adsorbed to the coal.

↓

Displacement of the adsorbed methane off the coal by the flu
gasses and recovery of the methane at the surface.

↓

This produced Coalbed Methane (CBM) is used as feedstock
production of H_2 or petrochemicals.

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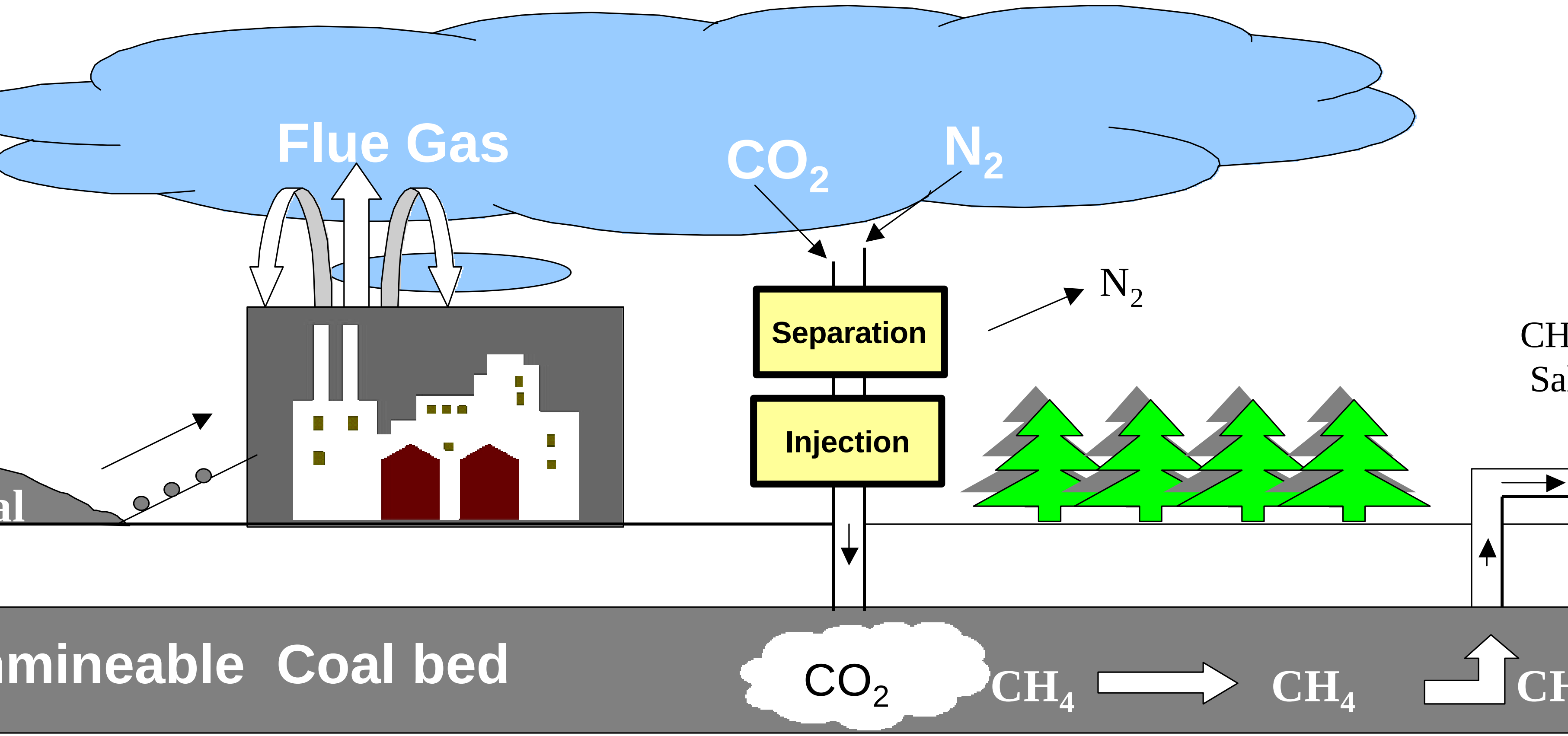
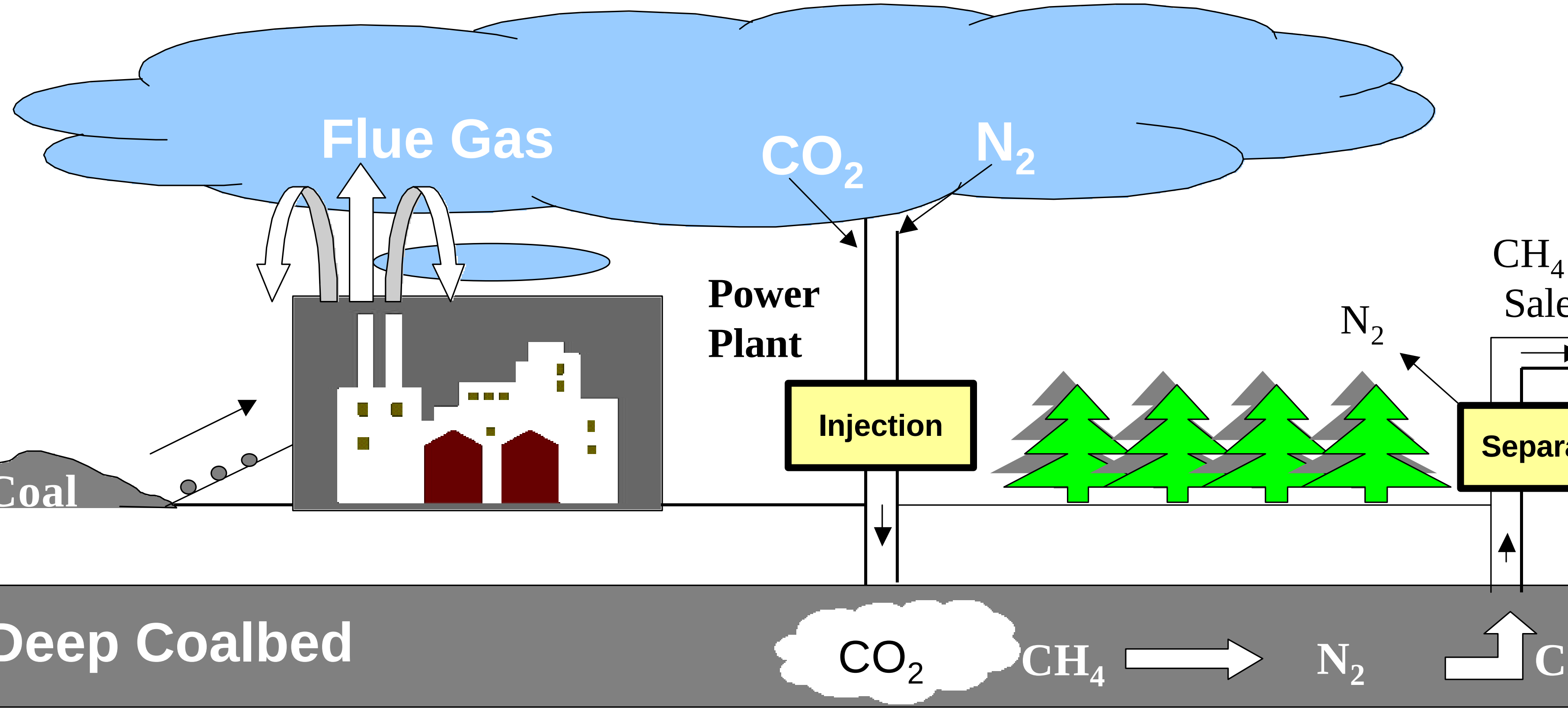
Green Power Plants



A Life-Cycle Approach to Production of Fossil Energy



- Enhanced coalbed methane (ECBM) recovery
- Sequestration of CO_2

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Cyclic Process

- Extraction of methane through production wells
- Burning of this methane as fuel in the power plant
- Disposal of the generated waste stack gases into the coal seam through injection wells
- Displacement of the adsorbed methane off the coal

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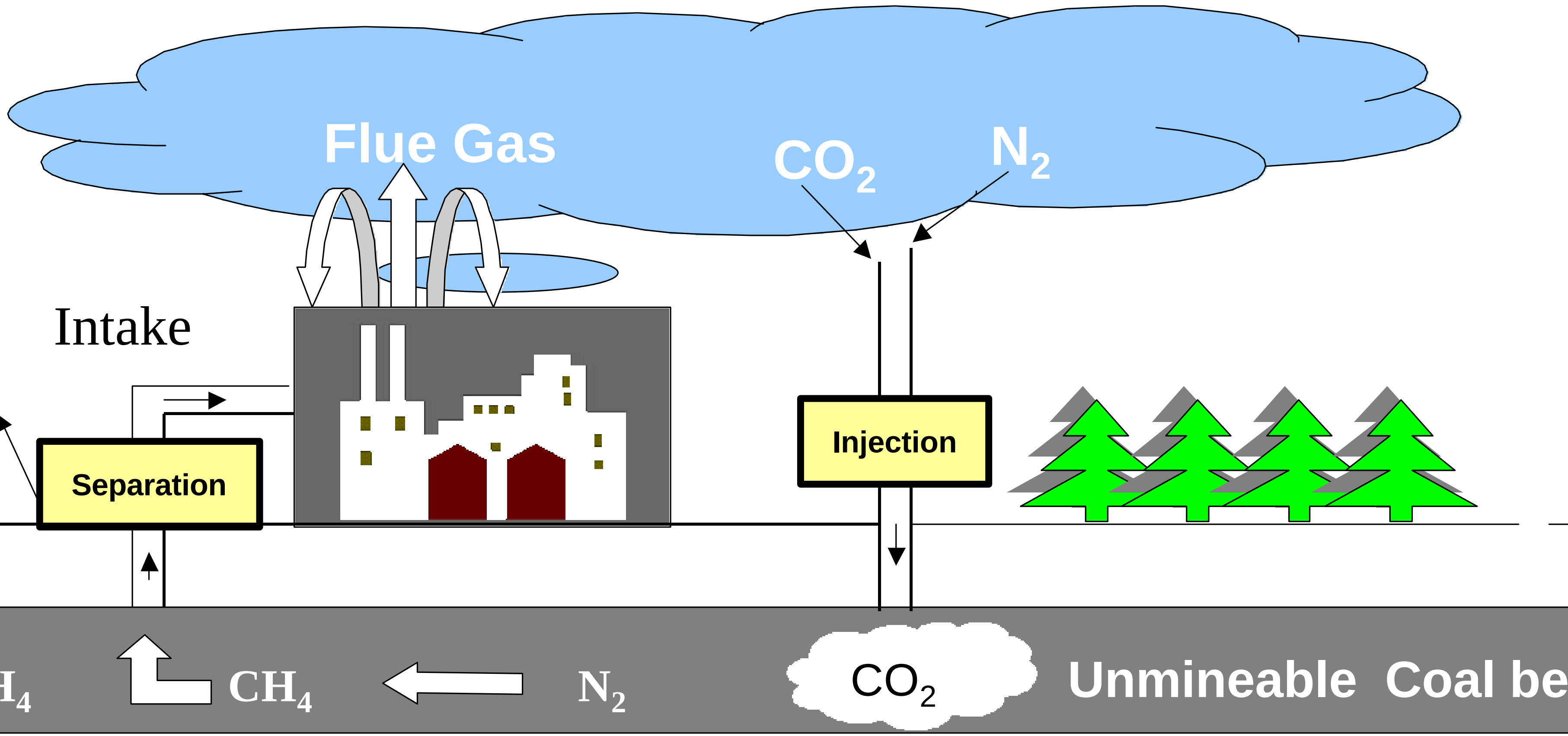
Green Power Plants



Semi - Cyclic Process

Extraction of methane through production wells

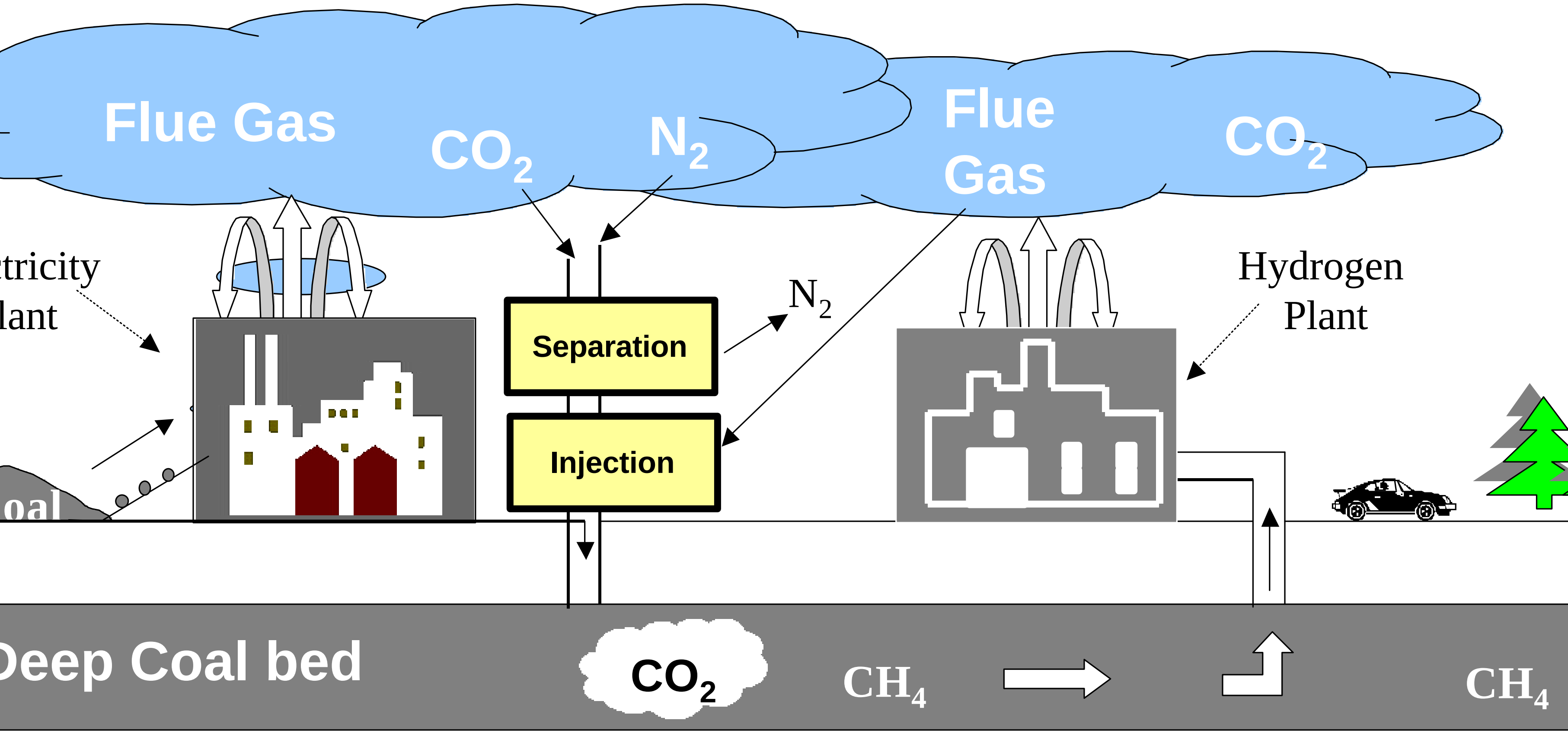
- Reforming of this methane into hydrogen

- Make-up CO_2 from stack gases o coal-fired power plant

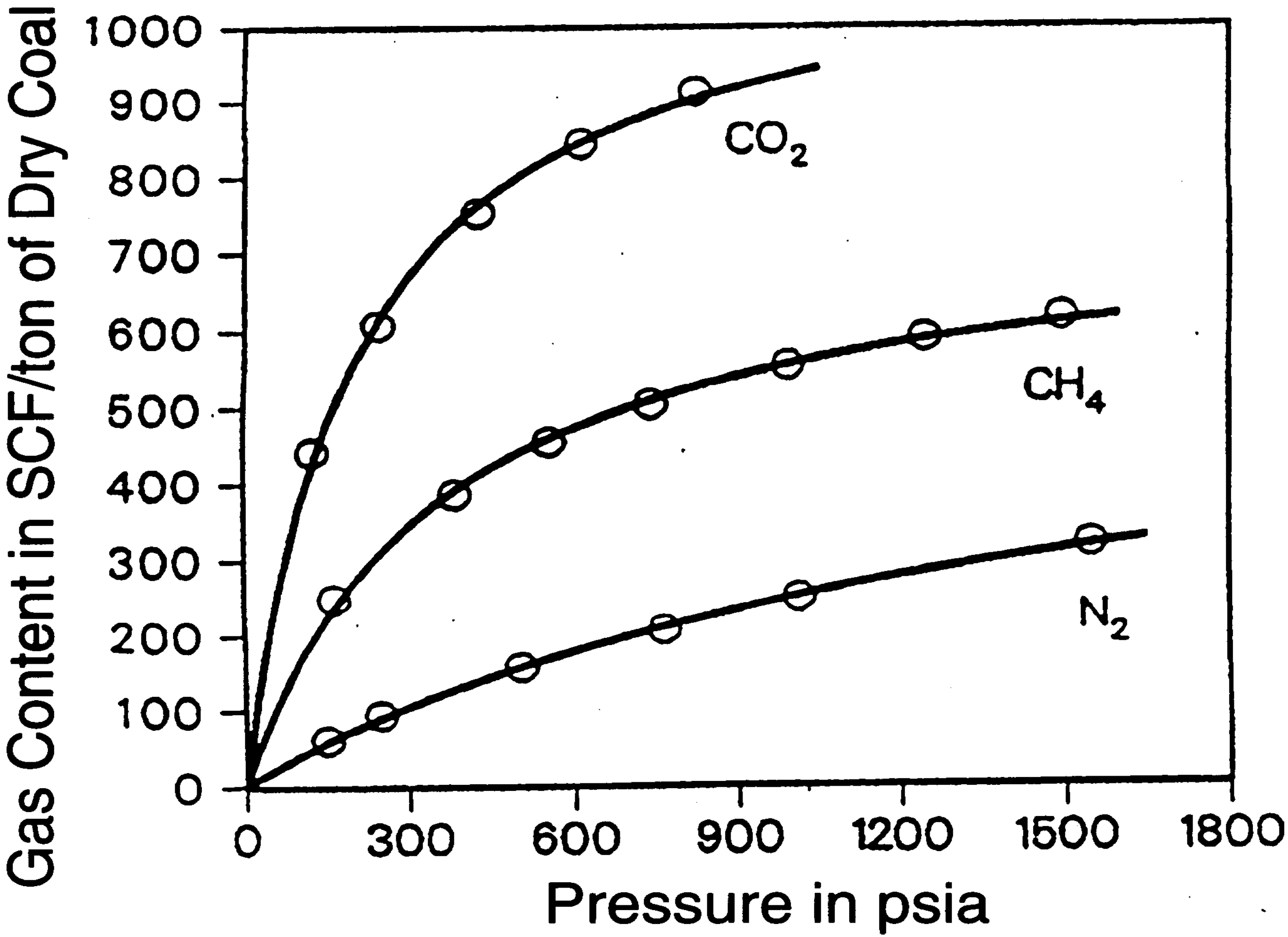
Disposal of the generated waste CO_2 gases into the coal seam through injection wells

Displacement of the adsorbed methane off the coal

Green Power Plants



Gas Capacity of San Juan Basin - Fruitland Coal



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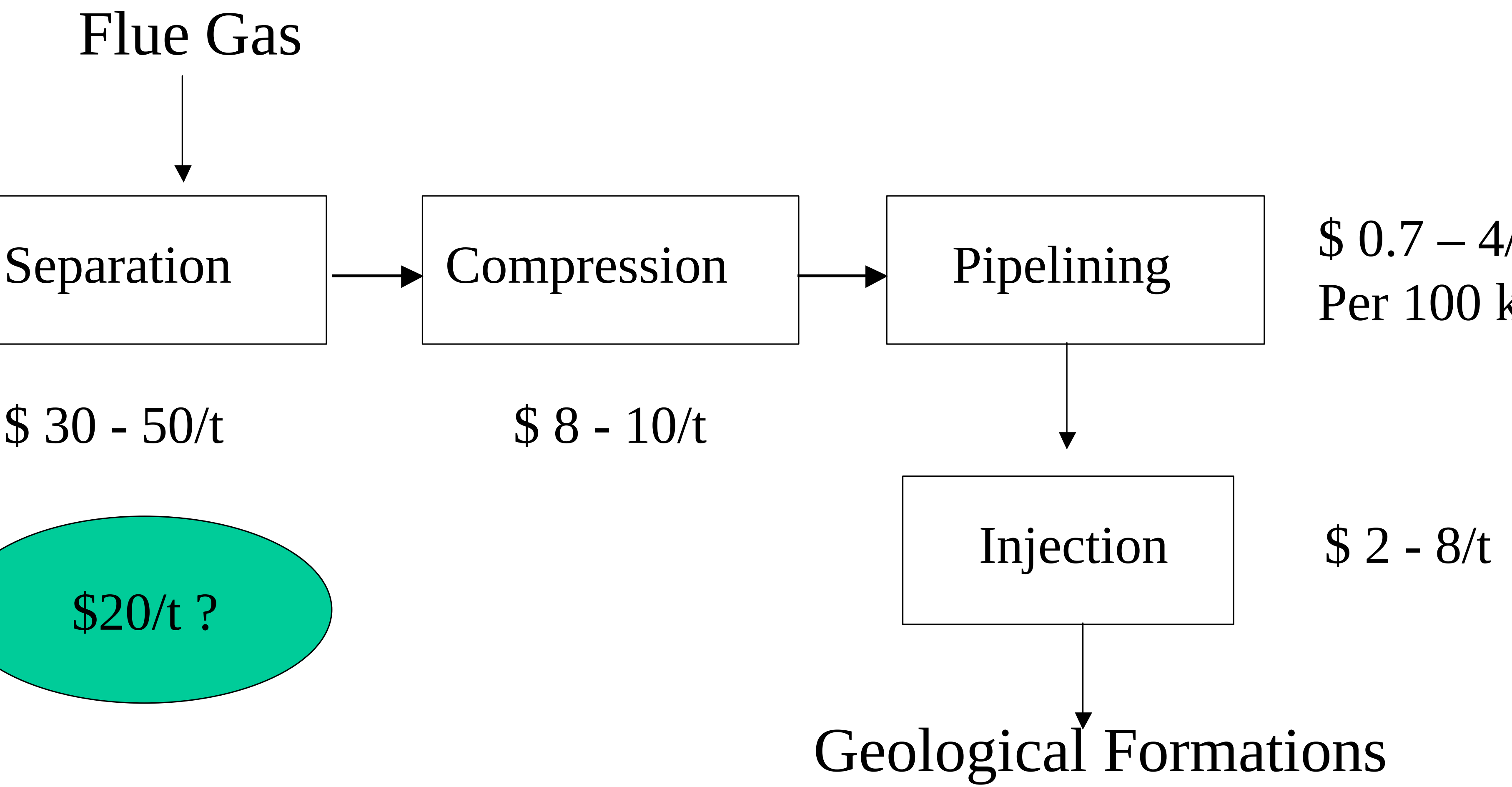
Flue Gas Injection is Less Expensive than Obtaining a Pure CO_2 Injection Stream???

Capturing CO_2 from Flue Gas



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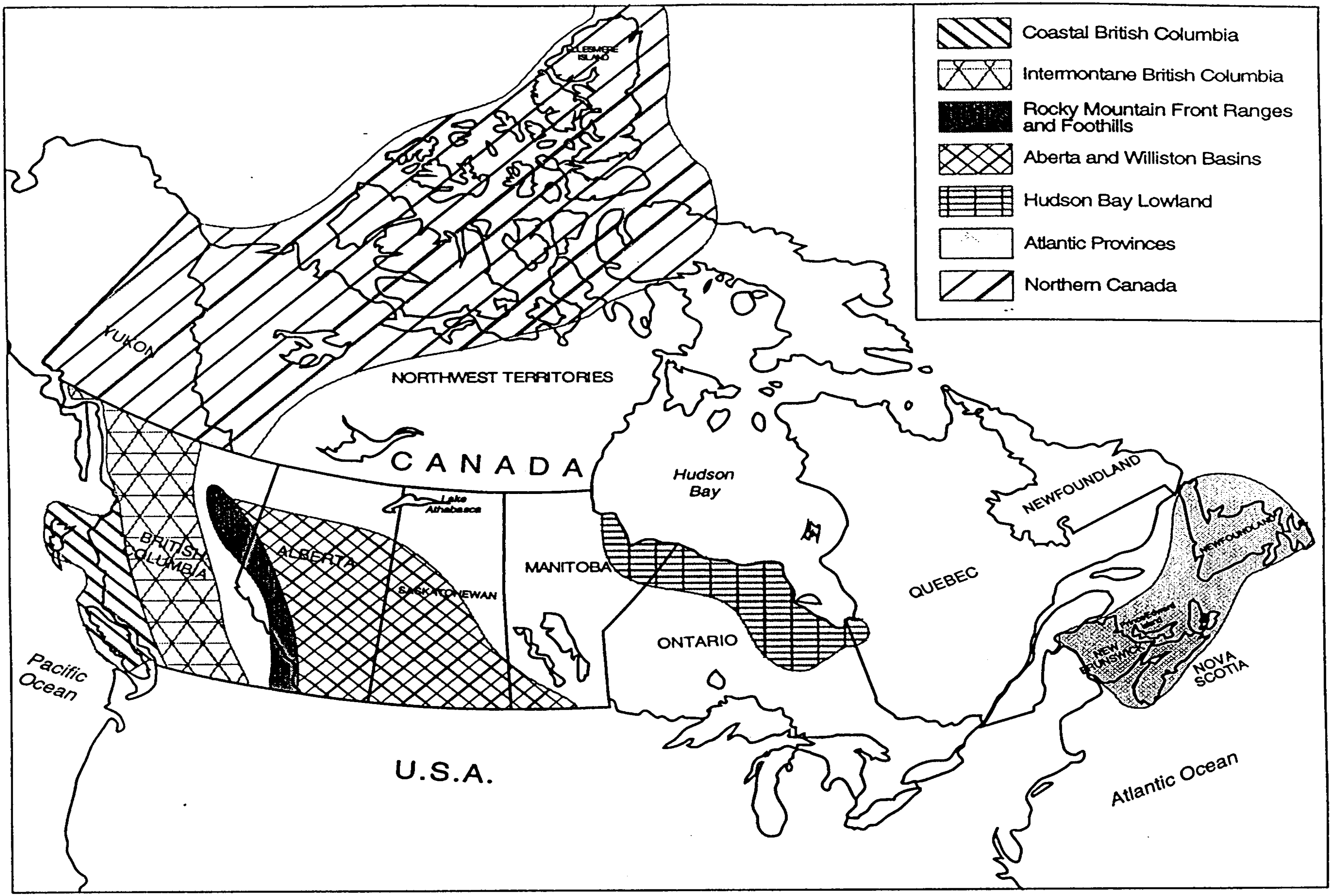

Figure 3.2.1-1 Major coal-bearing regions of Canada (after Smith, 1989).

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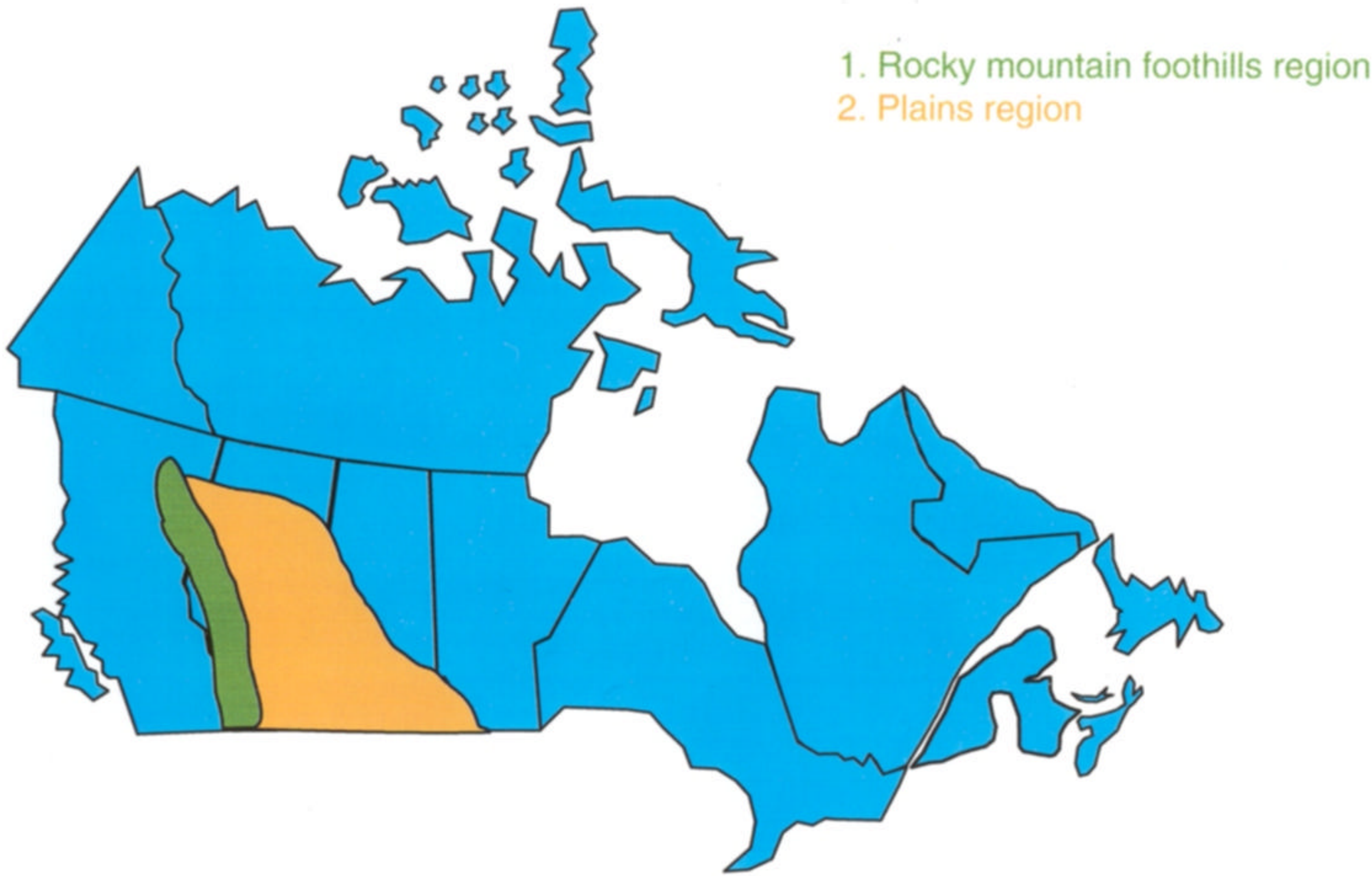
CO_2-ECBM Potential of Western Canada



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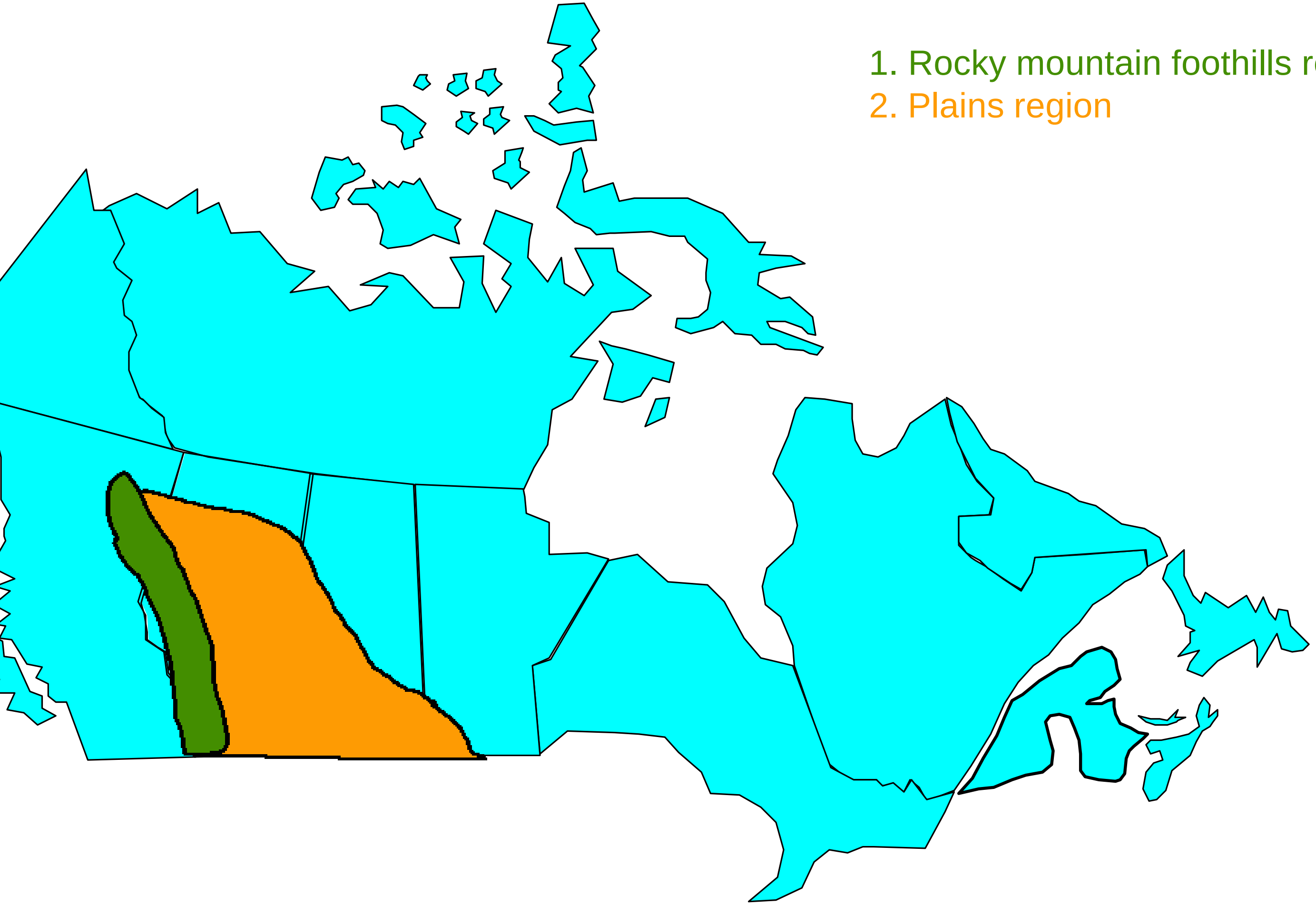
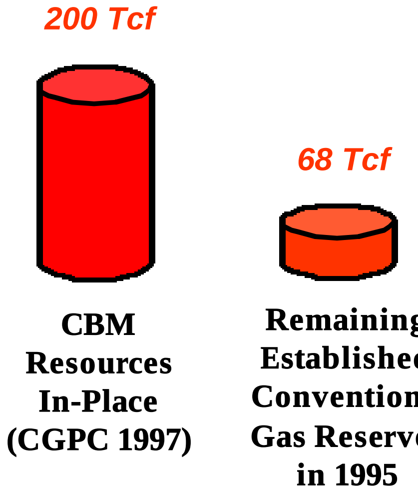
CBM Resources of Western Canada

1. Rocky mountain foothills region
2. Plains region





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CO_2-ECBM Potential of Western Canad

- CBM Recoverable Resources: 5 trillion m^3 (based on Canadian Gas Potential Committee, 1997)
- CO_2 Sequestration Potential: 18 giga tonnes (based on a CO_2/CH_4 adsorption ratio of 2/1)
- CO_2 Sequestration Capacity: > 100 years for all of CO_2 emissions in Alberta

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ARC CO_2-Enhanced Coalbed Methane Project

Measure Resource Properties of Alberta CBM Reservoirs

↓

Measure Flue Gas Composition versus Reservoir Response

↓

Improve Predictive Capability of ECBM Reservoir Simulators

↓

Model to Calculate Costs of Flue Gas/CO_2 Source

↓

Economic Evaluation of
CO_2-ECBM Reservoirs in Alberta

Attractiveness

International Participants

- Issued shares in licensing revenue from new technology developed in project
- May acquire licenses at 50% of value for internal use
- Potential of GHG credits from licensing

Domestic Participants

- Dollars contributed qualify for Canadian R&D tax credits
- Access to a better geological data base for selecting CBM targets in Alberta

lember Companies - Phase III Participants

Liquide Canada Inc
erta Geological Survey
erta Innovation and Science, (ASRA)
ervices Company Canada
Amoco Corporation
ington Resources (US)
adian Climate Change Action Fund
RO Petroleum (Australia)
ronment Canada (PERD)
OR Utilities Inc.
Technology Institute (US)
logical Survey of Canada
technical Engineering,
niversity of Alberta
Canada Resources Limited

Husky Energy Inc.
IEA Greenhouse Gas R&D Program
MGV Energy Inc.
Exxonmobil Canada
Netherlands Institute of Applied Geoscience TNO
PanCanadian Petroleum Limited
Saskatchewan Energy & Mines
Sproule International
Suncor Energy Inc.
Tesseract Corporation (US)
TransAlta Utilities
TransCanada Pipelines Ltd.
United Kingdom Department of Trade and Industry
United States Department of Energy

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Alberta Research Council Coalbed Methane – CO_2 Project

- Resource Properties:
  - Formation Evaluations
  - Ardley Coals
  - Edmonton Coals
  - Mannville Coals

- Predictive Capability:
  - Numerical Model Comparison and Improvements

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CBM Drilling Targets

Ardley coal zones at 200 meters depth

Edmonton coal zones at 500 meters depth

Mannville coal zones at 1300 meters depth

increasing permeability

Alberta Research Council Coalbed Methane – CO_2 Project

- Flue Gas Composition versus Reservoir Response:

  Four Micro-pilot tests: Fenn-Big Valley Site

  – 100% N_2
  – 53% N_2, 47% CO_2
  – 87% N_2, 13% CO_2
  – 100% CO_2

- Flue Gas Composition versus Cost:

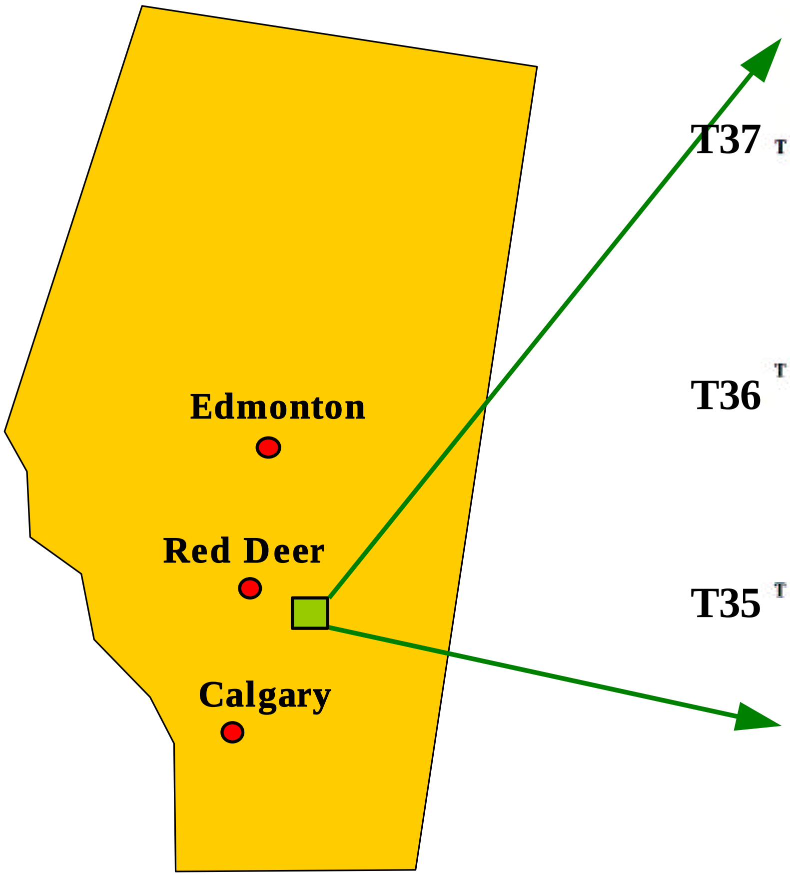
  Surface Facility Model

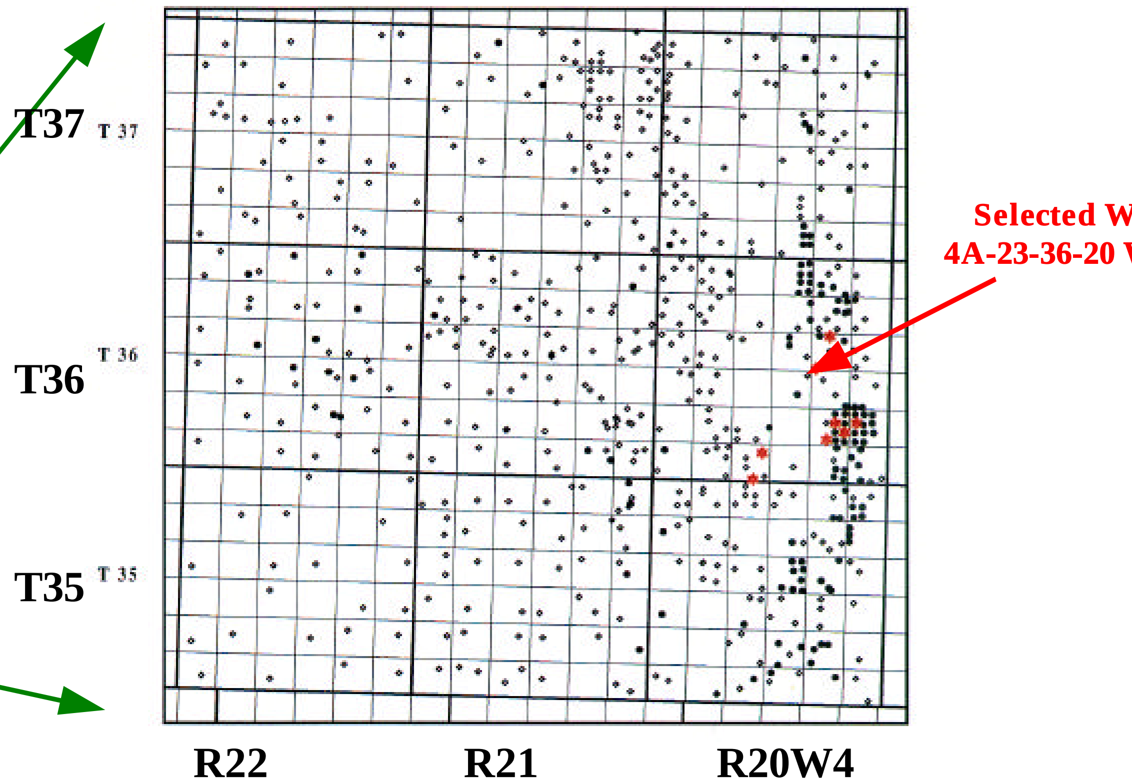
Fenn-Big Valley Site

- Known Reservoir Properties
- Pilot Operation Possible
- Productivity Similar to Amoco N_2 Pilot
- Permeability Level Common in Alberta
- Huge Resource if Enhanced Recovery is Significant

ARC Single-Well CO_2 Injection Micro-Pilot

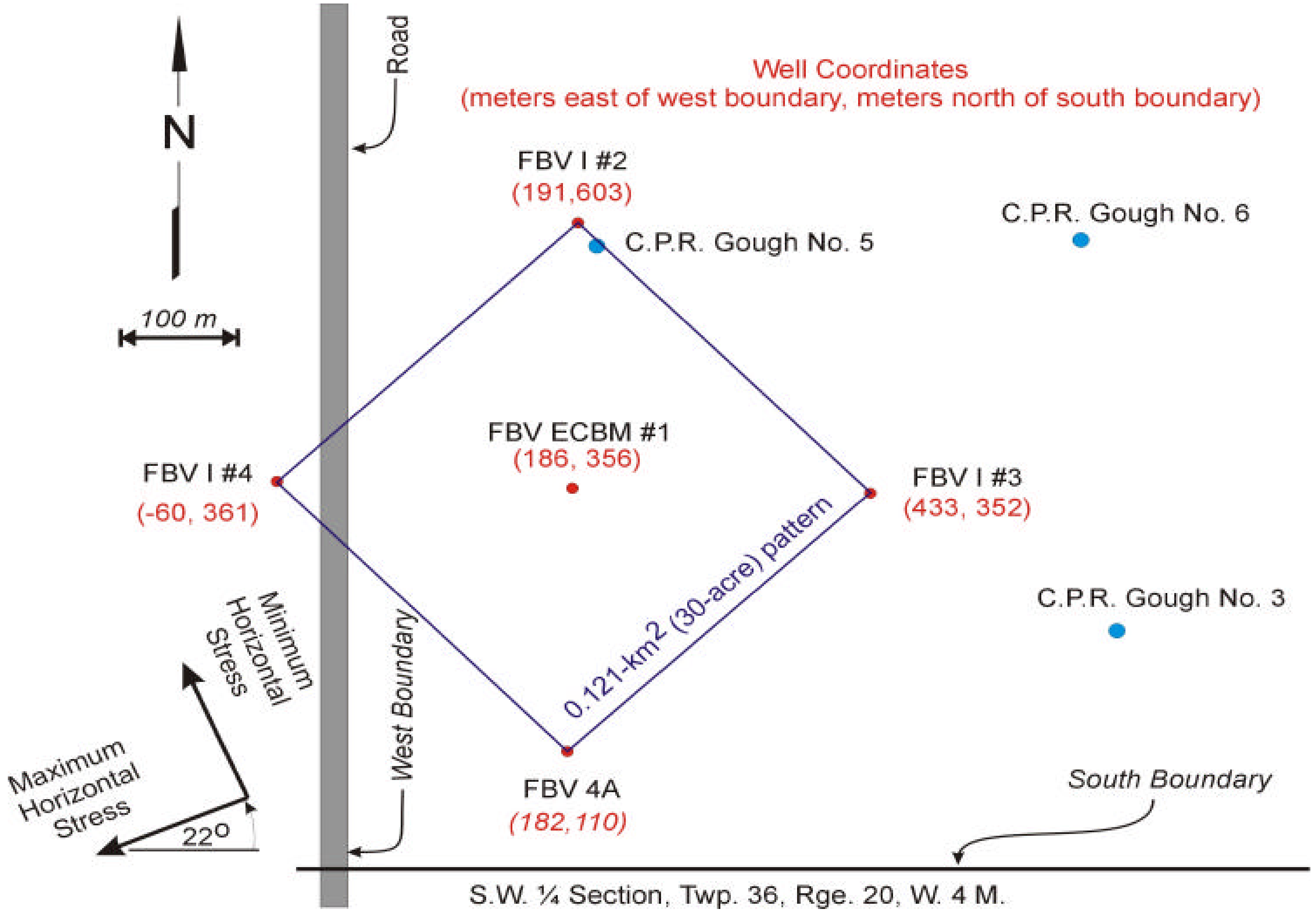
Fenn Big Valley, Central Alberta





Fenn Big Valley

Pilot Well Locations



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Mannville Coals

Medicine River coal thickness:

10.25 m (34.1 ft)

Gas-in-place volume (CH_4):

106.3 Mm^3/km^2 (9.73 $Bscf/mi^2$)

CO_2 Storage Capacity

Approx. 400,000 kg tons/km^2 (1,100,000 tons/mi^2)

ARC Micro-Pilot Goals

- Accurate measurement of injection and production behavior for single well
- Estimate reservoir properties and sorption behavior
- Calibrate numerical models based on history matching of filed data
- Forecast expanded pilot or full-field development production

Options for Coalbed Methane Recovery

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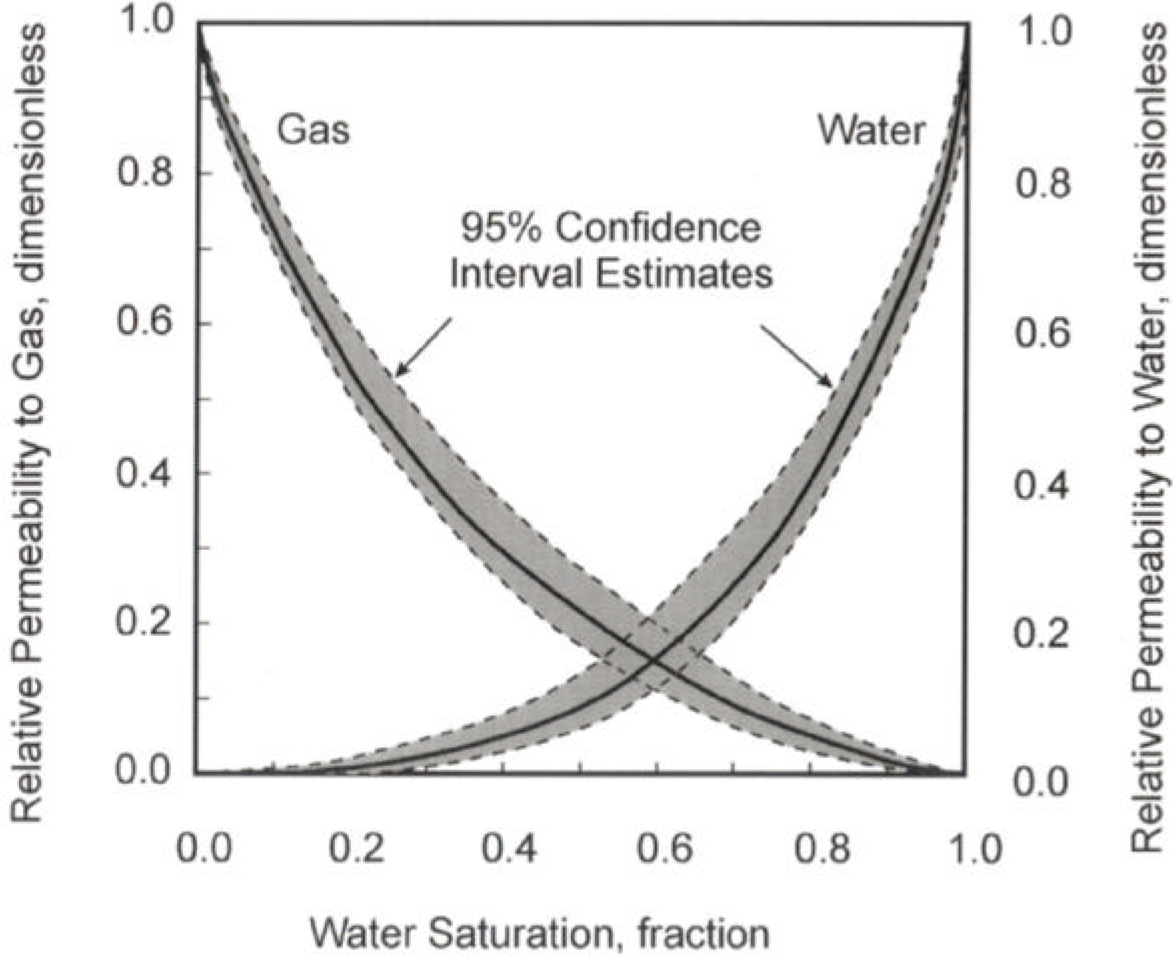
DUAL POROSITY

Coal matrix
(controls sorption)

Coal cleats
(controls permeability)

Relative Permeability Curves for CBM



San Juan Basin

Fruitland Coal

"Measurement of Rock Properties in Coal for Coalbed Methane Production", Gash, SPE 22909 (1991)

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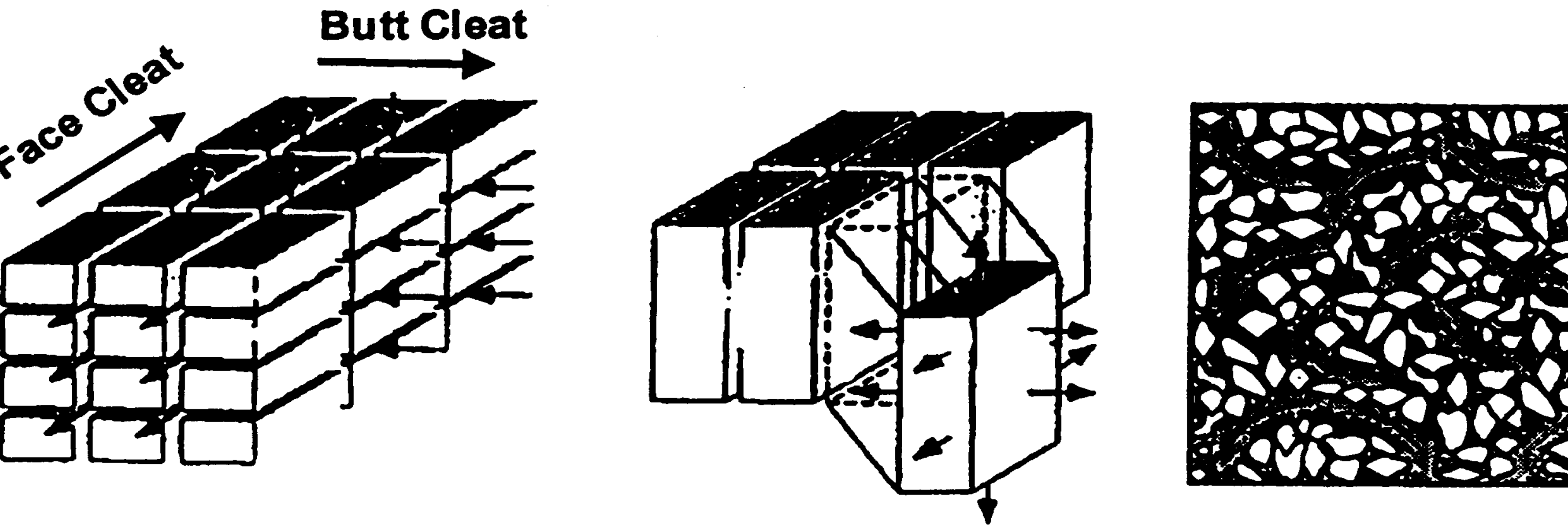
Process of Gas Transport in Coalbed Methane Reservoirs



❶ Fluid Production from Natural Fractures

❷ Gas Desorption from Cleat surfaces

❸ Molecular Diffusion through the coal matrix

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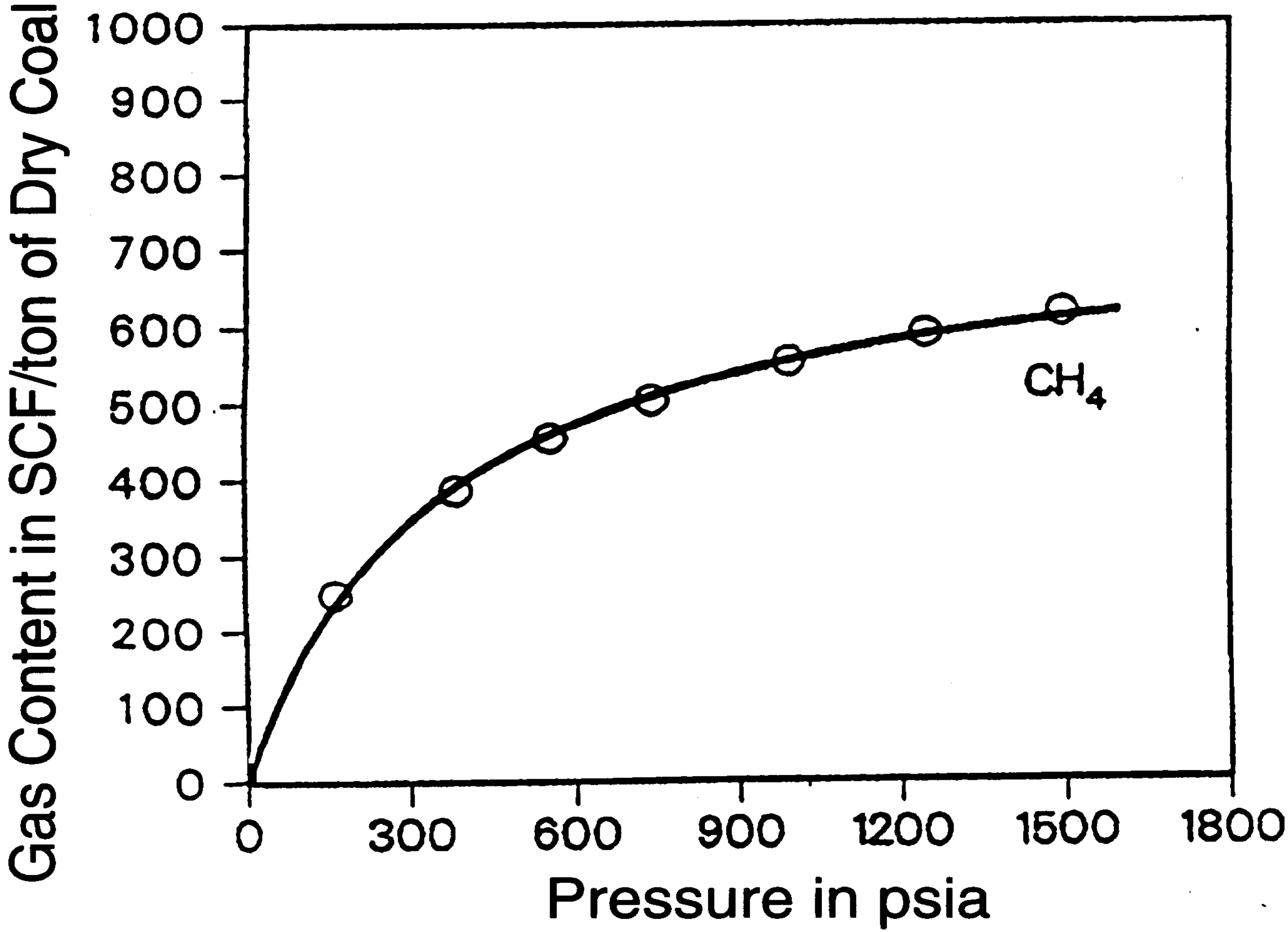
Gas Capacity of San Juan Basin - Fruitland Coal



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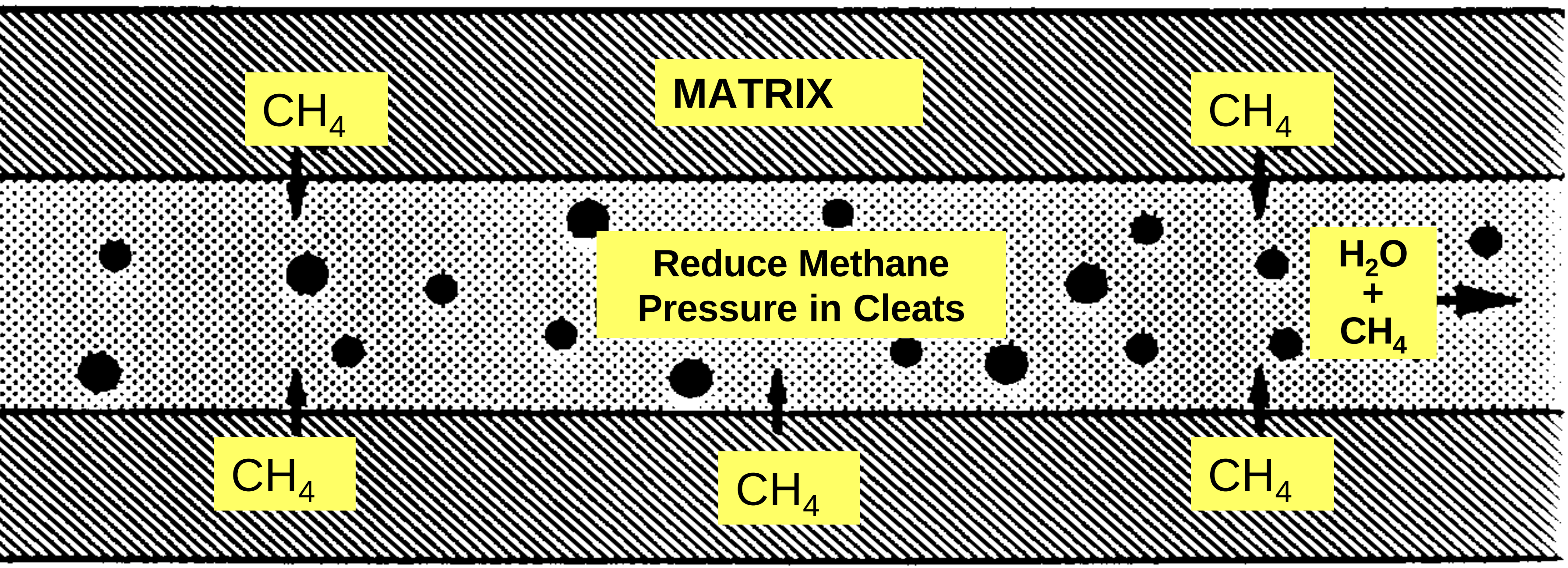
CBM Recovery Methods

- Primary CBM recovery
  - Pressure depletion
- Enhanced CBM (ECBM) recovery
  - Inert gas stripping using N_2
  - Displacement desorption using CO_2
  - Thermal desorption

Primary Coalbed Methane Recovery Mechanism

- **Reduce Cleat Pressure by Producing Water**
- **Methane Desorbs from Matrix and Diffuses to Cleats**
- **Methane and Water Flow to Wellbore**



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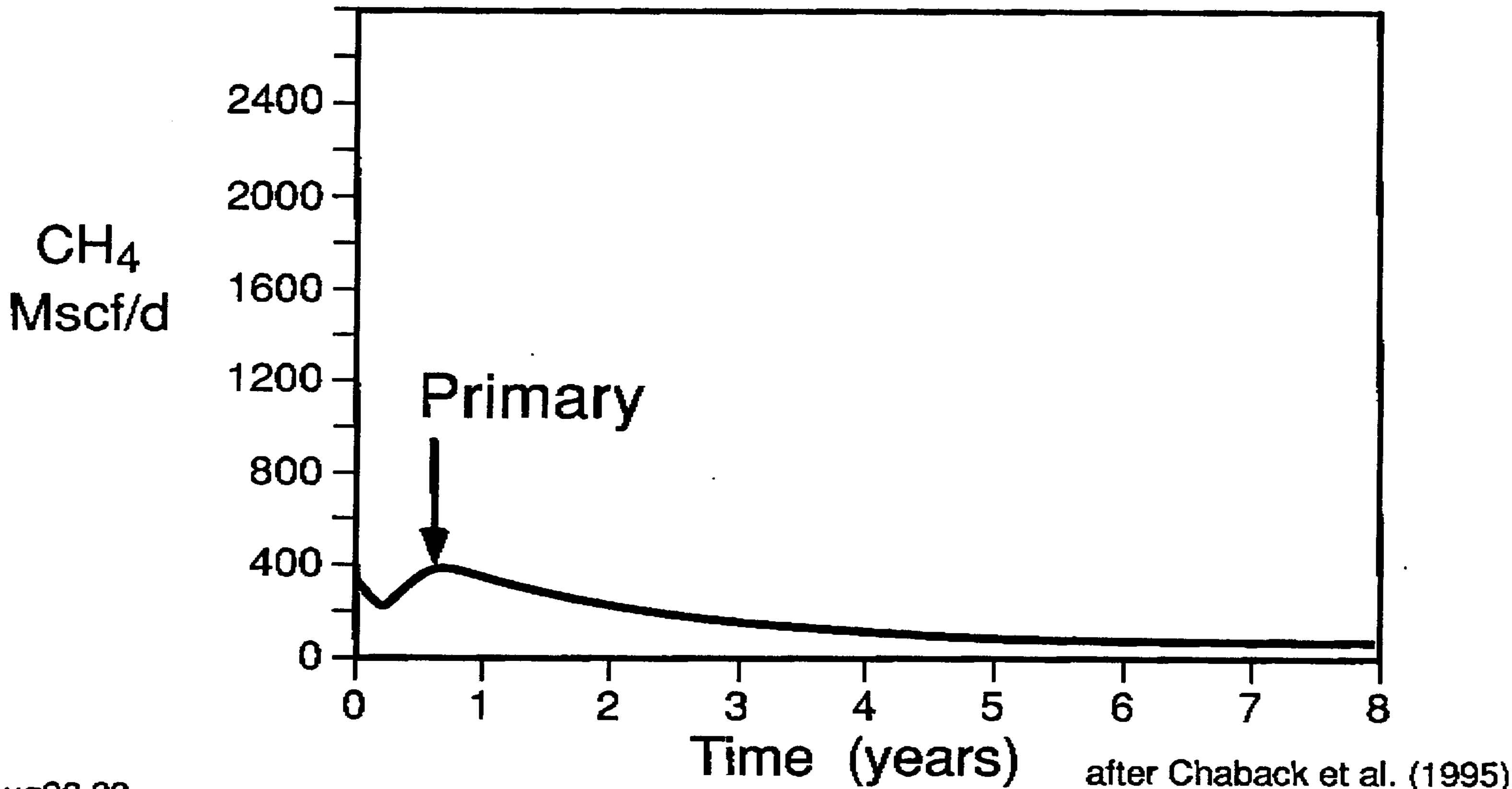
Coalbed Methane Recovery Rate



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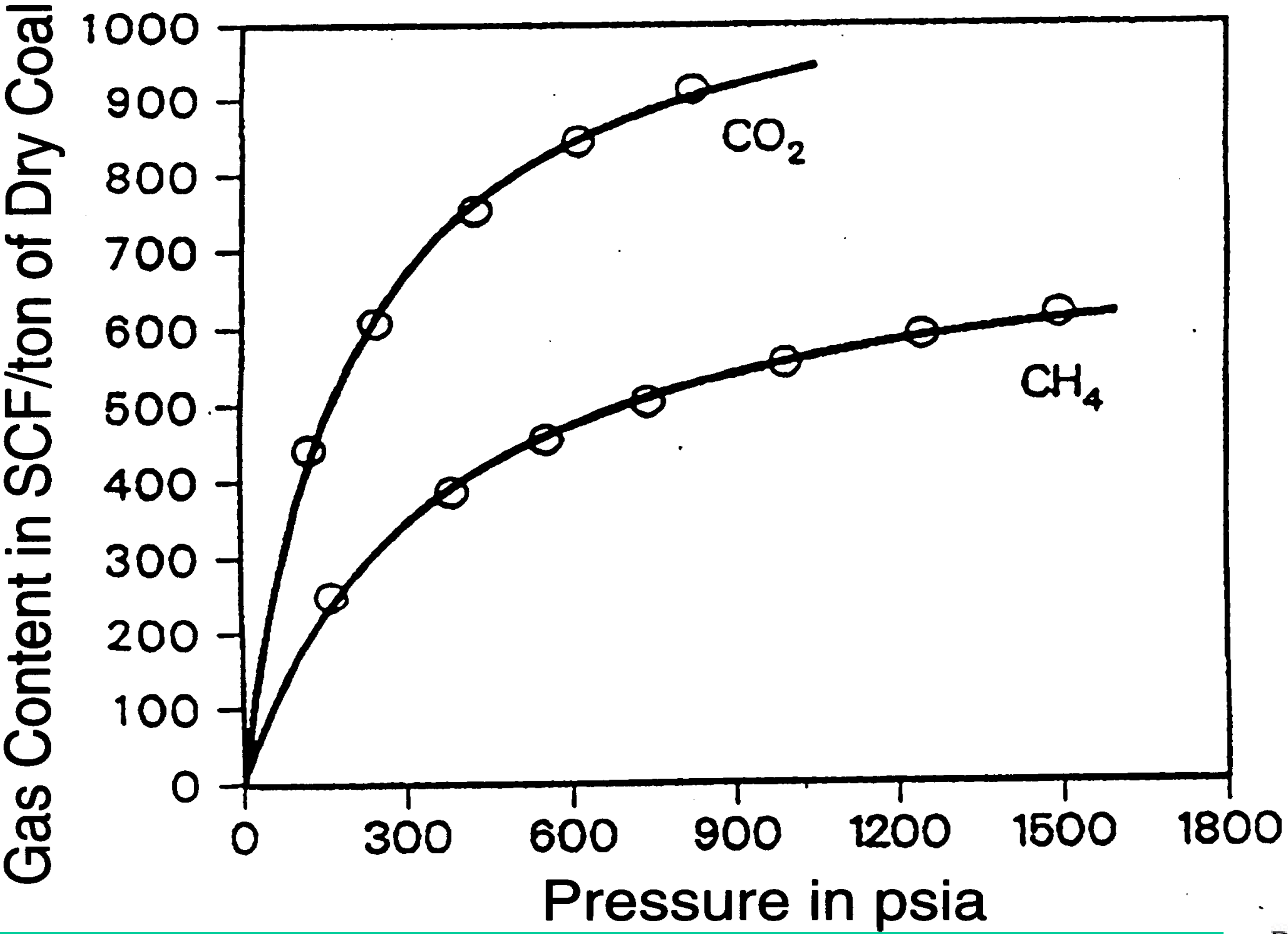
Relative Adsorption Strength

Component	Symbol	Atmospheric Pressure Boiling Point Deg Celsius
Helium	He	-268.9
Hydrogen	H_2	-252.8
Nitrogen	N_2	-195.8
Carbon Monoxide	CO	-191.7
Argon	Ar	-186.1
Oxygen	O_2	-182.8
Methane	CH_4	-161.7
Nitric Oxide	NO	-151.0
Xenon	Xe	-108.1
Ethane	C_2H_6	-88.3
Carbon Dioxide	CO_2	-78.3
Sulfur Hexafluoride	SF_6	-63.9
Hydrogen Sulfide	H_2S	-59.6
Propane	C_3H_8	-42.2
Sulfur Dioxide	SO_2	-10
Nitrogen Dioxide	NO_2	21.1
Sulfur Trioxide	SO_3	44.4

Gas Capacity of San Juan Basin - Fruitland Coal



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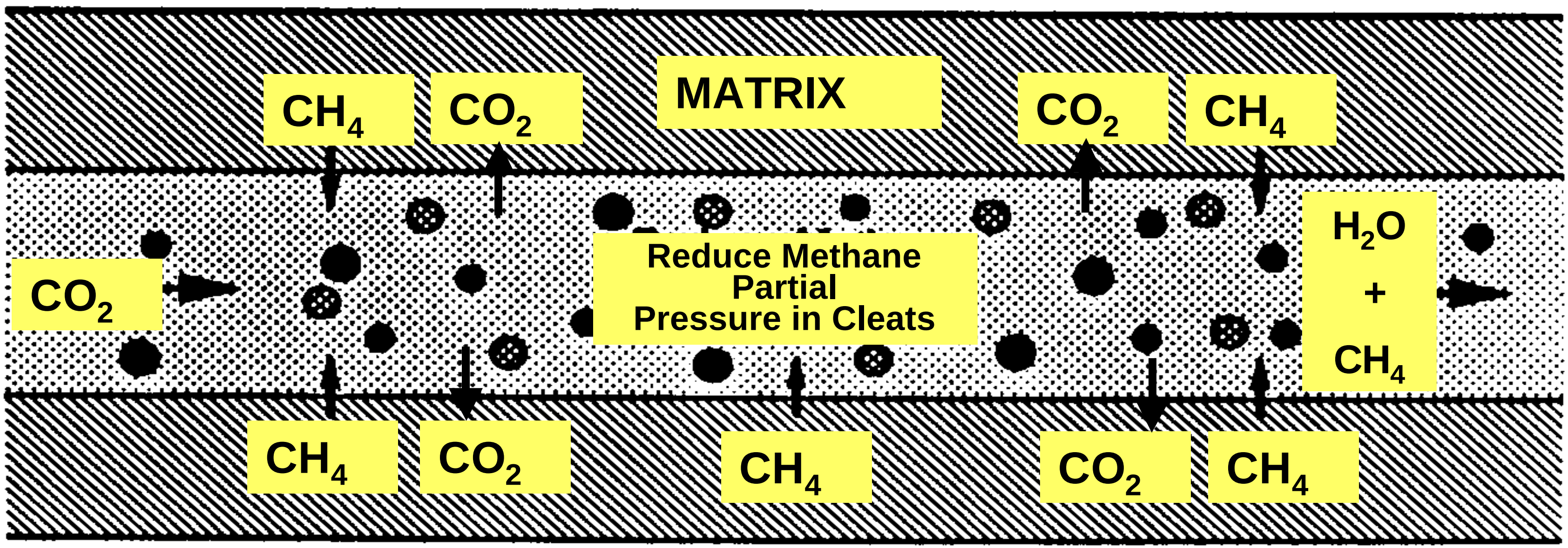
CO_2-ECBM Recovery Process

- Carbon dioxide preferentially sorbed and displaces hydrocarbons.
- Displaced hydrocarbons pressurize natural fracture system, increasing well deliverability
- Carbon dioxide breakthrough minimal
- "Sweeps" hydrocarbons from the coal

CO_2 - Enhanced Coalbed Methane Recovery Mechanism

- Inject Carbon Dioxide in Cleats
- Keep Total Cleat Pressure High
- Reduce Partial Pressure of Methane
- Carbon Dioxide Diffuses into Matrix and Adsorbs onto Coal
- Methane Desorbs from Matrix and Diffuses to Cleats
- Methane & Water Flow to Wellbore



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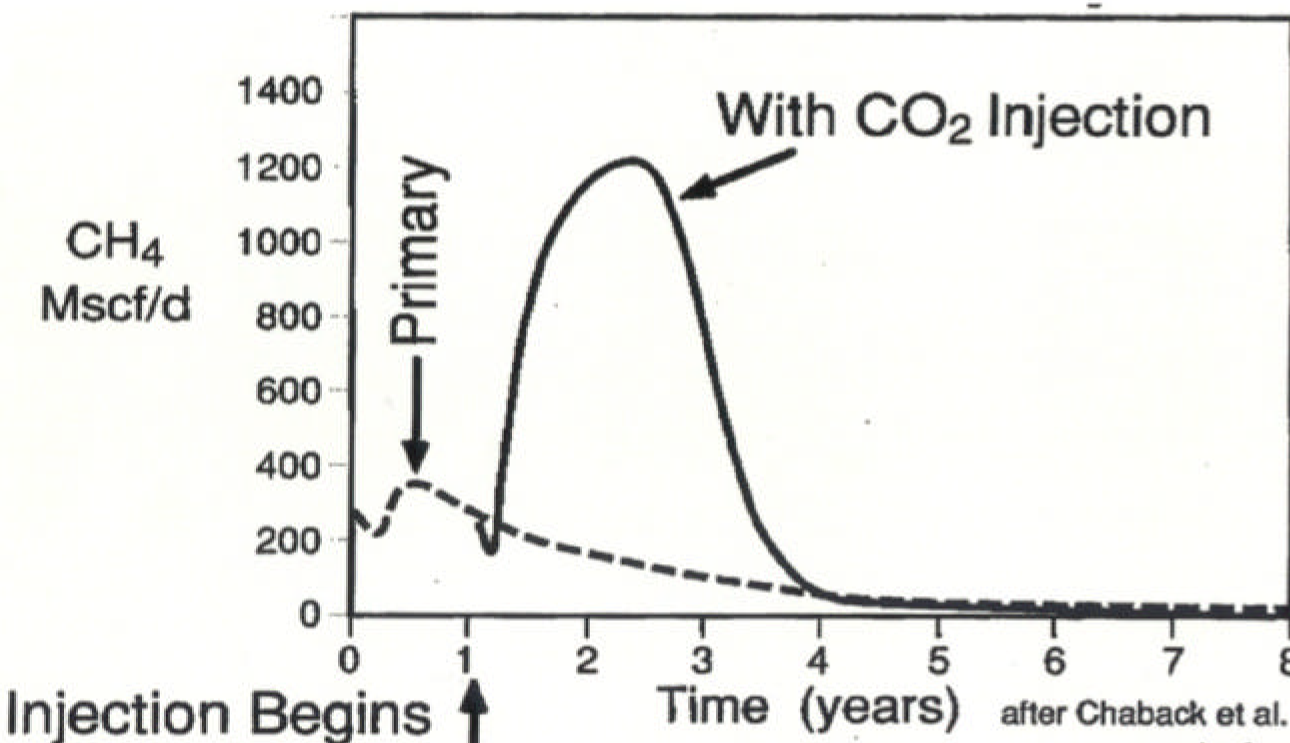
Coalbed Methane Recovery Rate



after Chaback et al. (1995)
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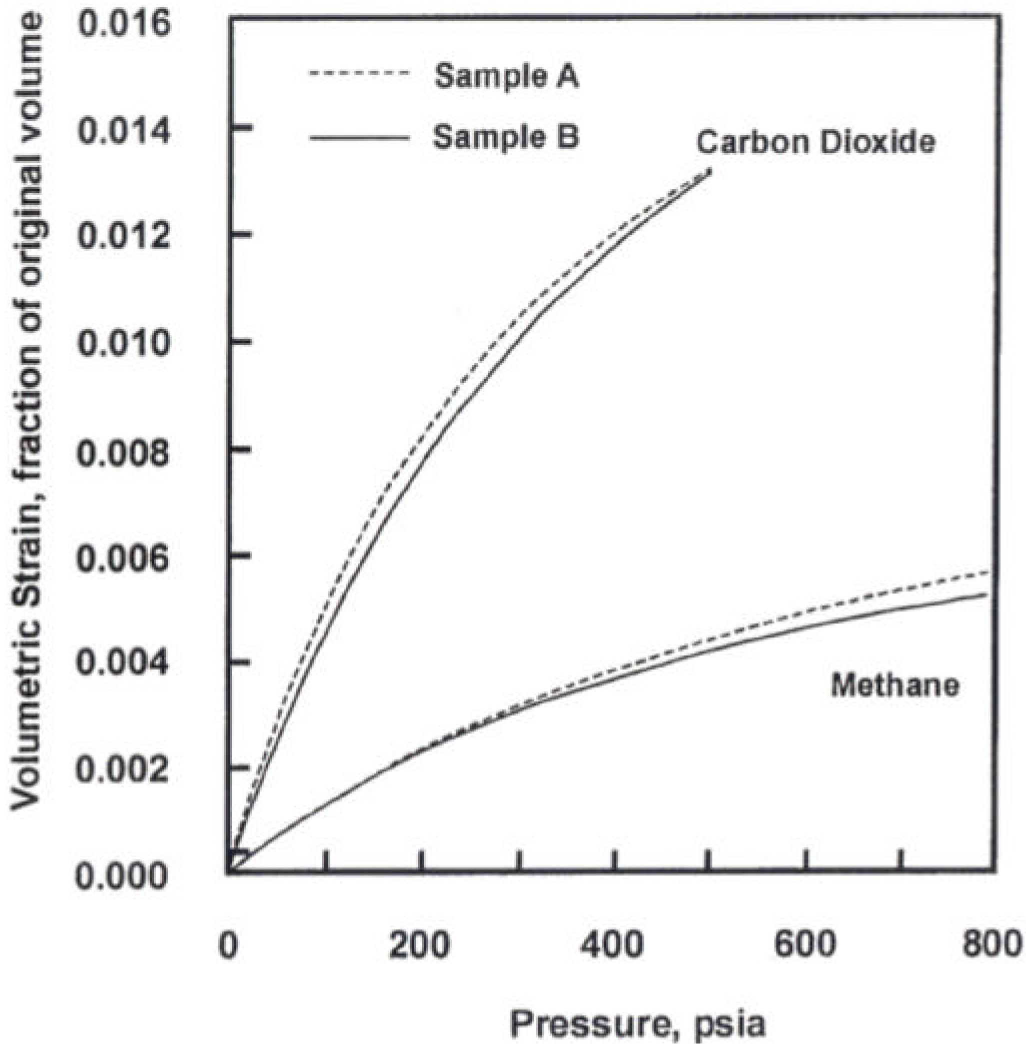
Expected Problems

- Limited CO_2 injectivity due to swelling
  - Reduced effective permeability to gas
  - Increasing with continued injection
- Inability to produce after injection

Coal Swelling



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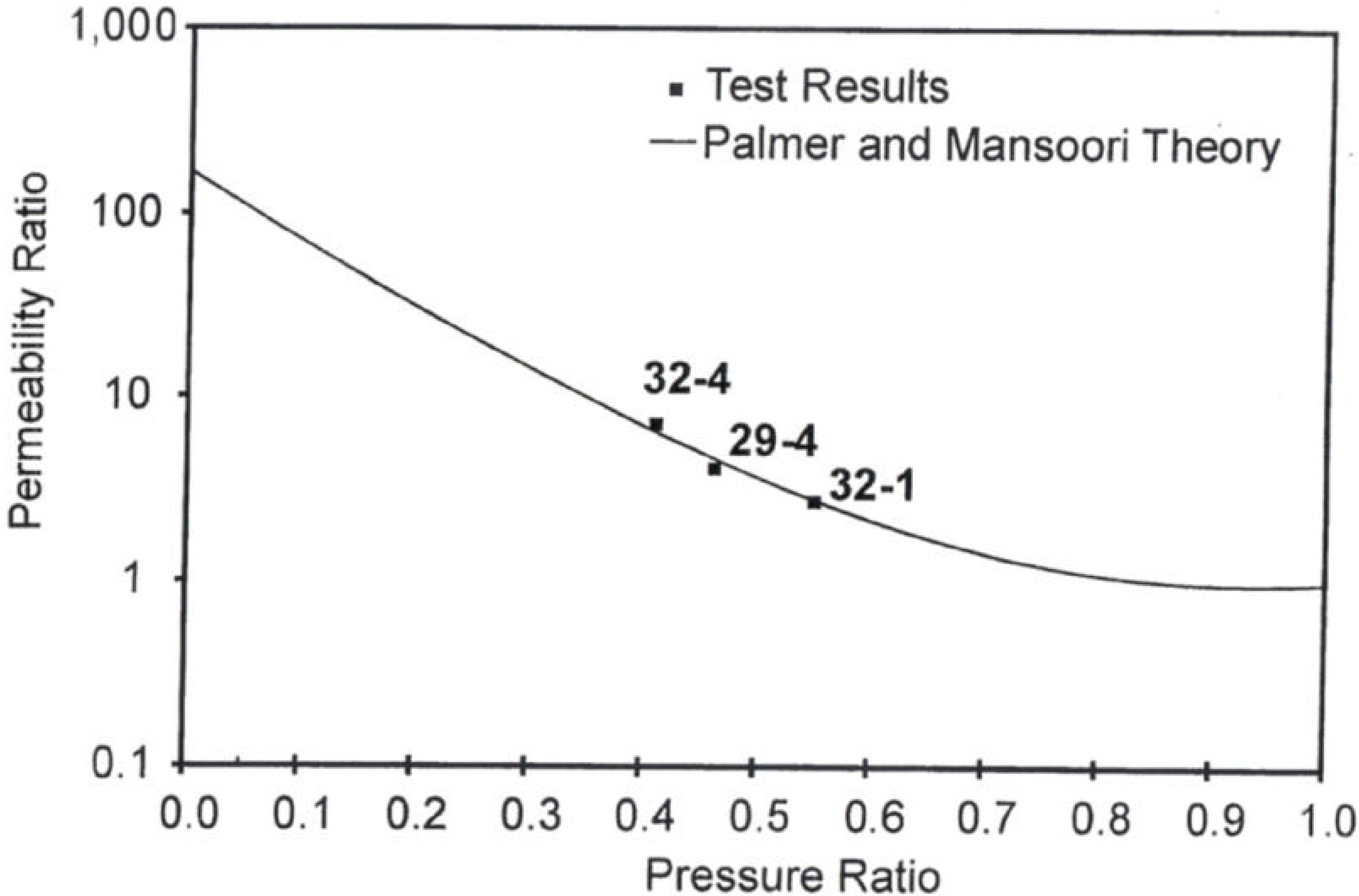
Absolute Permeability Change



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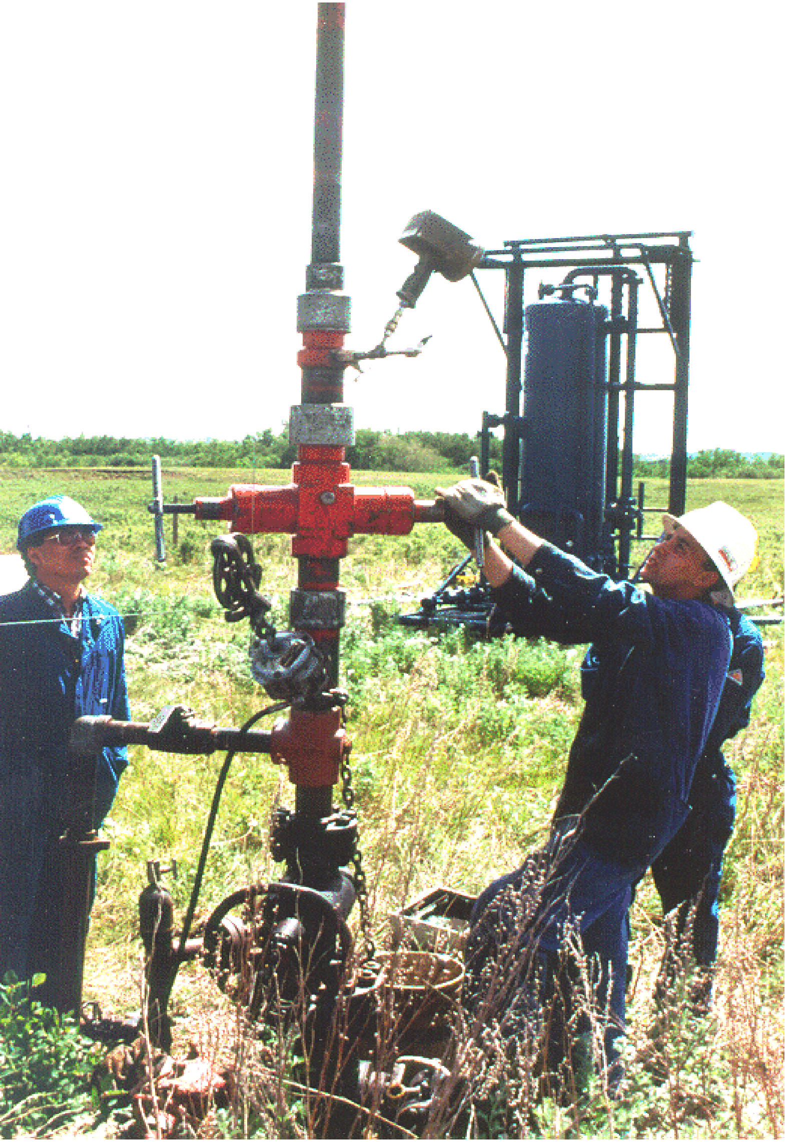
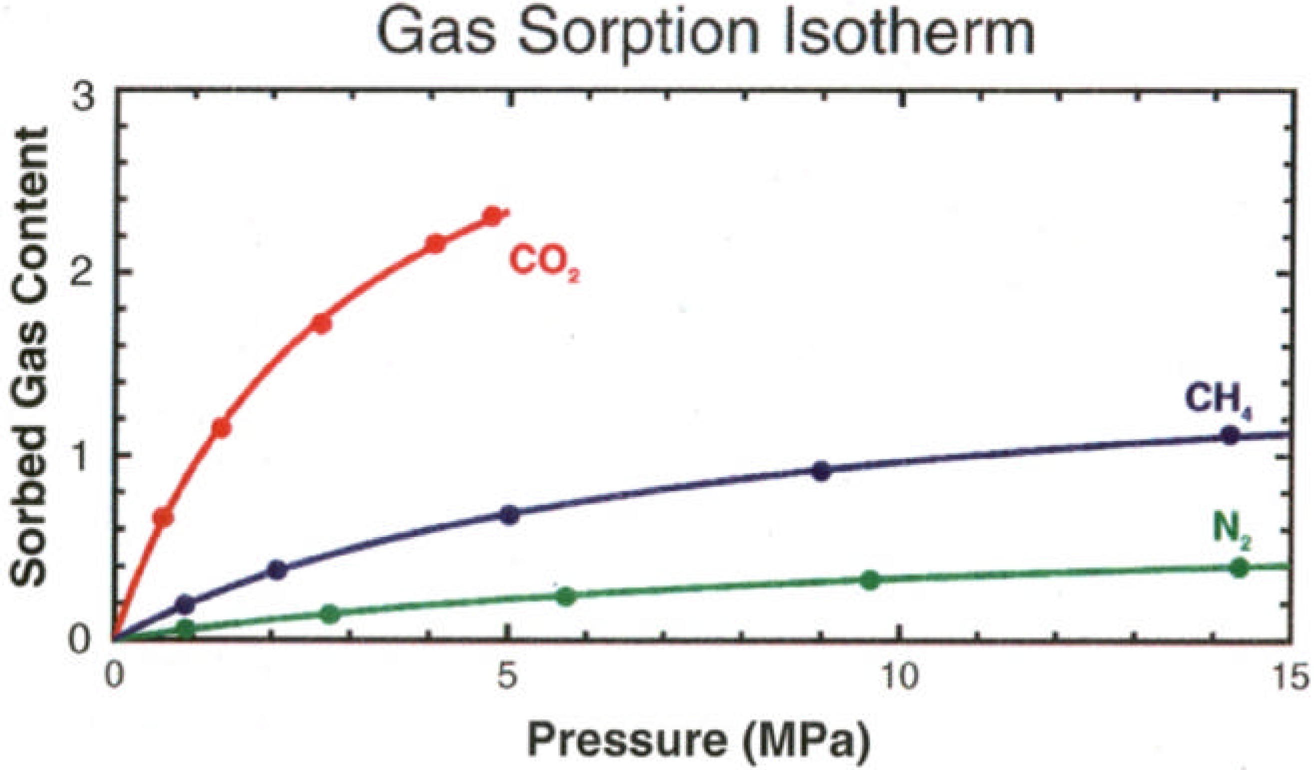
ARC Single Well CO_2 Injection Micro-Pilot



Sorption Data for Different Pure Gases



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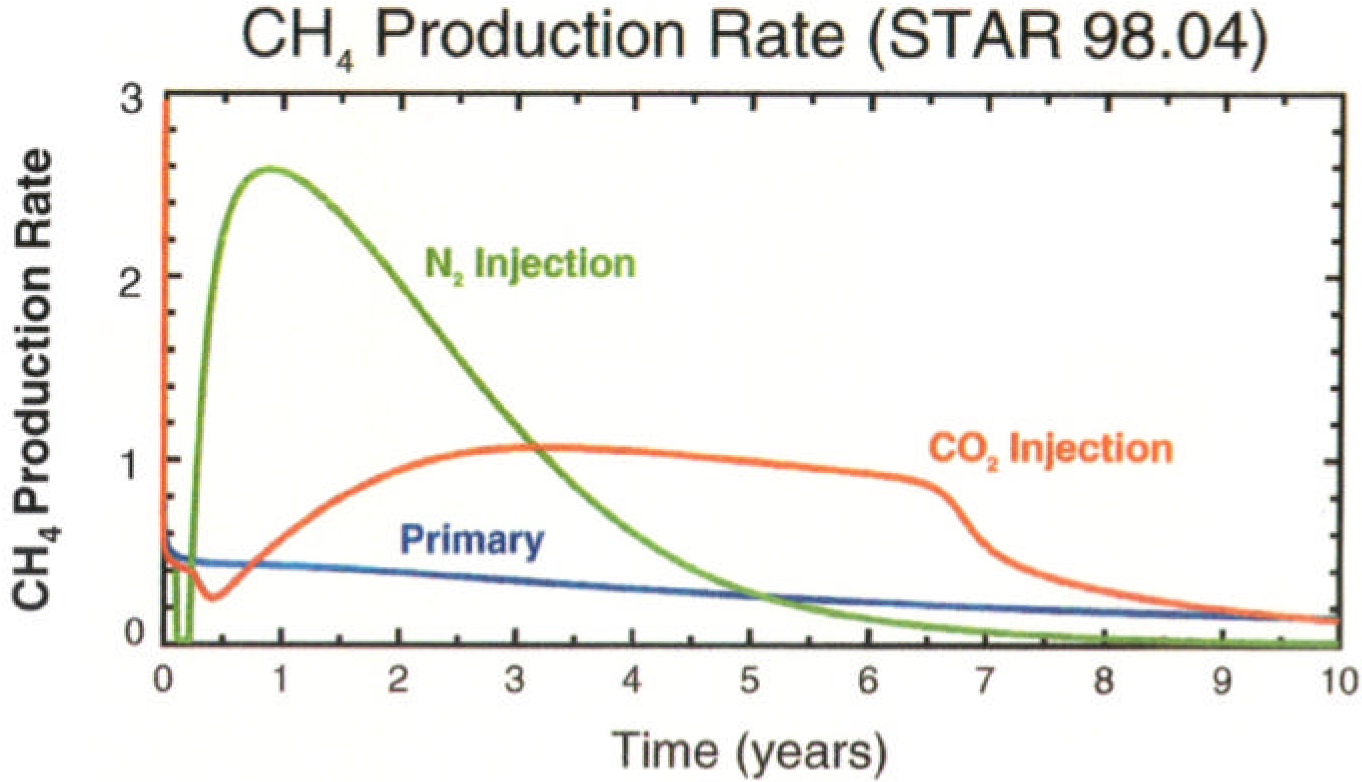
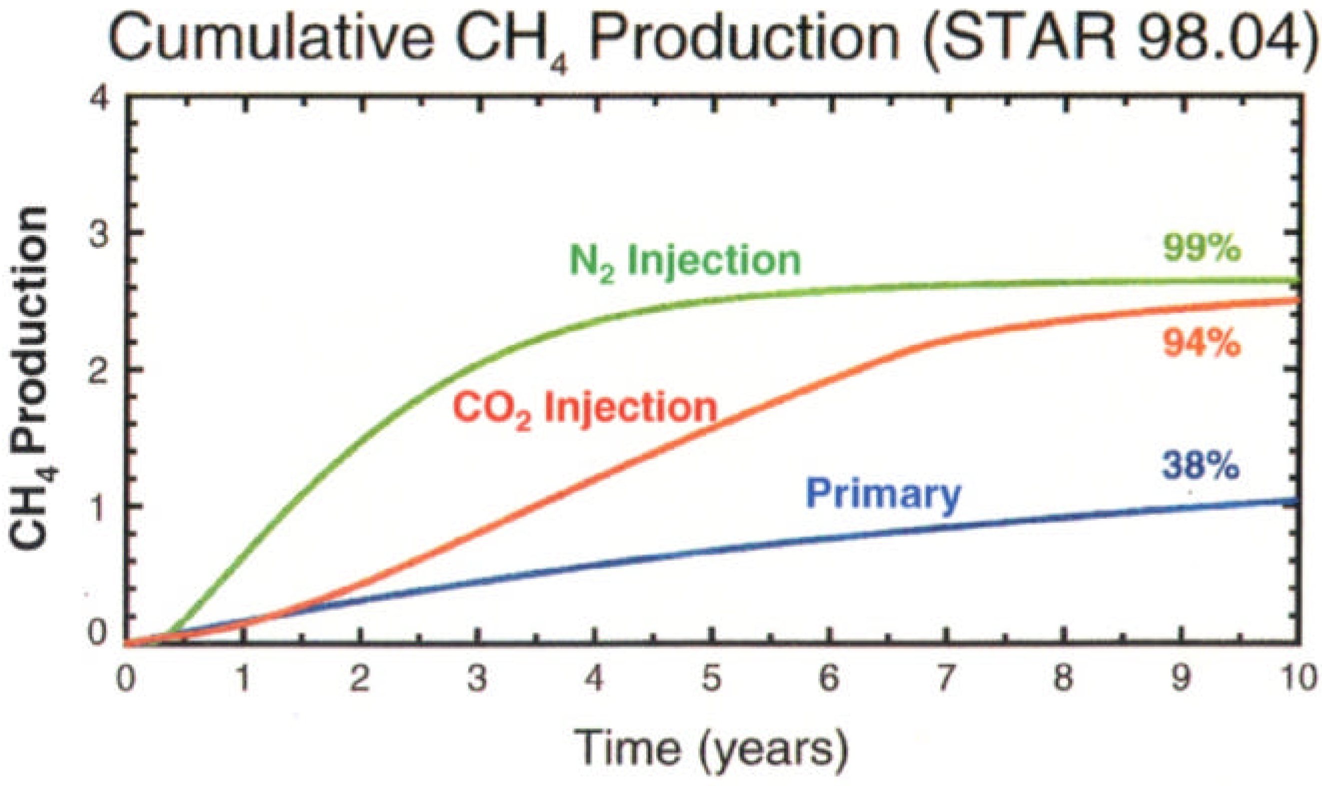
5-Spot Pattern Simulation
CH_4 Production Rate



5-Spot Pattern Simulation

CH_4 Recovery



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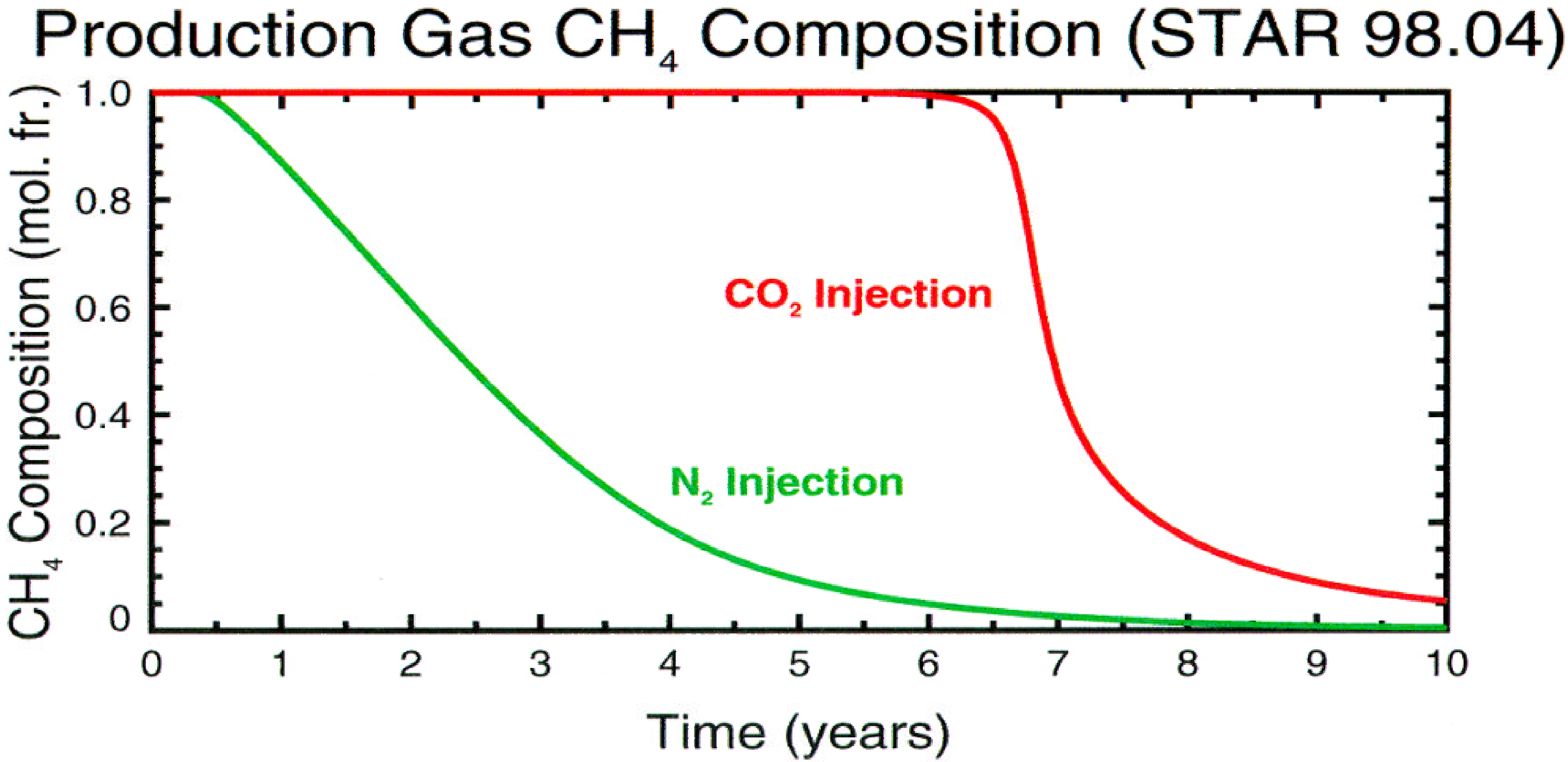
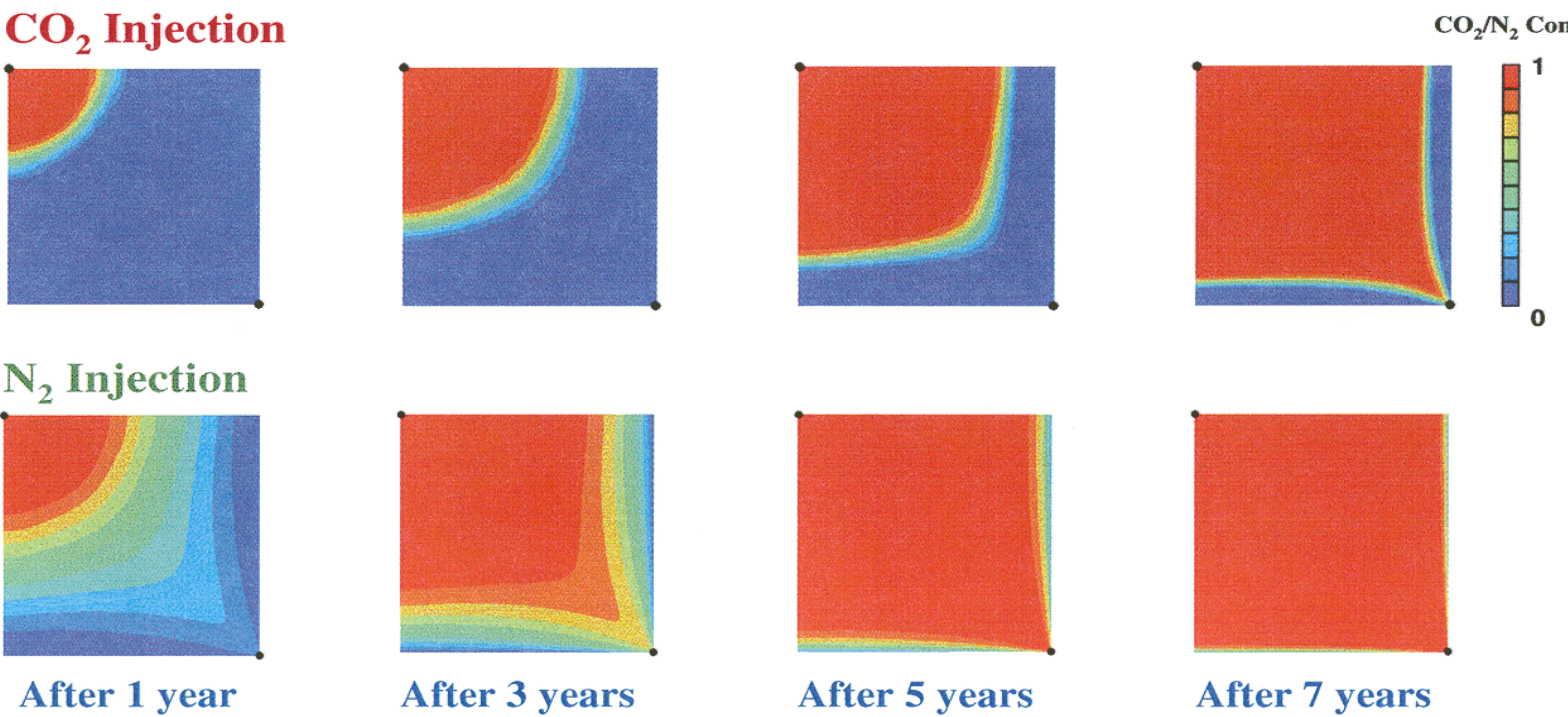
5-Spot Pattern Simulation

Production Gas Composition



Numerical Modelling
CBM Recovery Processes in 5-Spot Pattern



¼ of 5-Spot Pattern

Constant Injection Rate

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N_2-ECBM Recovery Process

- Increases diffusion rate of hydrocarbon gases from coal matrix into natural fractures
- Pressurizes fracture system, increasing well deliverability
- Nitrogen breaks through at production wells
- "Rakes" hydrocarbons from the coal

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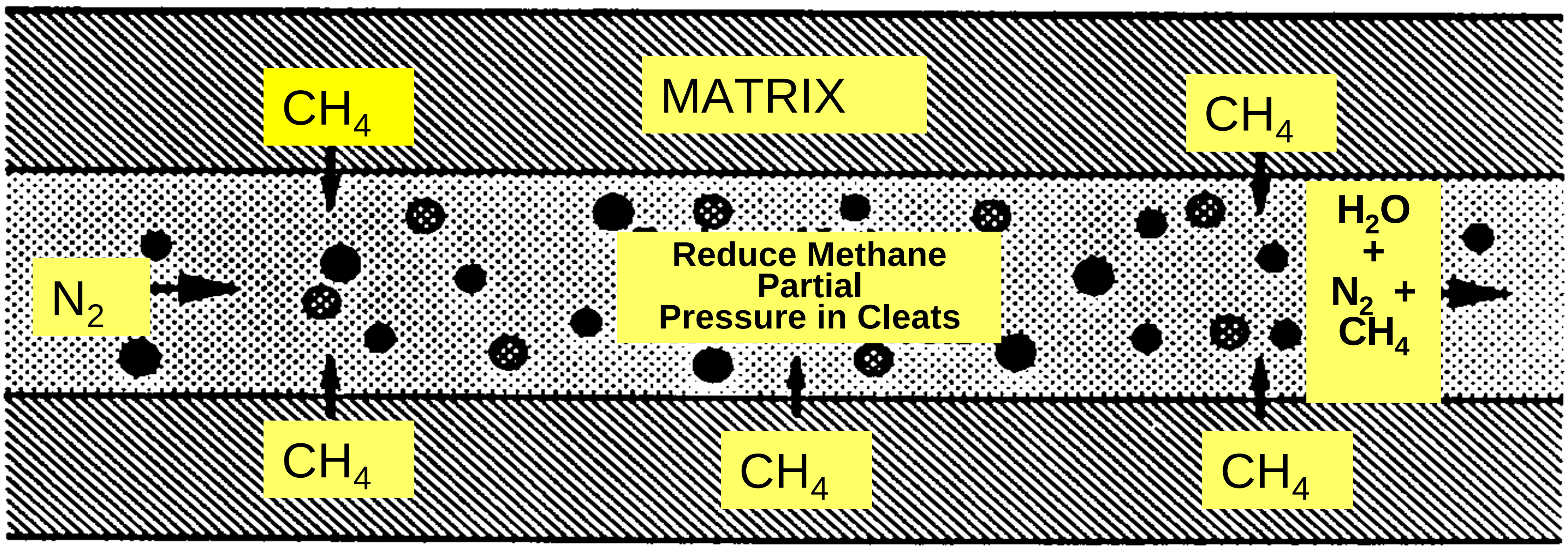
N_2 - Enhanced Coalbed Methane Recovery Mechanism

- **Inject Nitrogen in Cleats**
- **Keep Total Cleat Pressure High**
- **Reduce Partial Pressure of Methane**
- **Methane Desorbs from Matrix and Diffuses to Cleats**
- **Methane and Nitrogen & Water Flow to Wellbore**



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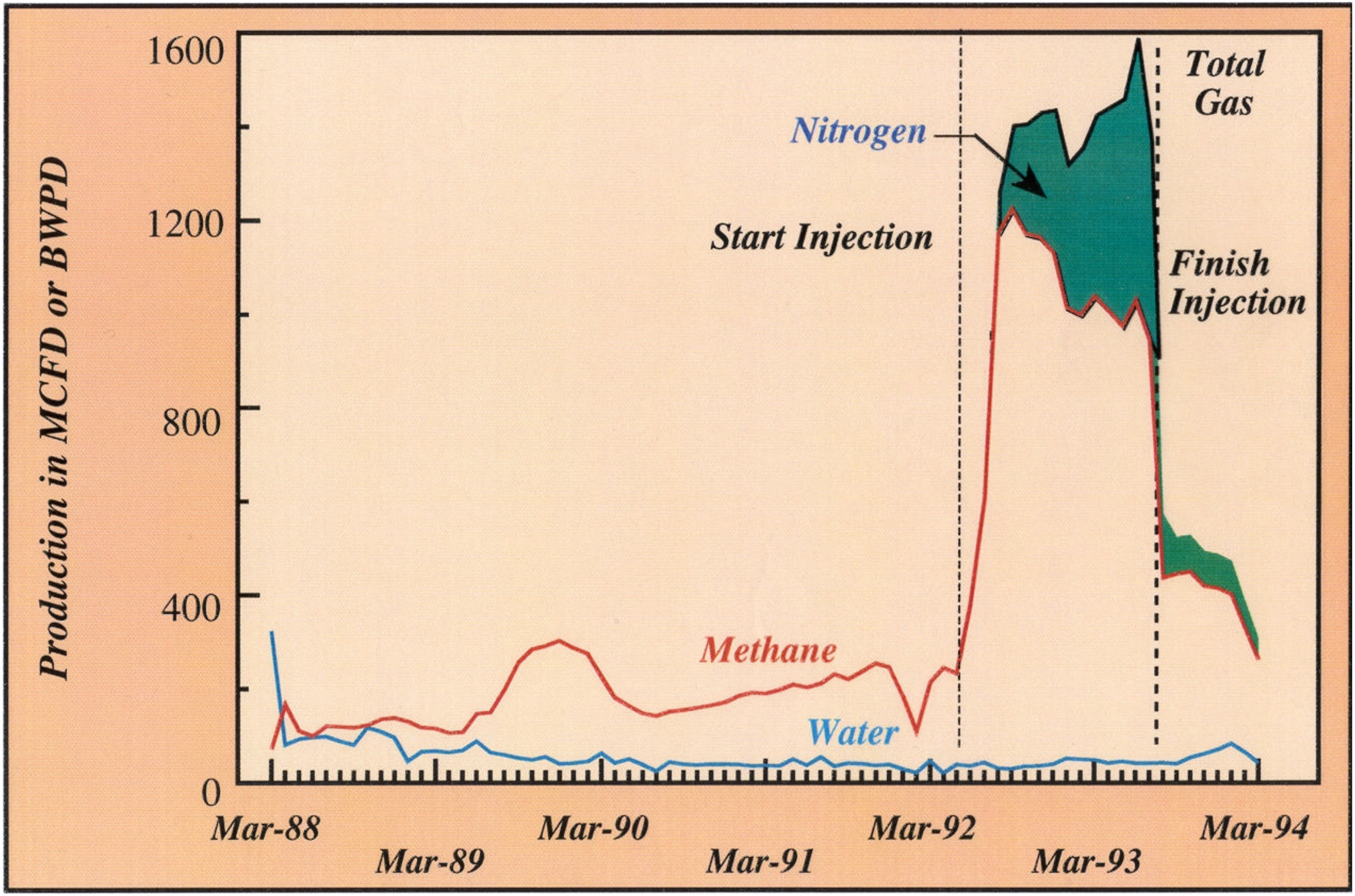
Amoco N_2 Field Pilot Performance



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Coalbed Methane - CO_2 Project

PHASES	YEAR	
I	1997	Proof of Concept for Alberta
II	1998	Single Well CO_2 Micropilot
III-A	1999	Single Well Flue Gas Micropilot
III-A	2000	Drill Shallow Coals <500 meters
III-B	2001	5-Spot Enhanced CBM Production
III-B	2002	Experimental O_2/CO_2 Recycle Power Plant
1998 -	2003	Targeting of Best CBM Reservoirs

In Deep C
>1000 met

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Figure 6. Pilot Project Surface Facility Layout.

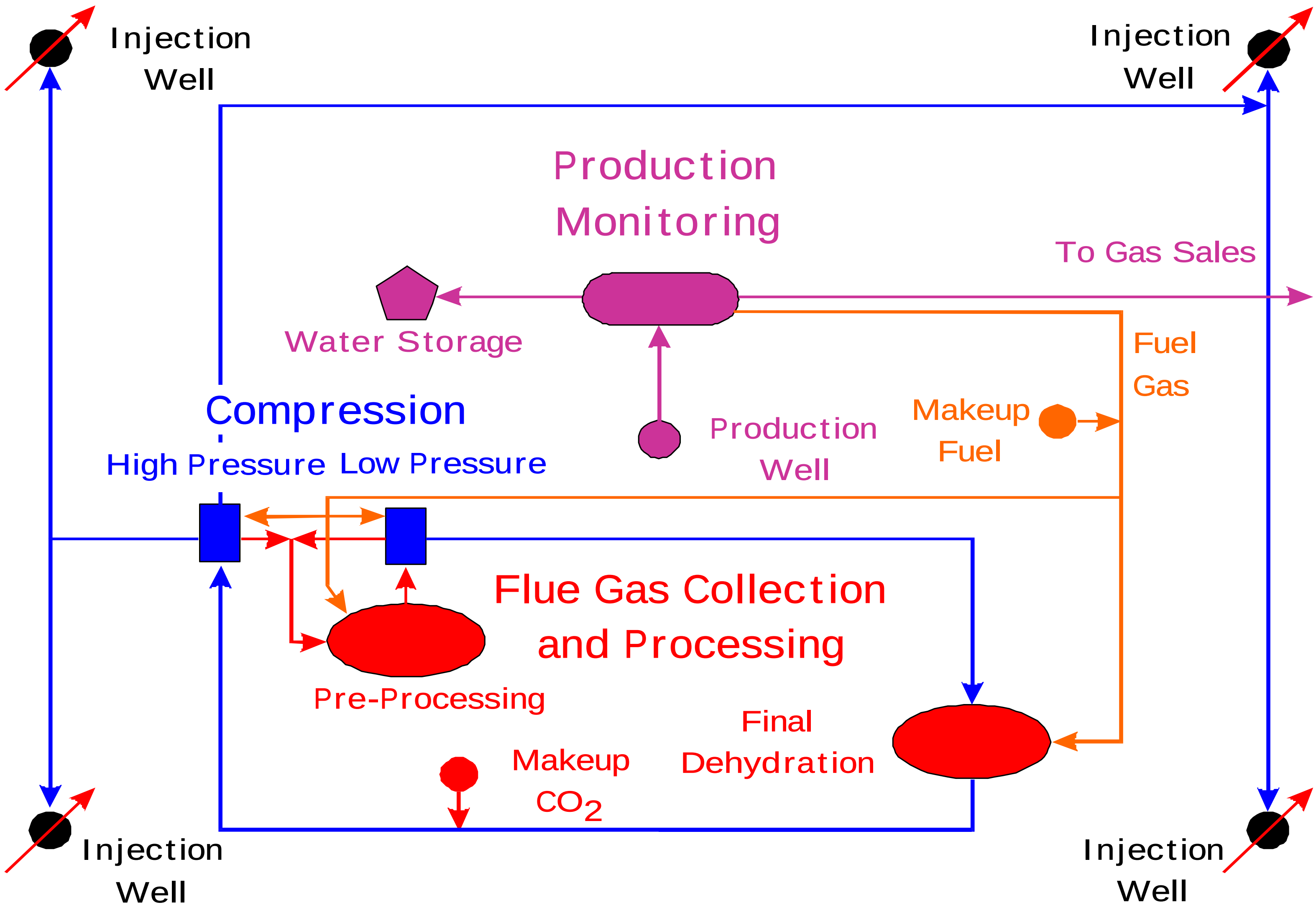

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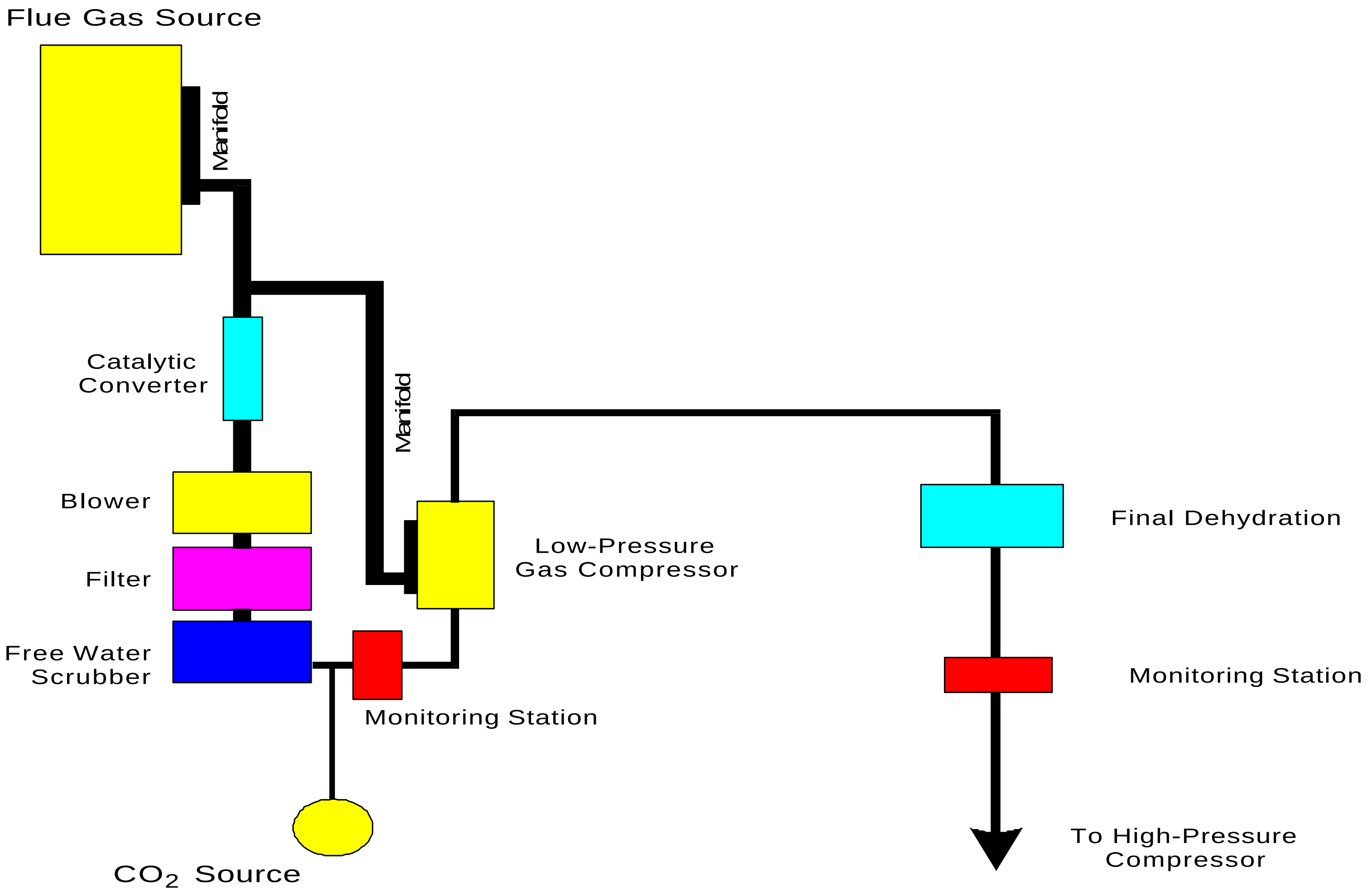
Figure 5. Conceptual Flue Gas Collection System



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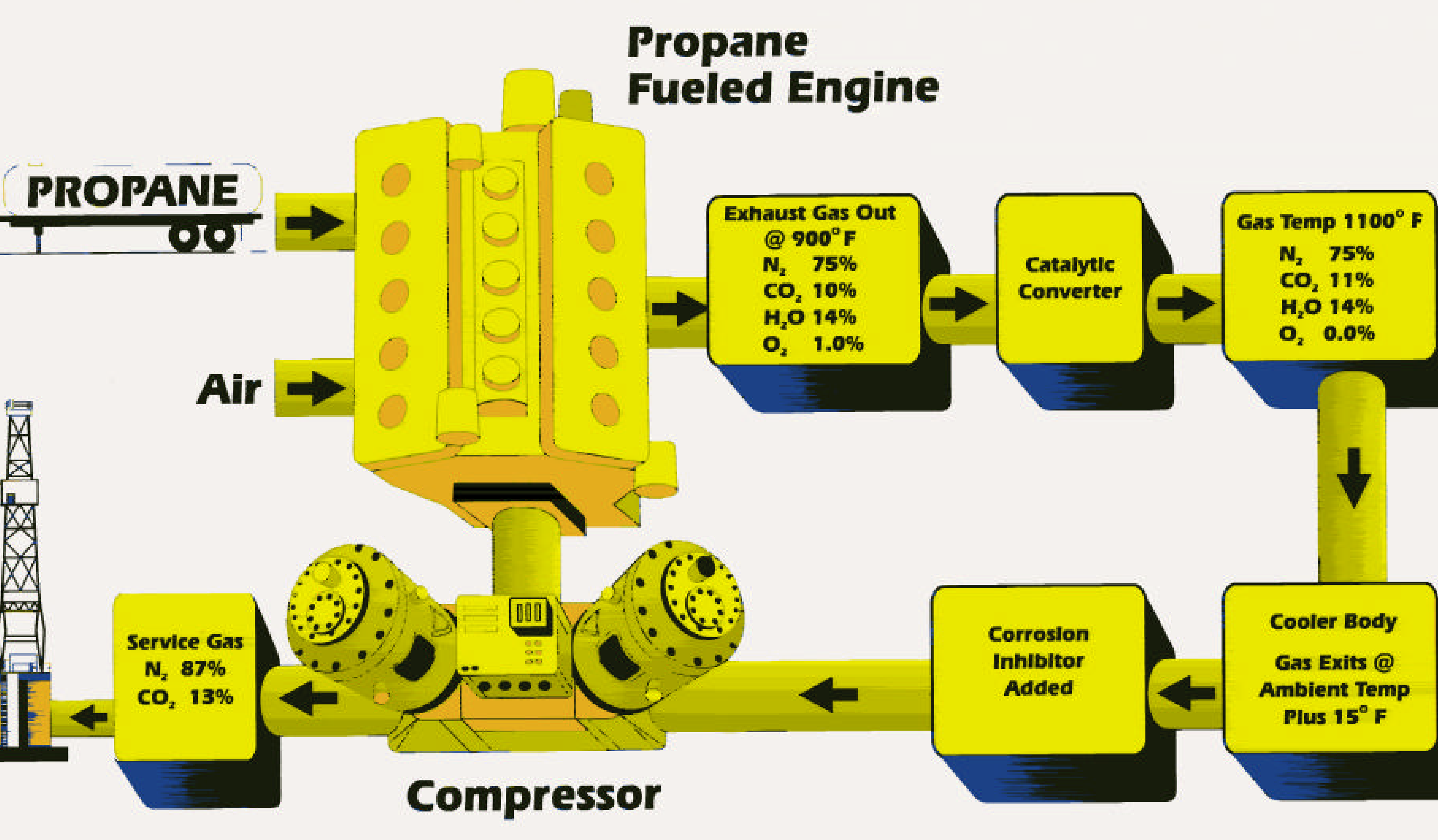
Northland Flue Gas Drilling Unit General Schematic



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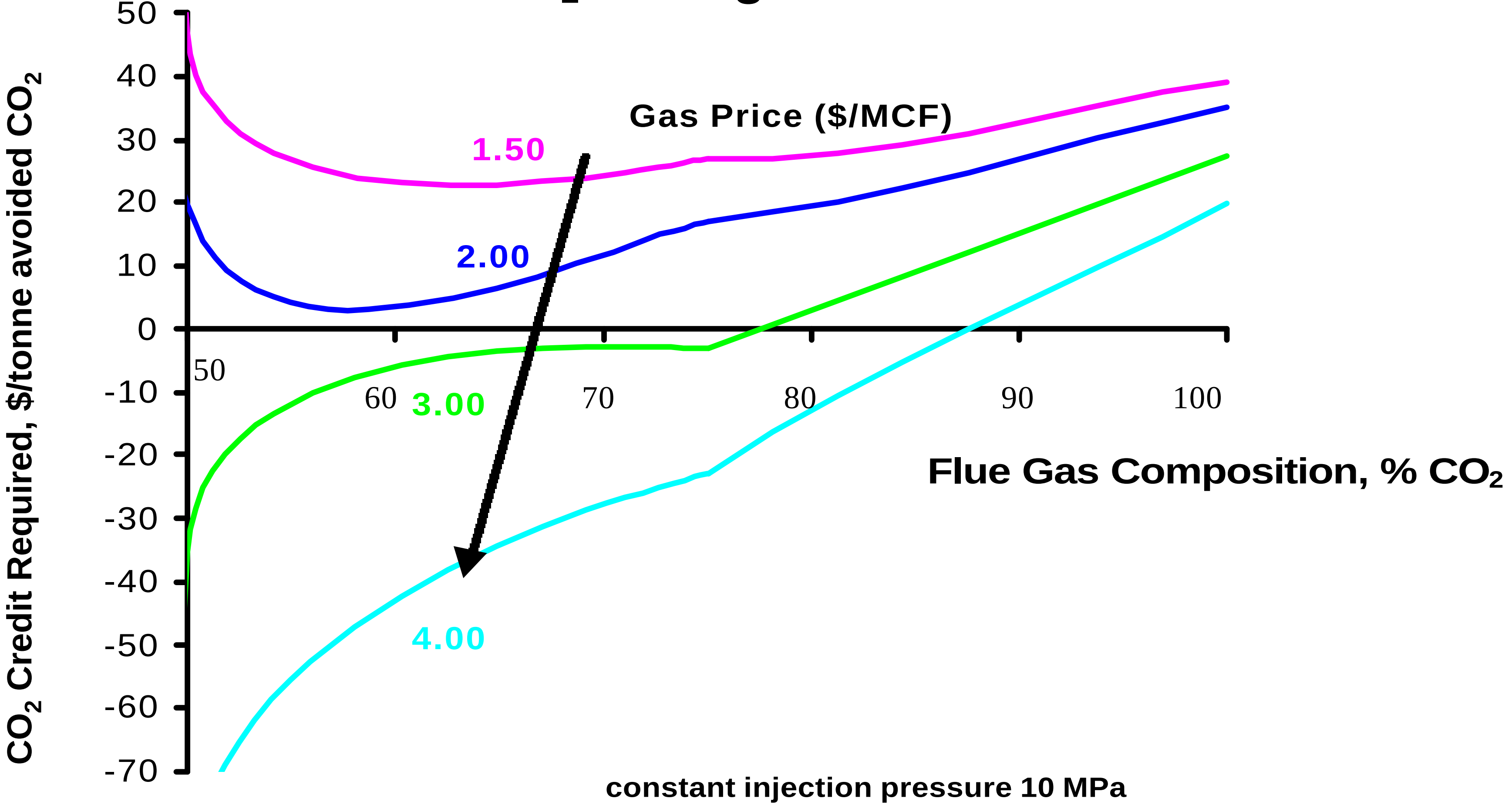
Economics of CO_2 Storage From Flue Gas



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Summary

- US produces 1 TCF of CBM annually
- Alberta has an abundant CBM resource
- No commercial production of CBM in Canada to date due to low permeabilities encountered
- Compared to EOR, ECBM does not require pure CO_2
- Injections of CO_2-rich gases into CBM reservoirs could significantly enhance recovery while stripping out CO_2, a GHG
- ECBM technology is at an embryonic stage of development but shows commercial potential

Future Goals

Describe Alberta's CBM and unconventional gas resources

Improve reservoir simulator for ECBM

Measure CBM reservoir response to CO_2-enriched flue gas injection

Quantify costs of CO_2-enrichment of industrial CO_2 waste streams

Demonstration consisting of a 5 spot CO_2 -ECBM pilot in Alberta

Benefits

- A synergy between an increased supply of fossil fuel and decreased greenhouse gas emission is established using the EGR process
- Recovering CBM will lead to increased total gas reserves
- Recovered methane can be used as fuel for power plants. Alternatively, the gas can be sold for profit, leaving coal again as the fuel of choice for power plants
- The use of CBM and disposal of the waste CO_2 in deep geologic sinks leads to reduction in CO_2, the major culprit of global warming and long term climate instability