Coalbed Methane Issues in U.S. Northern Rockies and Canada

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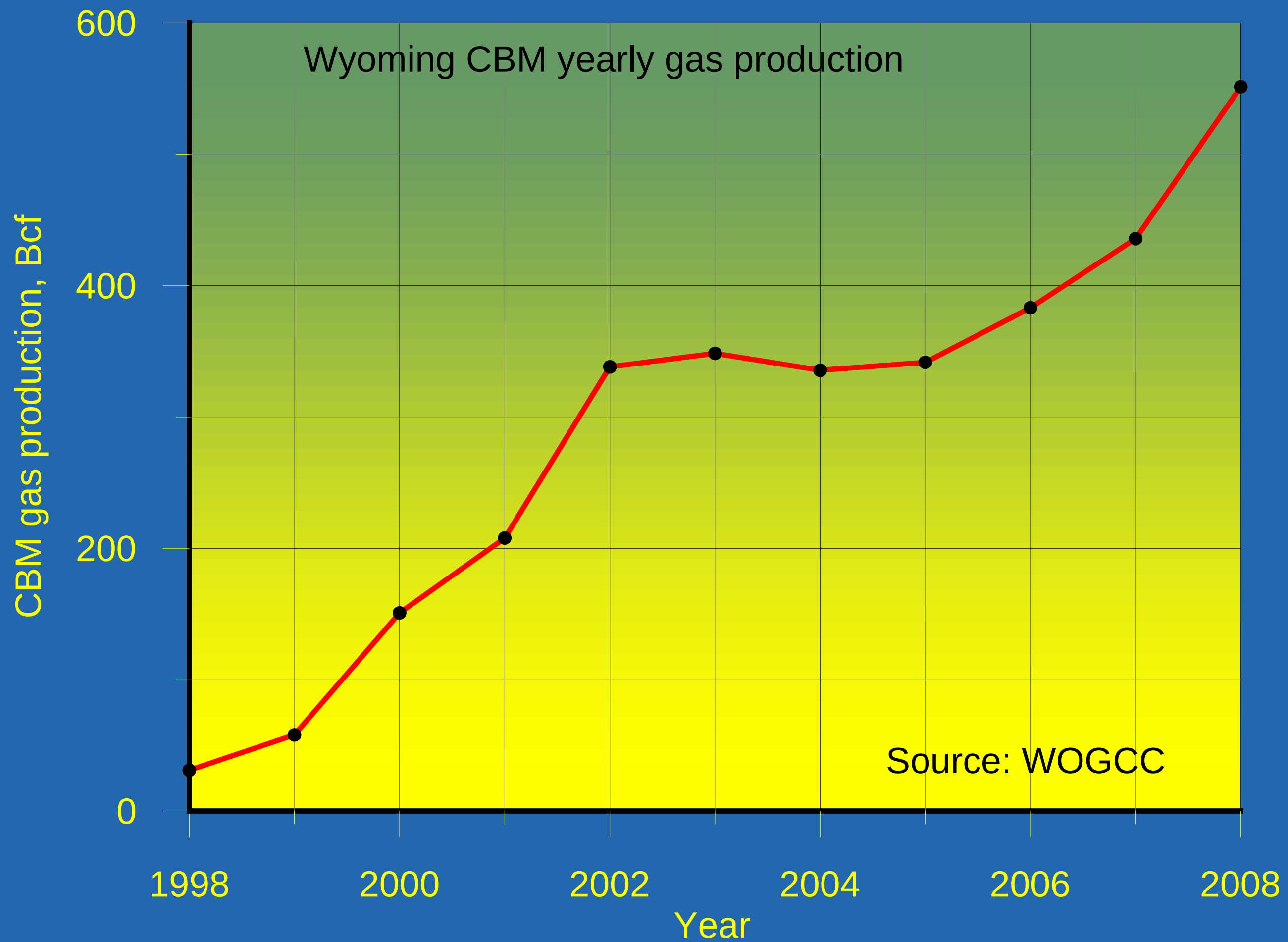
CBM Background

- CBM in US: 6 Bcf/D or 10% of the total U.S. production
- Worldwide CBM reserves: between 3500 Tcf and 9500 Tcf
  - Total world consumption = 100 Tcf/yr
  - Provide between 35 and 95 years of current total world natural gas needs

U.S. Northern Rockies

- CBM dominated by Powder River Basin in Wyoming
  - 98% of CBM production in Wyoming is from PRB
  - About 29,000 wells drilled
    - 21,000 producing
    - 8,000 shut in
      - 51% of shut in wells waiting for infrastructure installation

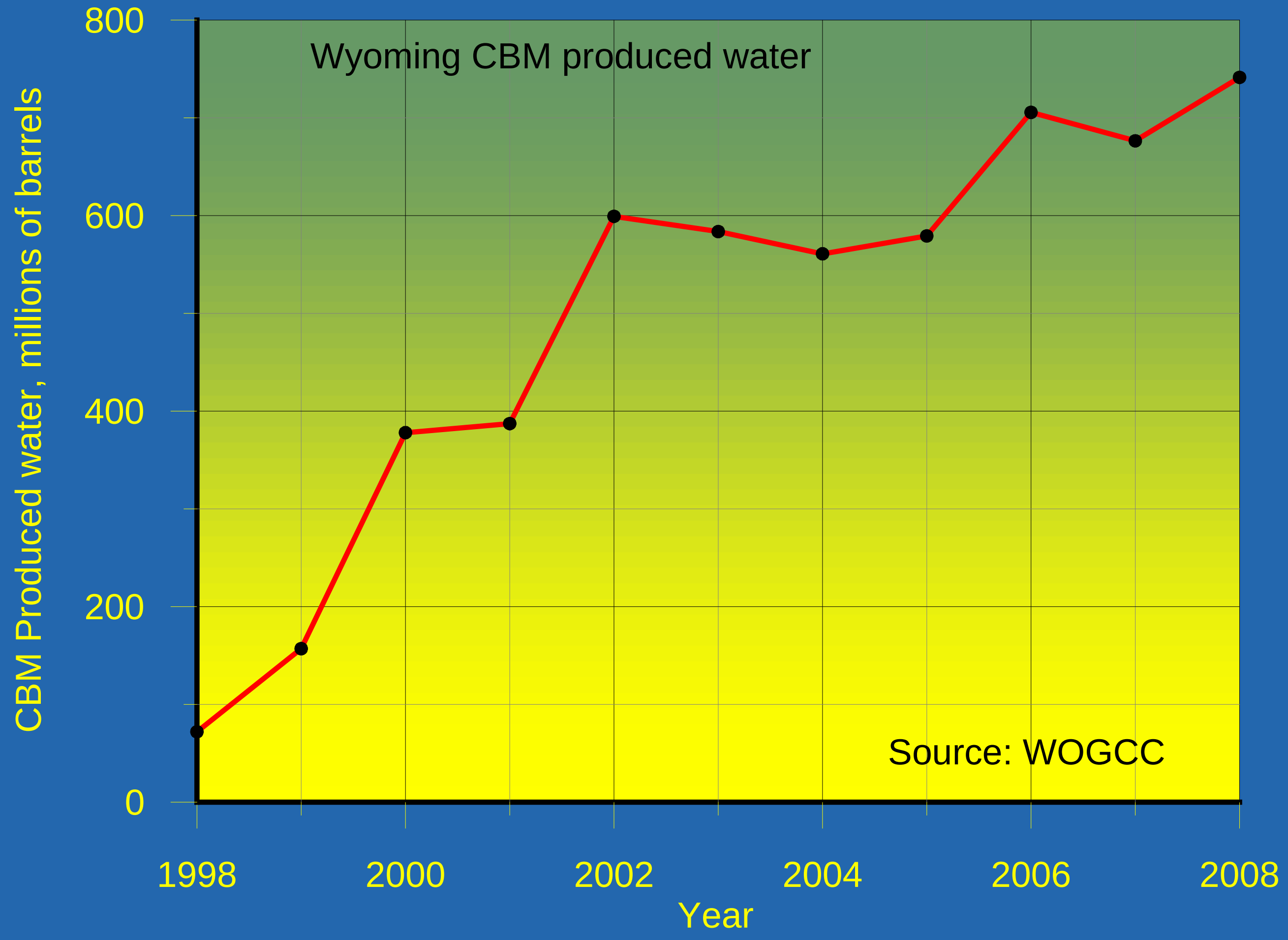
Wyo CBM Gas Production



~10% of U.S. daily CBM production

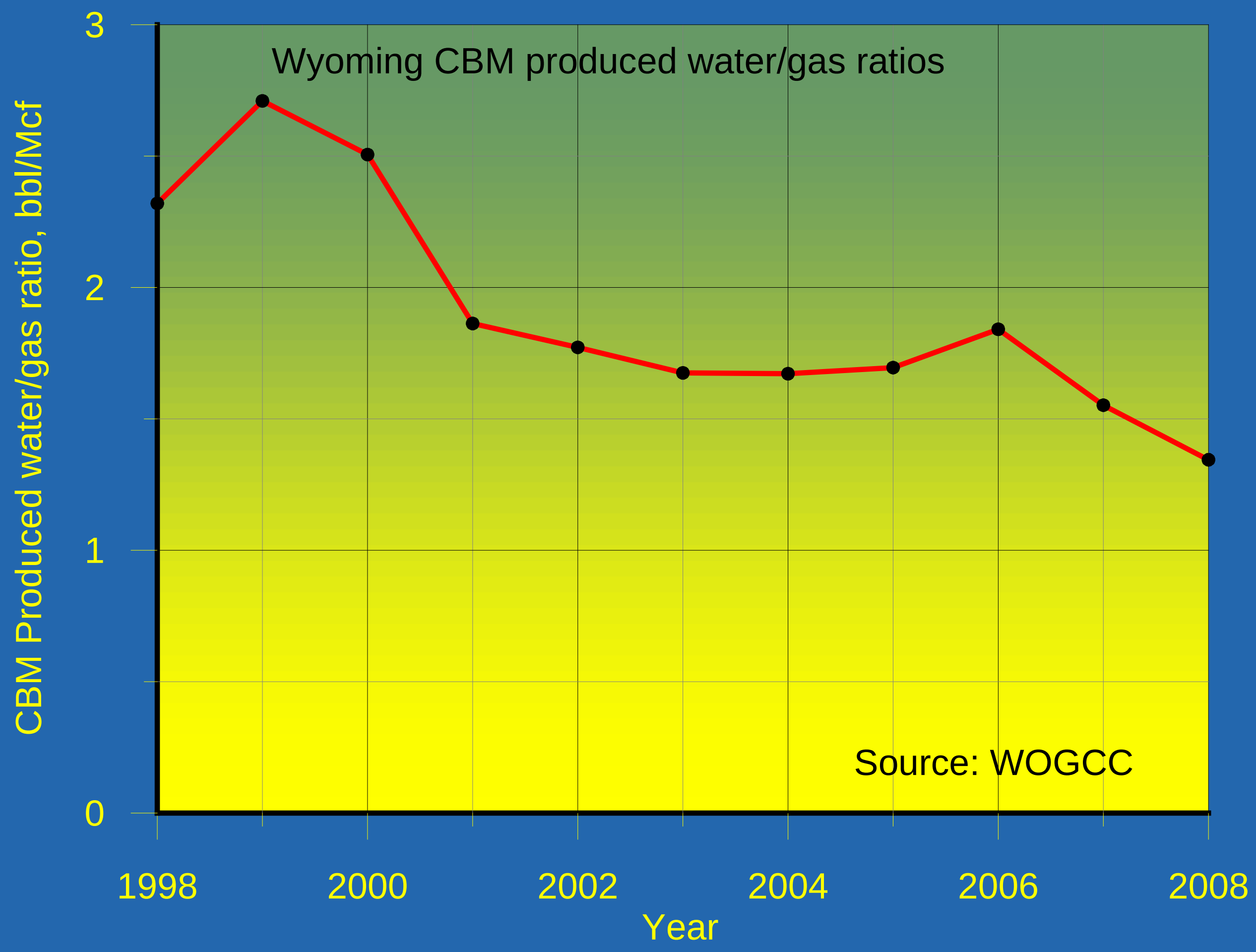
3.2 Tcf total gas produced

Wyo CBM Produced Water



6 billion barrels total

Wyo CBM Water/Gas Ratio



PRB CBM Produced Water Disposition

- 56% (300 million barrels) discharged down ephemeral and perennial drainages
  - 11% is treated
- 31% (170 million barrels) contained in off-channel pits
  - 6% used in irrigation projects (soil amendments usually needed)
- 13% (72 million barrels) re-injected into class II and V wells

CBM Water in Montana

- Water production in 2007 was 39.4 million barrels
  - 7% of Wyoming's production
  - 35% was treated and discharged to surface

U.S. Northern Rockies

- Biggest public issue: Produced Water
  - How much will be removed?
  - How much will be discharged to surface?
  - What is its quality?
  - How will surface discharge affect current surface water?

Produced Water Issues

- Treatment technology has been developed
  - D. Lamb of the Wyoming DEQ: “There are a lot of different technologies – and in all honesty, they are existing technologies – that are being reoriented to this specific area”
  - Reverse osmosis and ion exchange are common
- A political and cost issue
  - At heart of lawsuit between Montana and Wyoming
  - Cost is prohibitive to widespread implementation
    - $0.50/bbl to $1.00/bbl of water

CBM in Canada

- Total CBM in-place resource in Alberta is estimated to be 500 Tcf
- Major plays
  - Horseshoe Canyon Coals
    - First CBM target
    - Shallow
    - Classified as “dry” coals with very little water production
  - Mannville Coals
    - Deeper than Horseshoe Canyon coal
    - Covers larger area

Other CBM Issues

- Permeability changes and reservoir simulation
  - Sorption-induced swelling/shrinkage
- Completions
  - Drilling fluids
  - Multi-zone completions

Permeability Models

- Models for field conditions
  - Palmer & Mansoori
  - Shi & Durucan
  - ARI model
  - CMG model
- Models for laboratory conditions
  - Robertson & Christiansen

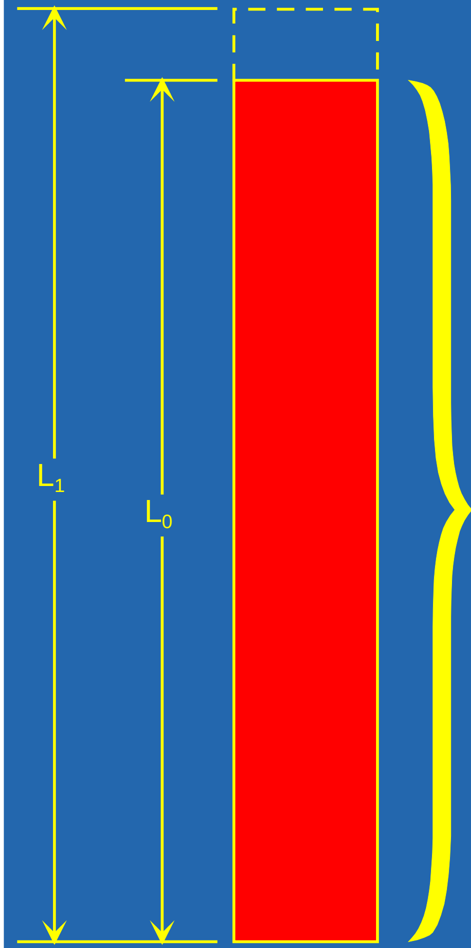
Is Sorption-Induced Strain Important?

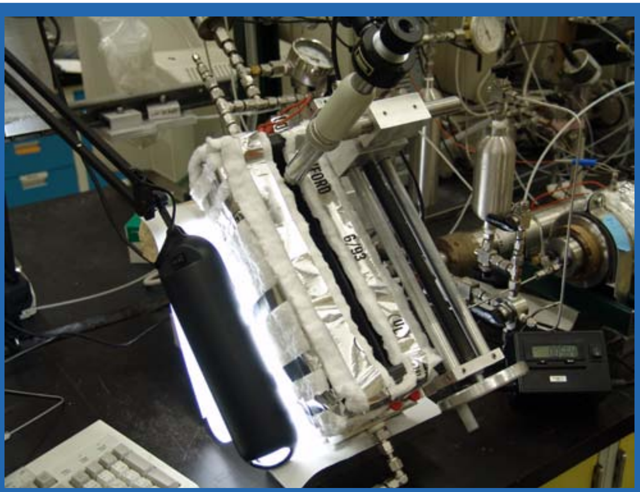
- What is sorption-induced strain ($S_{s\text{-}i}$)?
  - Strain, $S = \frac{\Delta V}{V}$
  - Swelling or shrinkage caused by gas desorption/adsorption
- Permeability is strong function of $S_{s\text{-}i}$
- As much as 90% of the change in reservoir permeability may be due to sorption-induced strain

INL progress on S-I Strain and Permeability in Coal

- Sorption-induced strain
- Strain-pressure curve
- Coal permeability model

Direct Optical Measurement of Strain





=3/4” or 2 cm

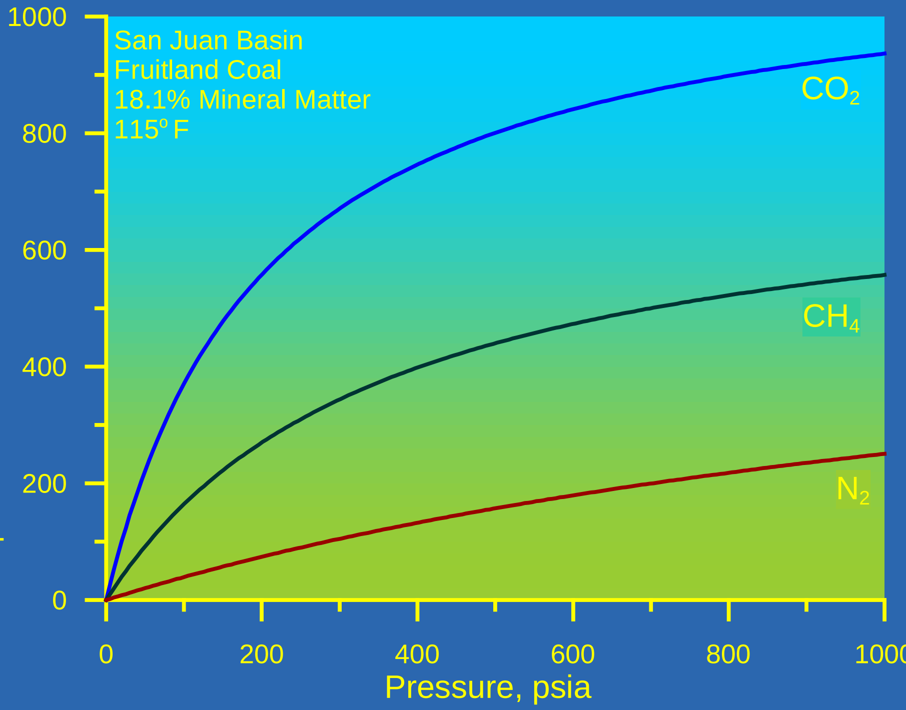
$$Strain = \frac{L_1 - L_0}{L_0}$$

- **Easy to collect**
- **Small samples w/o cleats**
- **Measured while in pressure cell with optical port**

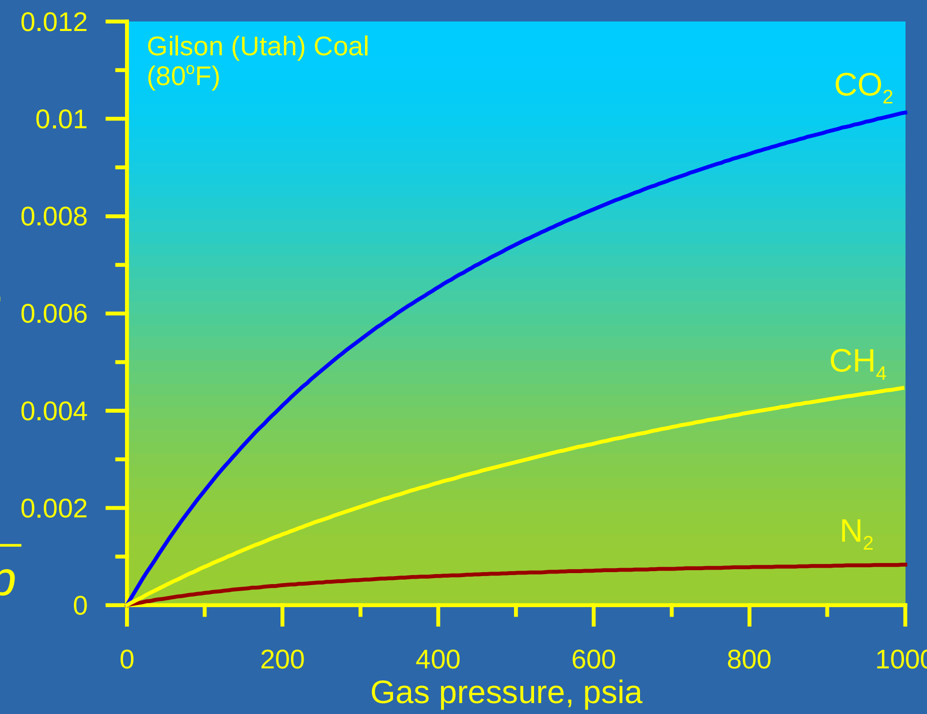
Similarity between

- **Sorption isotherms and**
- **Sorption-induced strain**
- **Both modeled using Langmuir-type equations**

$$q = \frac{q_s p}{b + p}$$

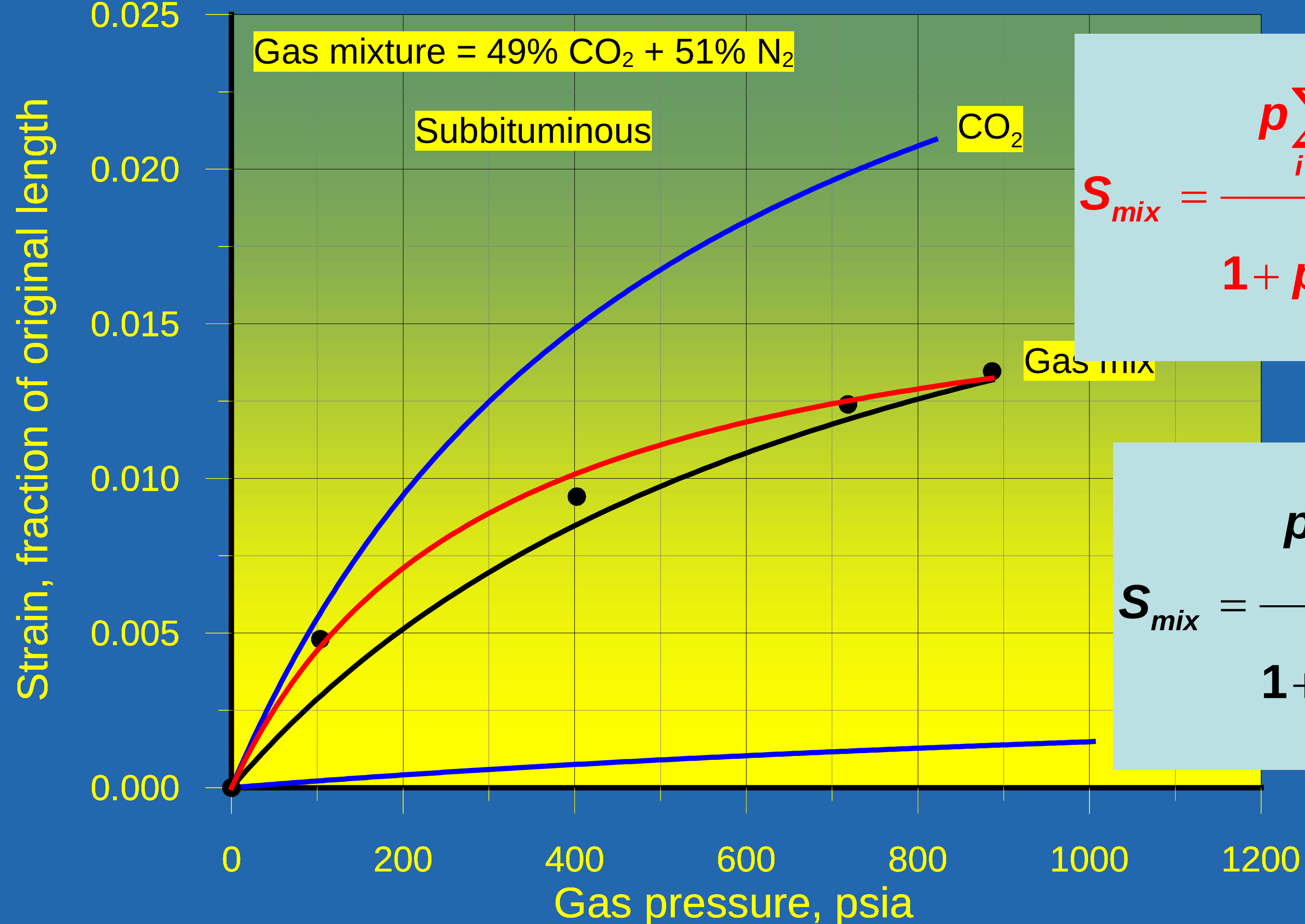


$$C_m = \frac{V_L p}{p_L + p}$$



$$S = \frac{S_L p}{p_{SL} + p}$$

Strain Measurements and Modeling for Gas Mixtures



$$S_{mix} = \frac{p\sum_{i=1}^{n}\left(\frac{S_{L_i} y_i}{\eta_i p_{S_{L_i}}}\right)}{1 + p\sum_{i=1}^{n}\left(\frac{y_i}{\eta_i p_{S_{L_i}}}\right)},$$

$$S_{mix} = \frac{p\sum_{i=1}^{n}\left(\frac{S_{L_i} y_i}{p_{S_{L_i}}}\right)}{1 + p\sum_{i=1}^{n}\left(\frac{y_i}{p_{S_{L_i}}}\right)},$$

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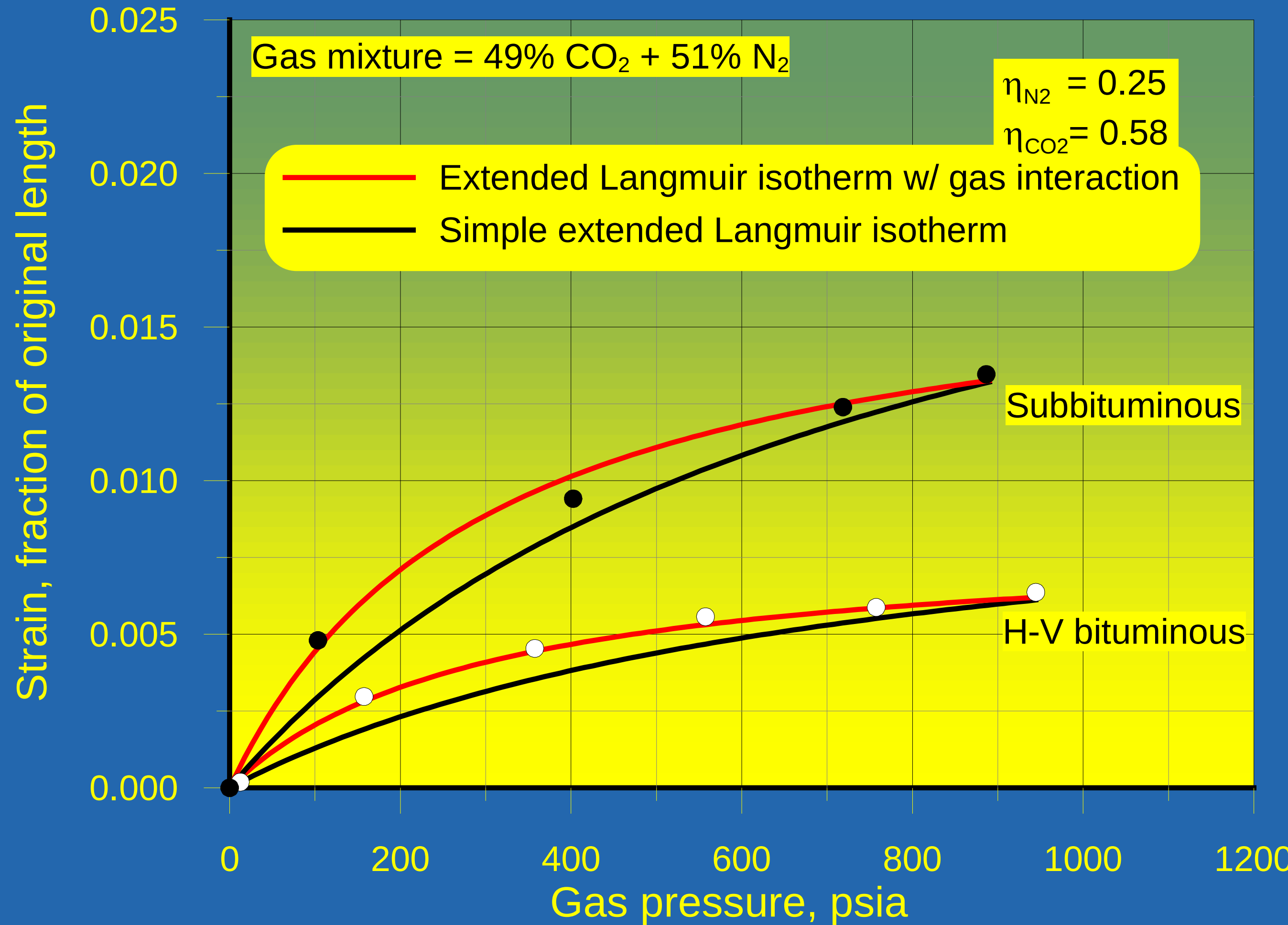
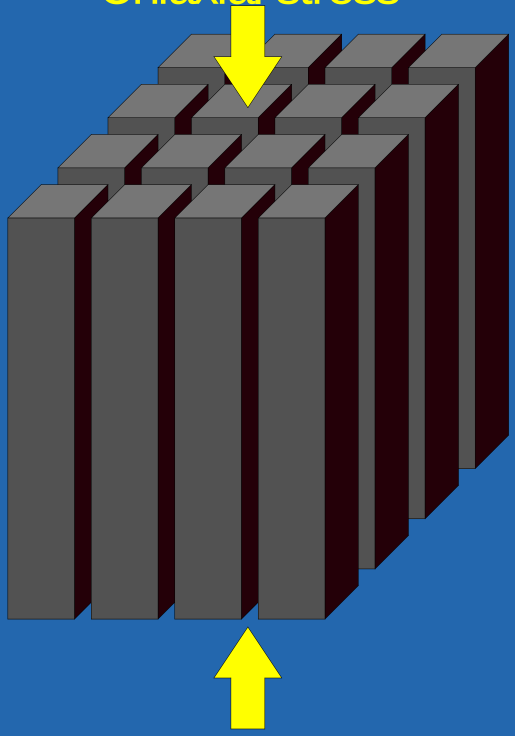


Differences between Field and Lab

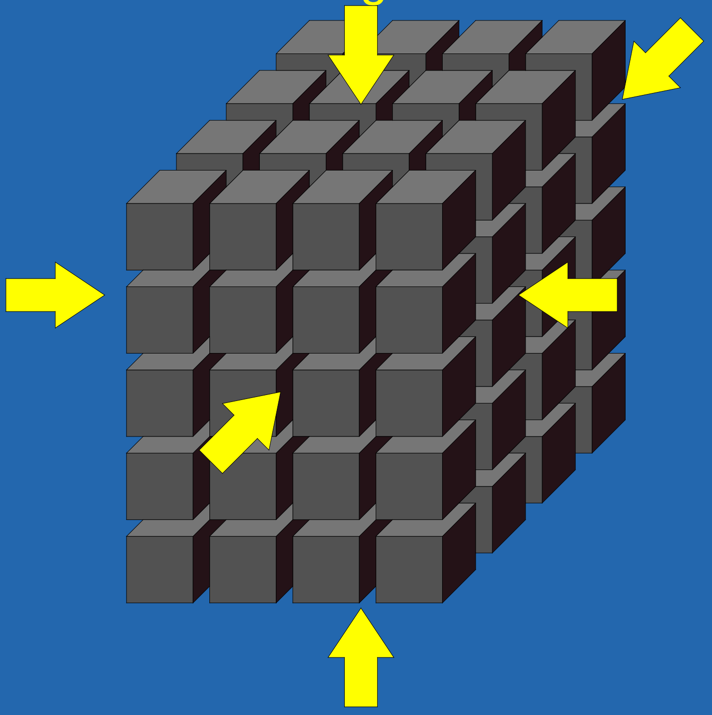
Assumptions of field models

Uniaxial stress



Laboratory conditions

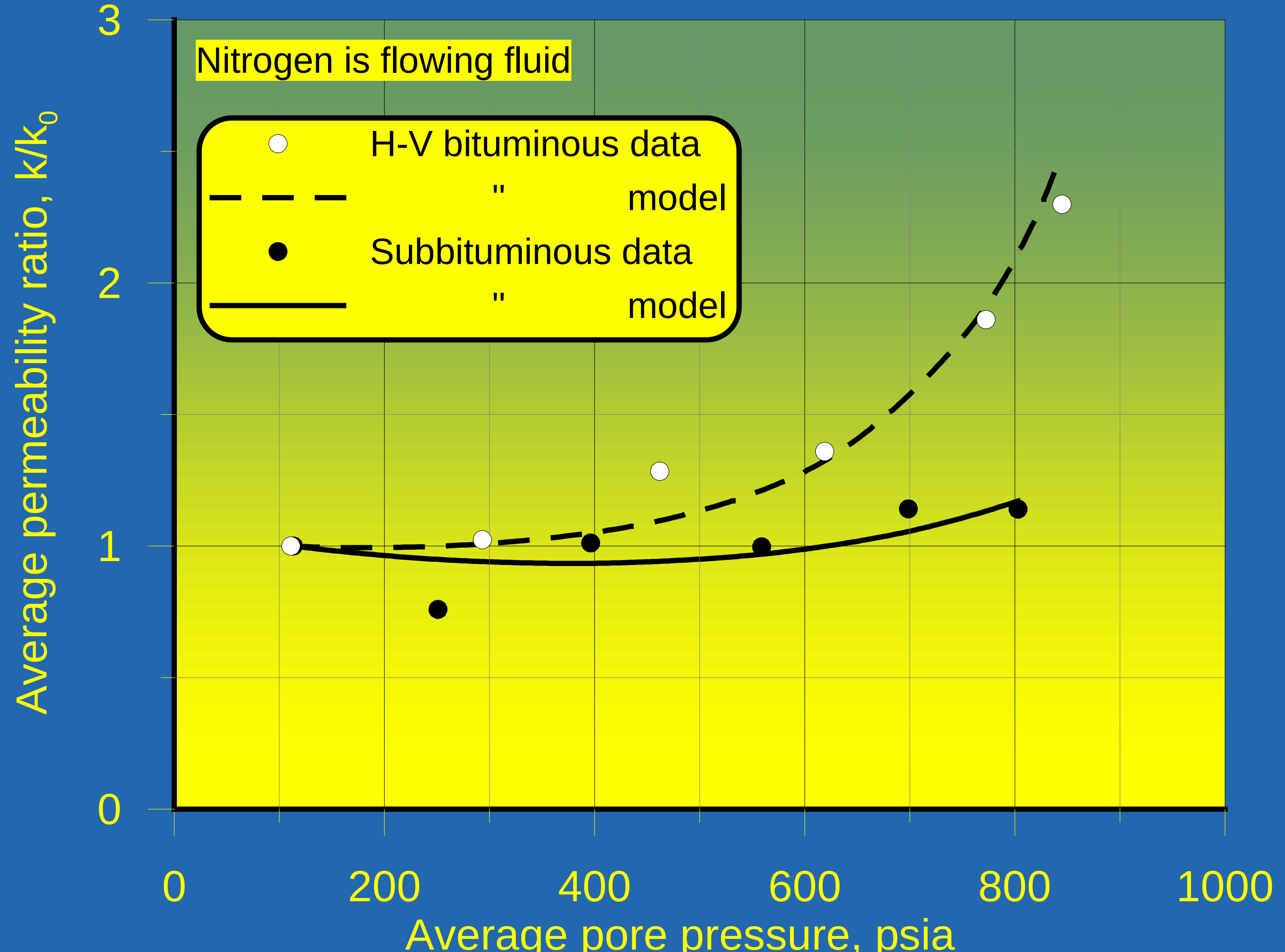
Hydrostatic confining stress



Permeability model

$$\frac{k}{k_0} = \exp\left[\overbrace{3c_0 \frac{1-\exp\left(\alpha \Delta p_p\right)}{-\alpha}}^{fracture\,compressibility} + \overbrace{\frac{9}{\phi_0}\frac{\left(1-2\nu\right)}{E}\Delta p_p}^{matrix\,compressibility} \underbrace{-\frac{9}{\phi_0}\frac{S_L p_{S_L}}{\left(p_{S_L}+p_{p_0}\right)}\ln\left(\frac{p_{S_L}+p_p}{p_{S_L}+p_{p_0}}\right)}_{sorption-induced\,strain} \right].$$

Permeability Data and Modeling Results



Permeability Model Uses

- Can model carefully controlled experiments
- Used to determine critical variables in field permeability models
  - Fracture compressibility
  - Young's modulus
  - Poisson's ratio
  - Sorption-induced strain

A Few Research Needs for Coalbed Methane

- Reduce water disposal costs
- Better completion fluids and methods
- More data for permeability models
- Sorption-induced strain on many different coals
- Correlation between gas content isotherm and sorption-induced strain isotherm
- More mixed-gas strain modeling
- Better permeability models

Thank You

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Question and answer time