Stanford University

Global Climate & Energy Project

GCEP Research Symposium

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CO_2 Sequestration and Enhanced Coalbed Methane Recovery

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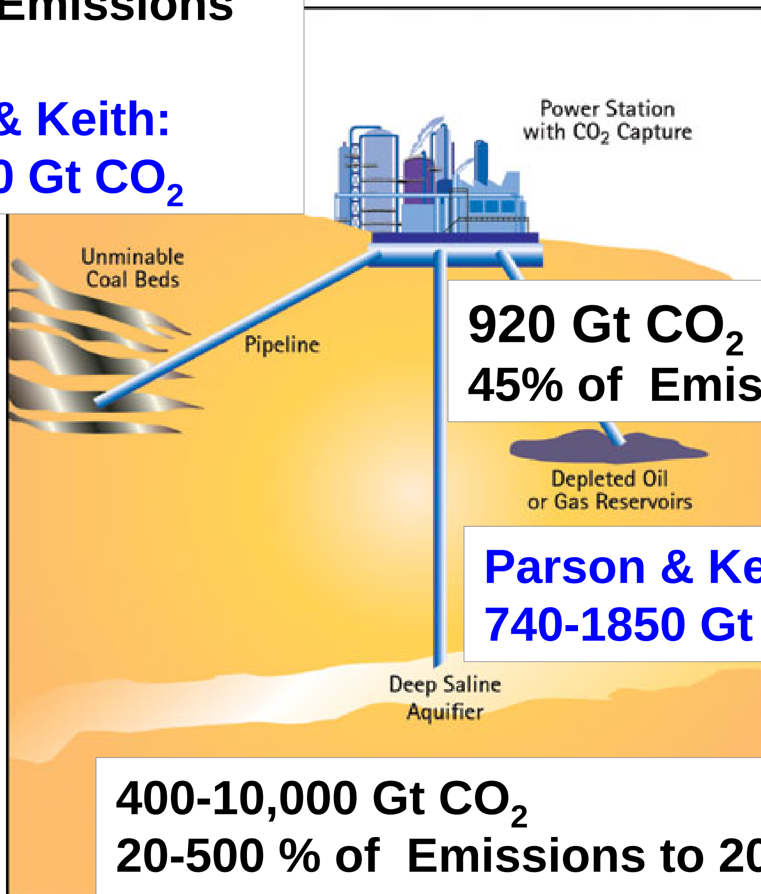
Energy Resources Engineering

Why study coalbeds?

IEA: 40 Gt CO_2
<2% of Emissions to 2050
Parson & Keith: 370-1100 Gt CO_2



920 Gt CO_2
45% of Emissions to 2050

Parson & Keith: 740-1850 Gt CO_2

400-10,000 Gt CO_2
20-500 % of Emissions to 2050
Parson & Keith: 370-3700 Gt CO_2

- **add certainty to volume estimates**
- **store other contaminants**
- **smother fires**
- **significant challenges for monitoring**
- **coal is intrinsically interesting**

IEA: Comparative potentials at storage costs of up to \$20/t CO_2

What are we trying to do?

- Elucidate fundamental mechanisms relevant to enhanced methane production and gas storage in coal because poor predictions result, in part, from incomplete knowledge of physical mechanisms.
- Our niche is our ability to probe simultaneously sorption, transport, and permeability to gas
  - experimentally
  - analytically
  - numerically

Today's Presentation

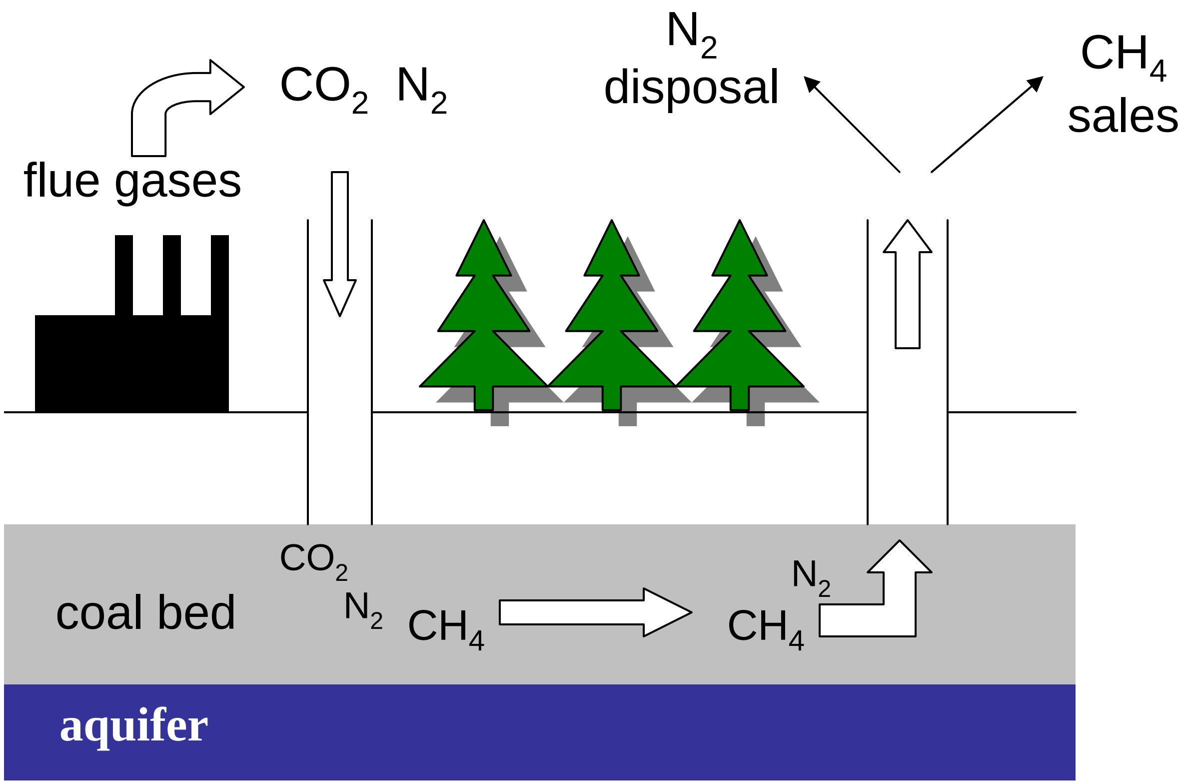


image source: C.J. Seto

- desorption through reduction of partial pressure
- 80-90% recovery of methane

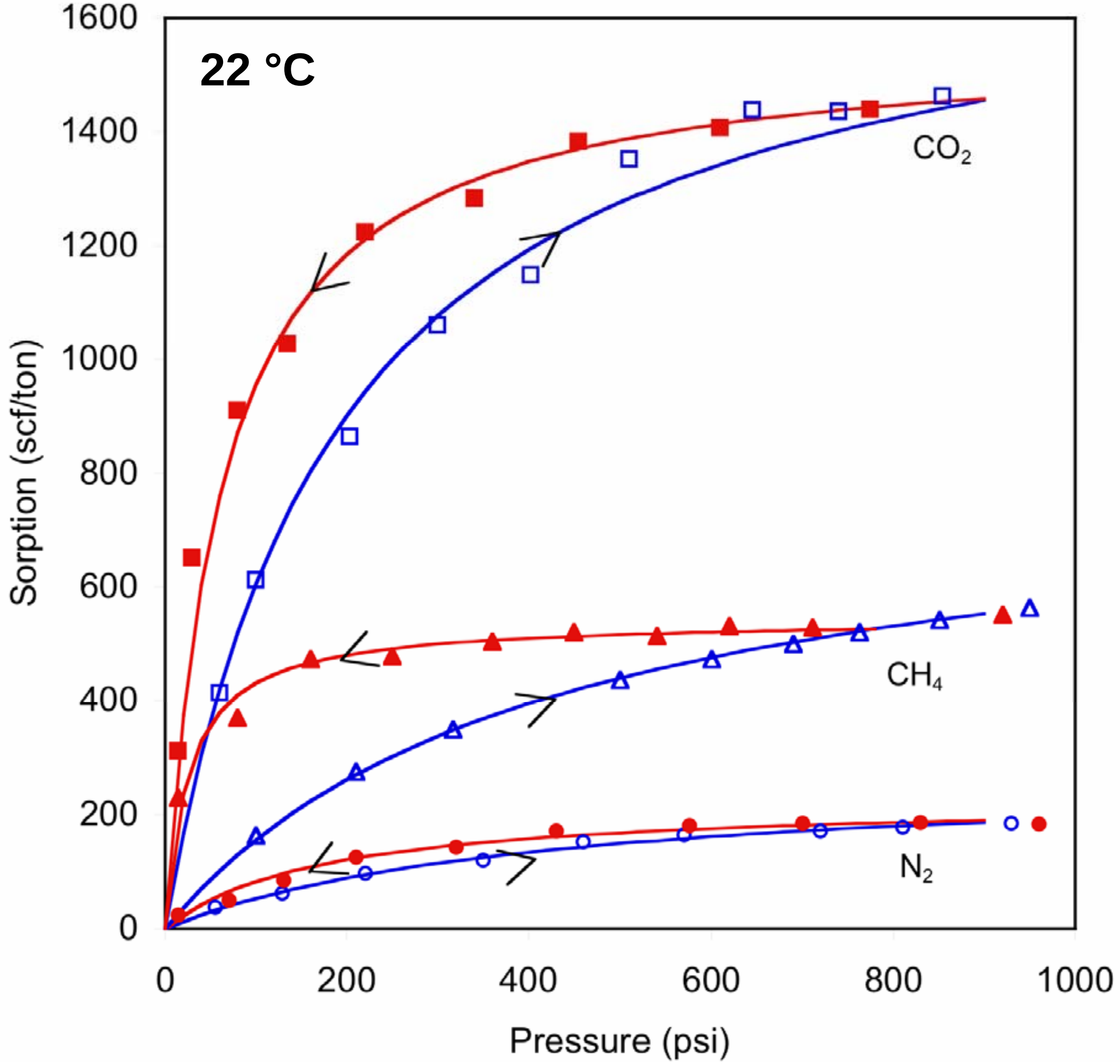
- **How much gas adsorbs on coal?**
- **How do we probe flow mechanisms?**
- **Is coal permeability sensitive to the type of gas?**
- **How does water flow?**

How much gas adsorbs?

CO_2, CH_4, N_2 Sorption

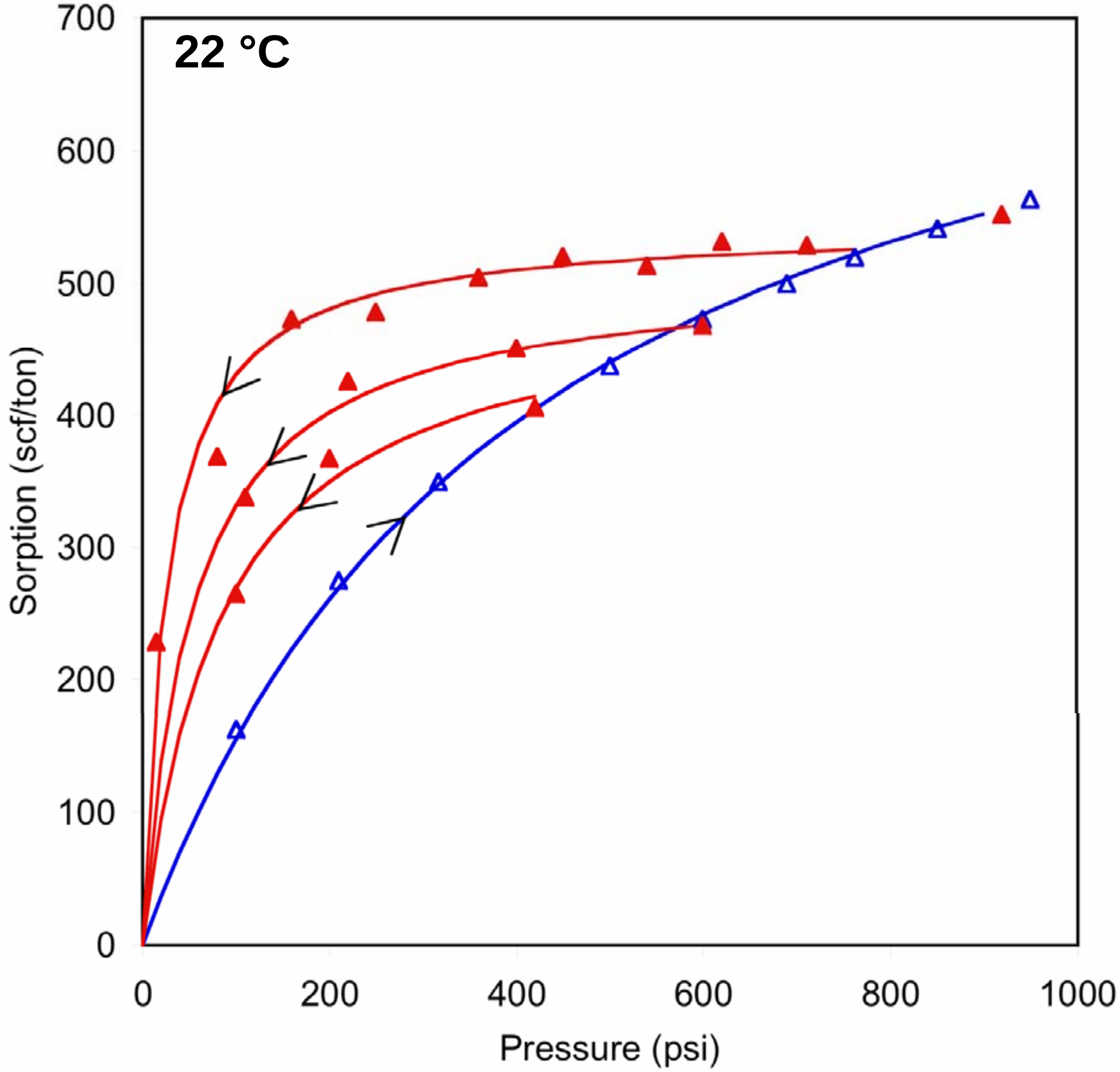
Ground Powder River Basin (WY) Coal

- Pure components are well fit by Langmuir isotherm
- CO_2 adsorbs preferentially
- adsorption hysteresis for all gases

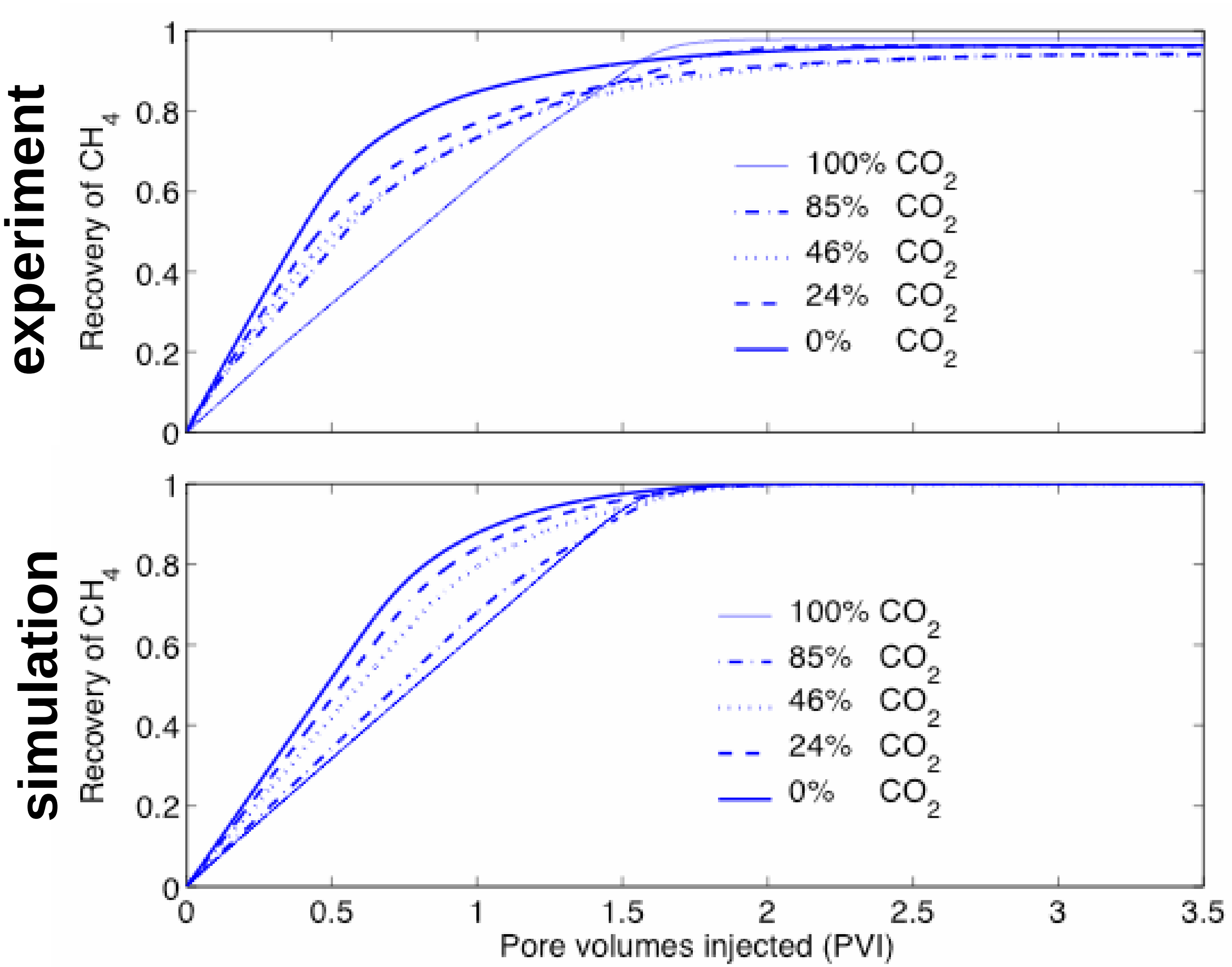


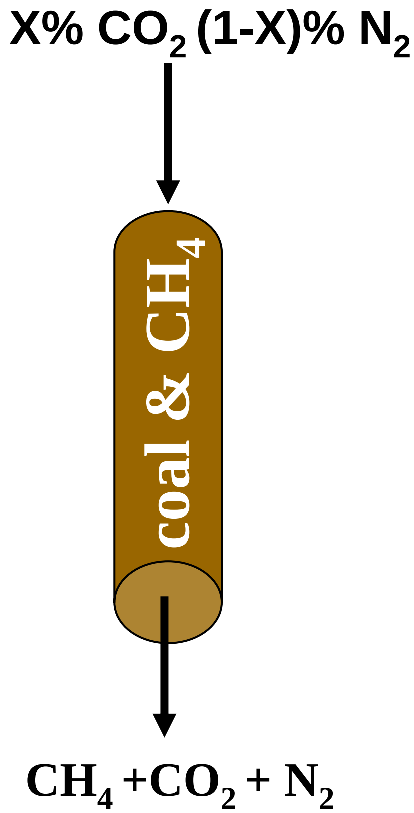
CH_4 Scanning Loops

Initial pressure influences desorption hysteresis



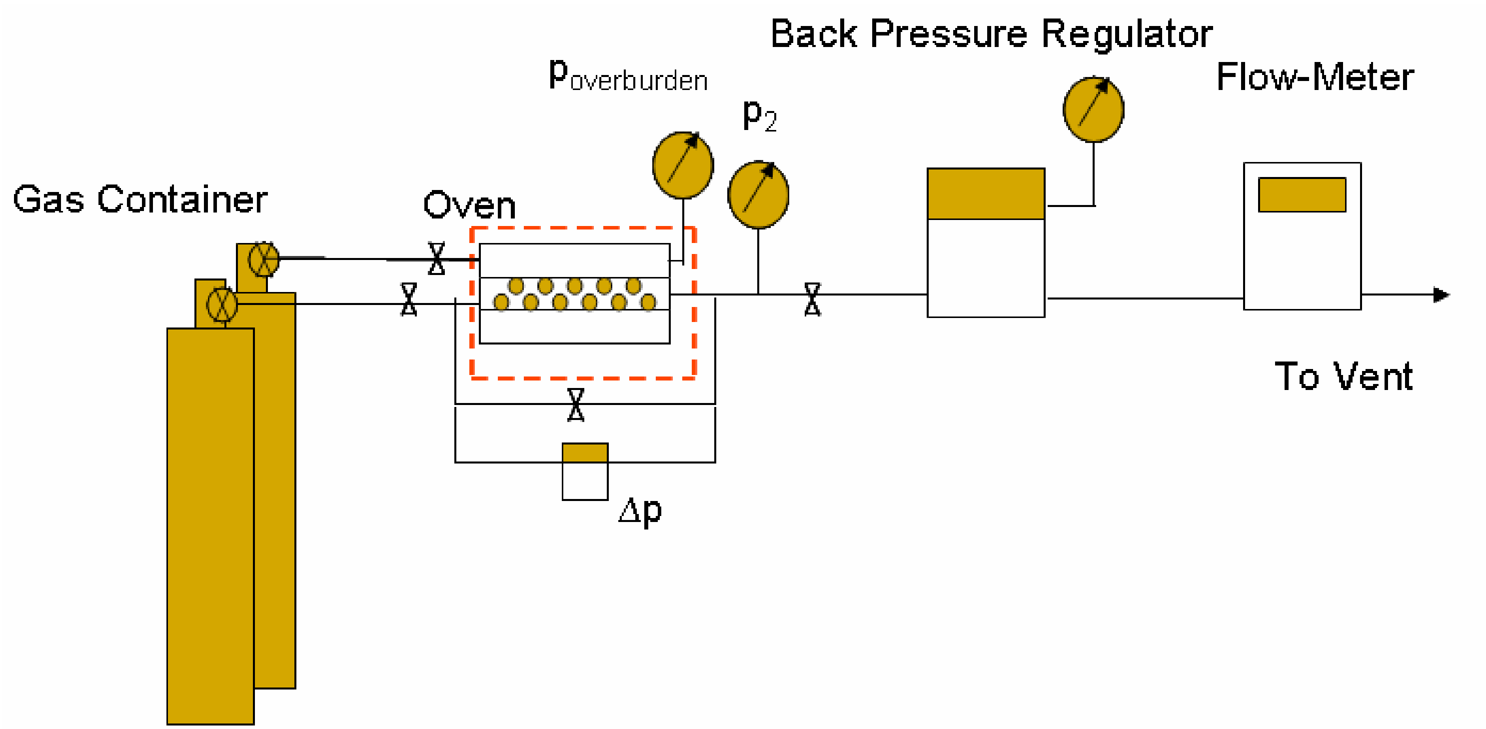
Competitive Adsorption and Recovery





How do we probe mechanisms?

sorption/permeability/gas injection



- **Pore pressure: 60~1100 psi**
- **Net effective stress: 300-400 psi**
- **Gas mixtures made in the lab by weight**

Coal Coring and Processing

Cryogenic versus conventional

PRB coal samples are provided by Montana Bureau of Mines and Geology. The core recovery is less than 2%

Composite Coal

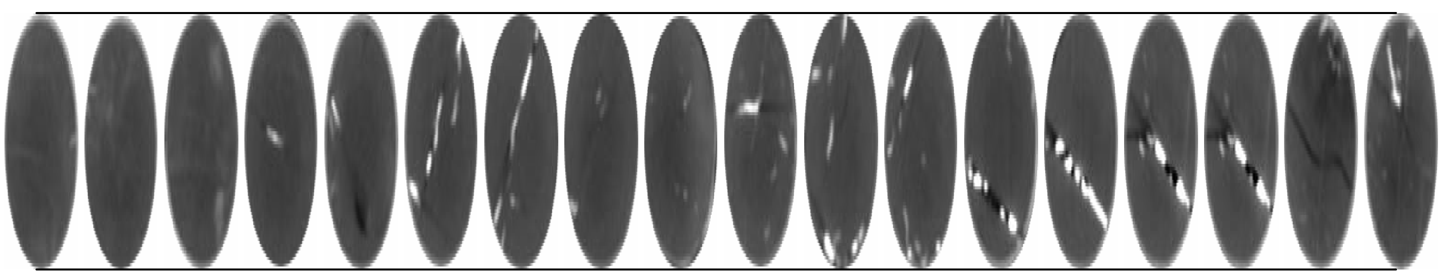
Total length: 21.17 cm

Diameter: 2.79 cm

Porosity: 7%

Permeability to He: 1.7 md

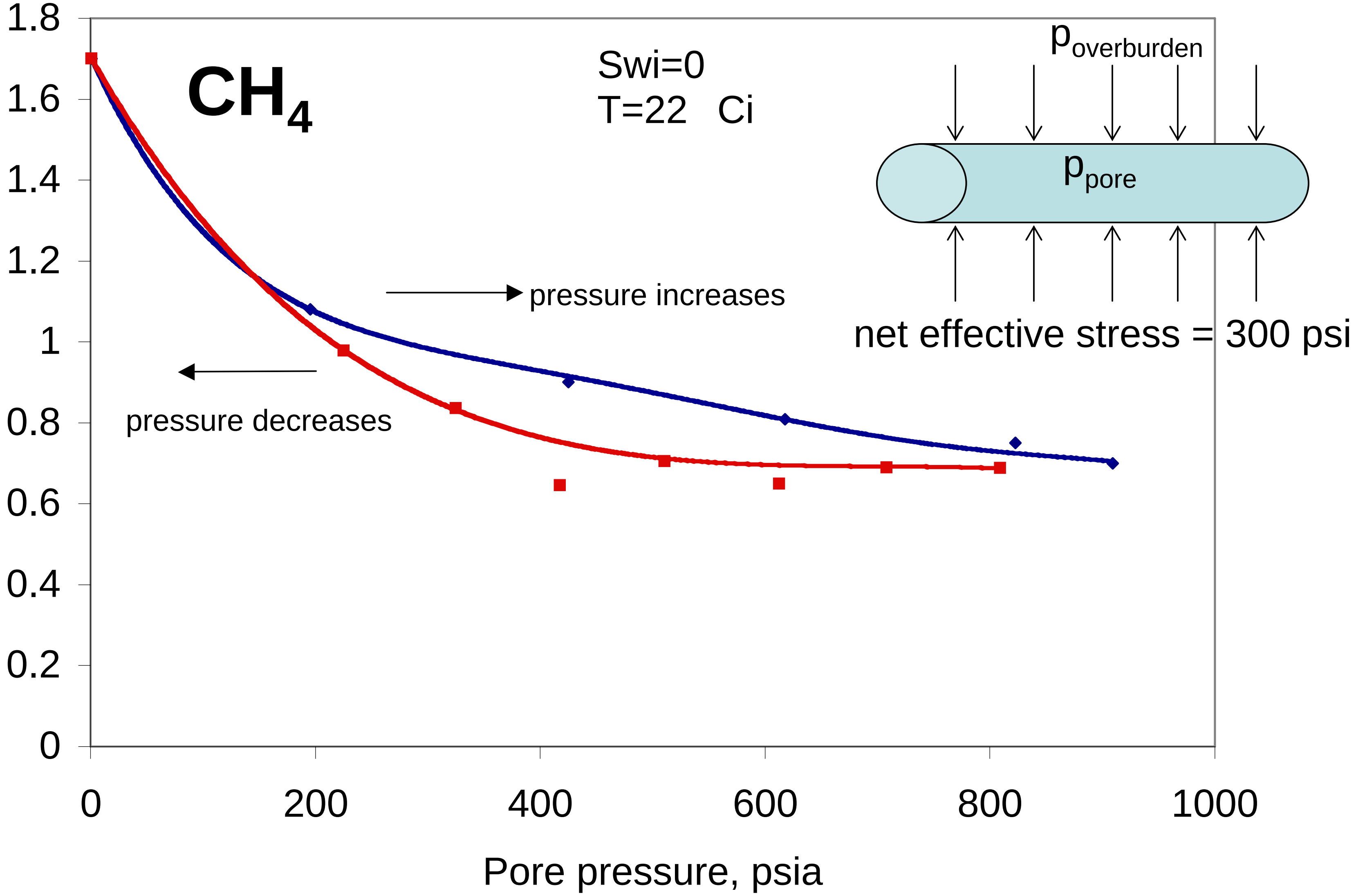
Intact composite coal plugs



Corresponding CT-images

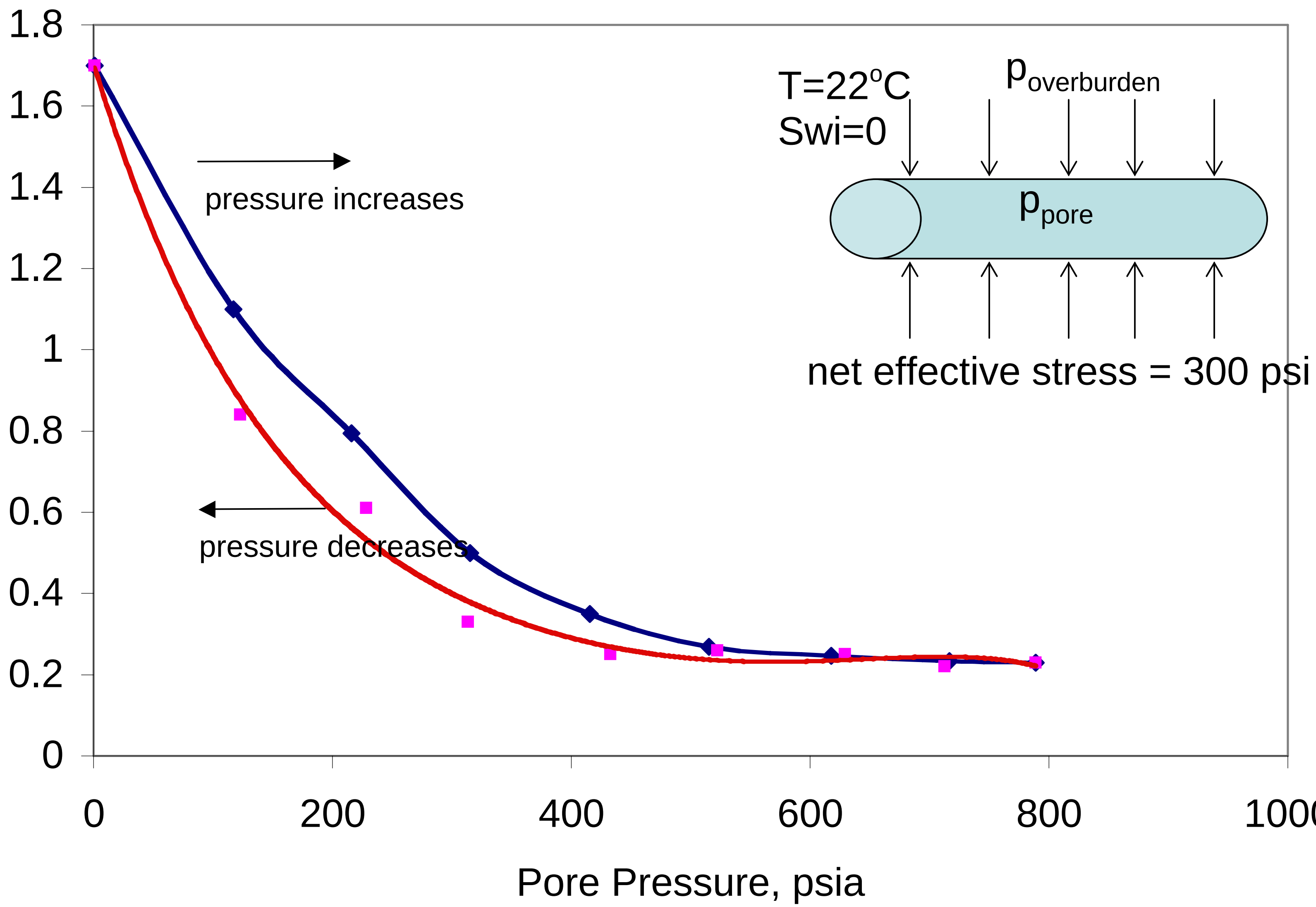
Is permeability sensitive to gas?

hysteresis loading/unloading



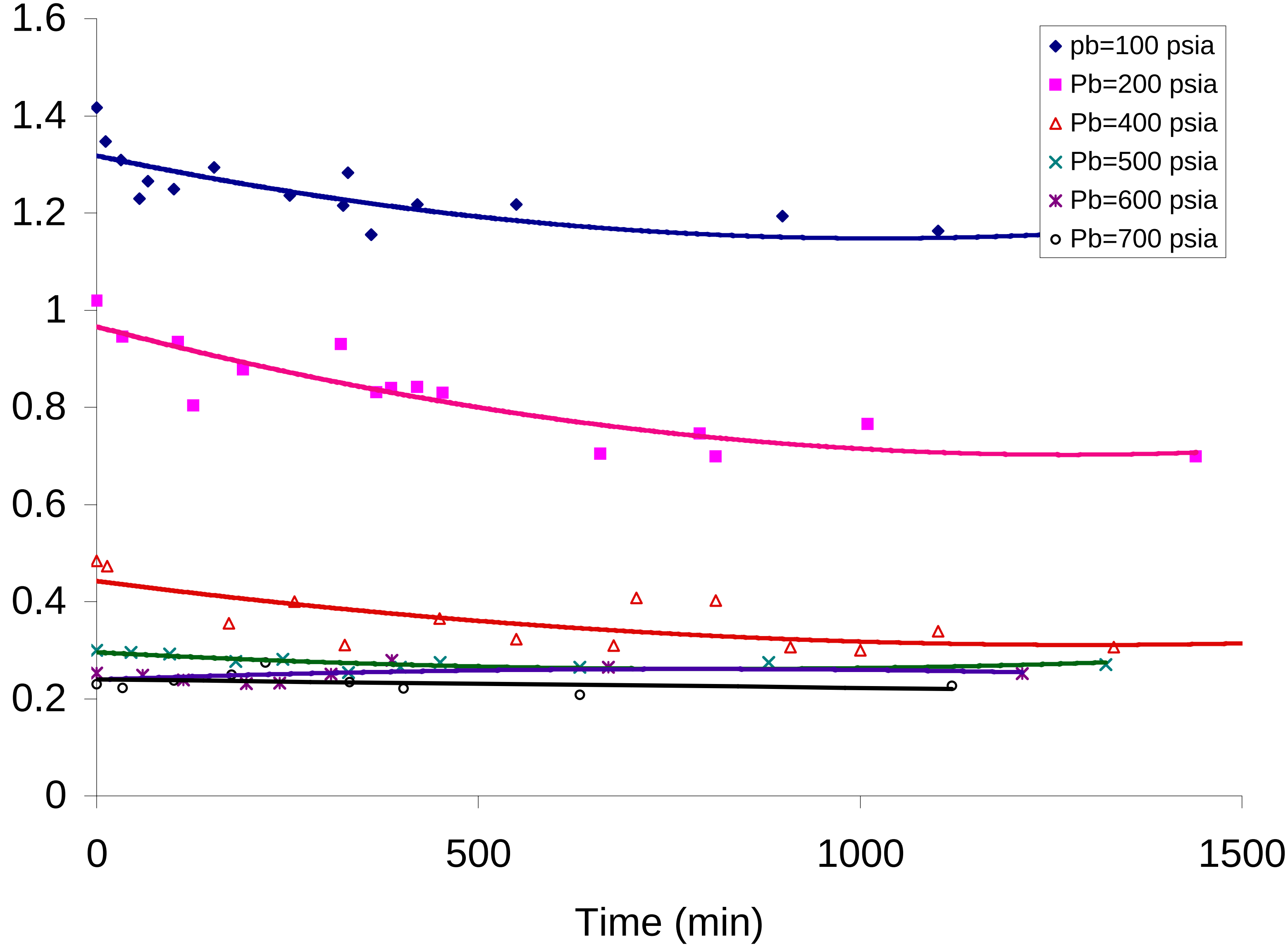
Permeability to CO_2

hysteresis loading/unloading



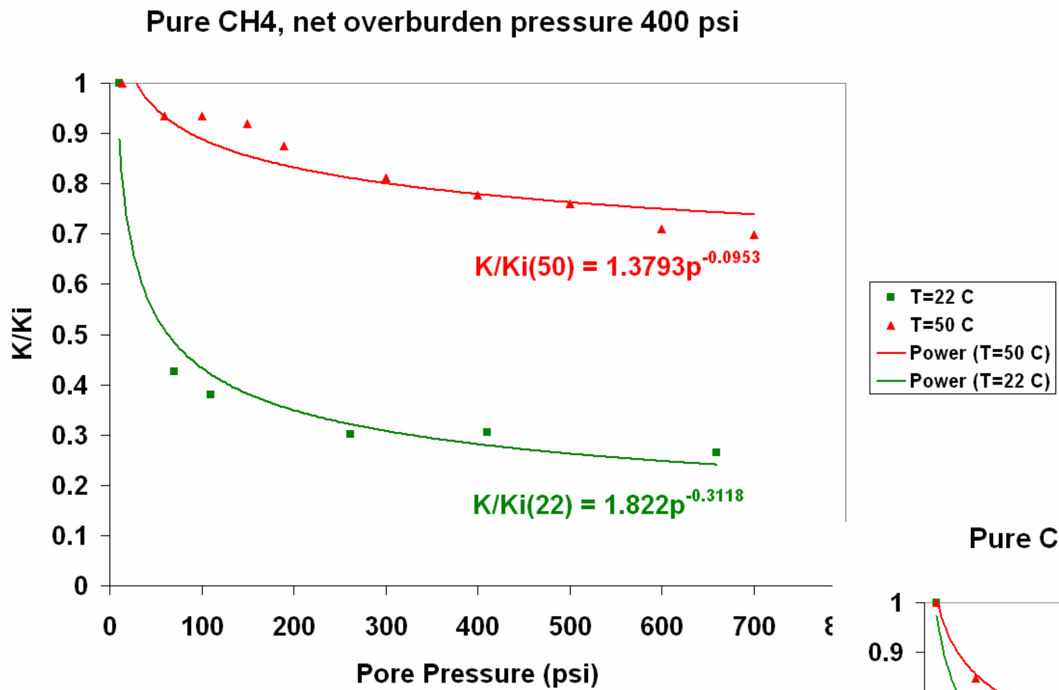
Time to Steady Flow

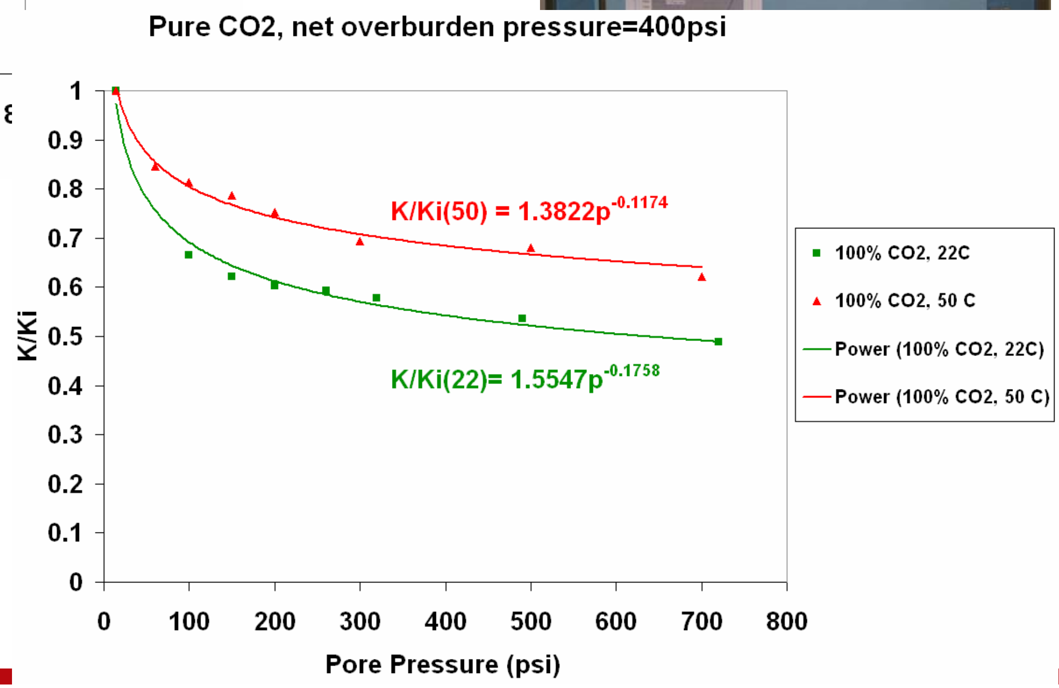
increasing pressure



Effect of Temperature

generally, adsorption decreases with T





Ground Powder River Basin (WY) Coal

Today's Presentation

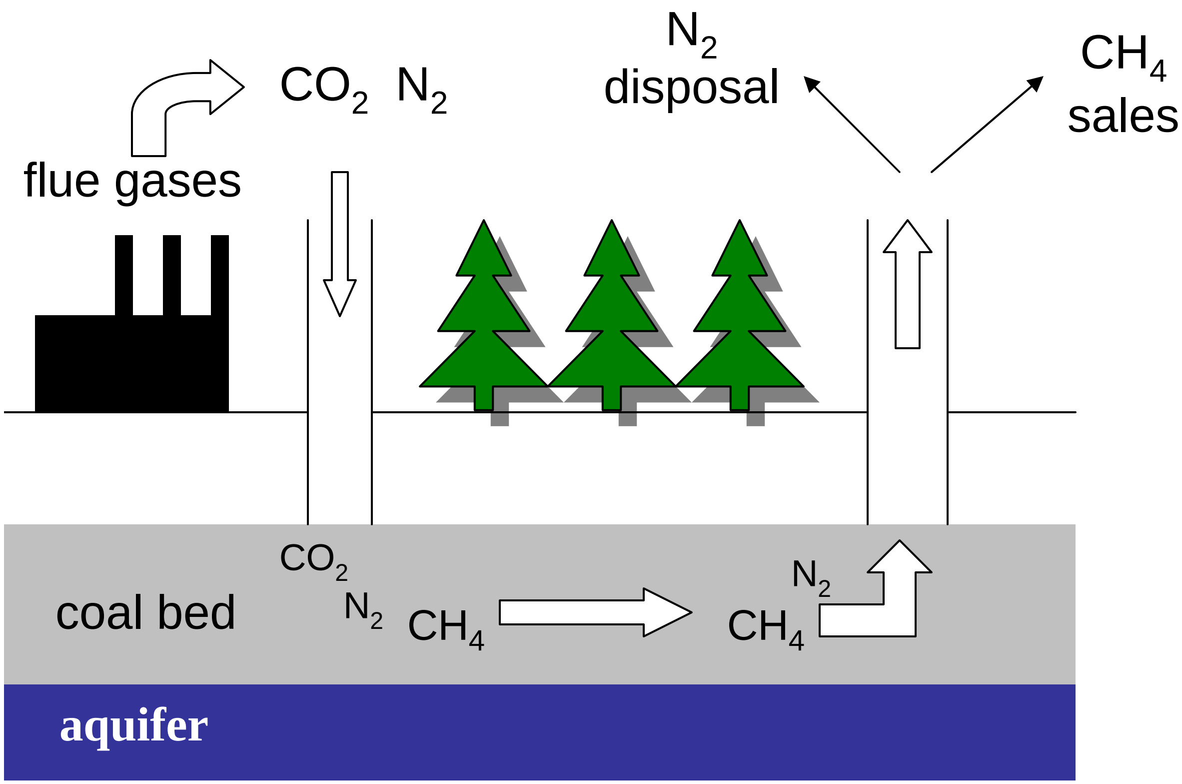


image source: C.J. Seto

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- How much gas adsorbs on coal?
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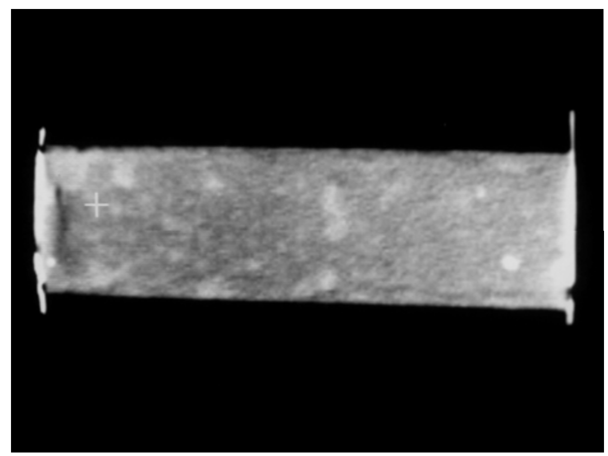
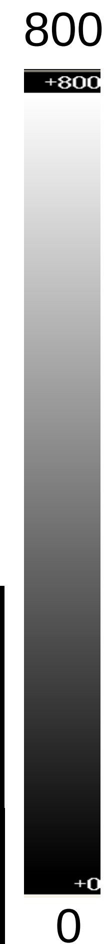
- **How does water flow?**

How does flow through coal?

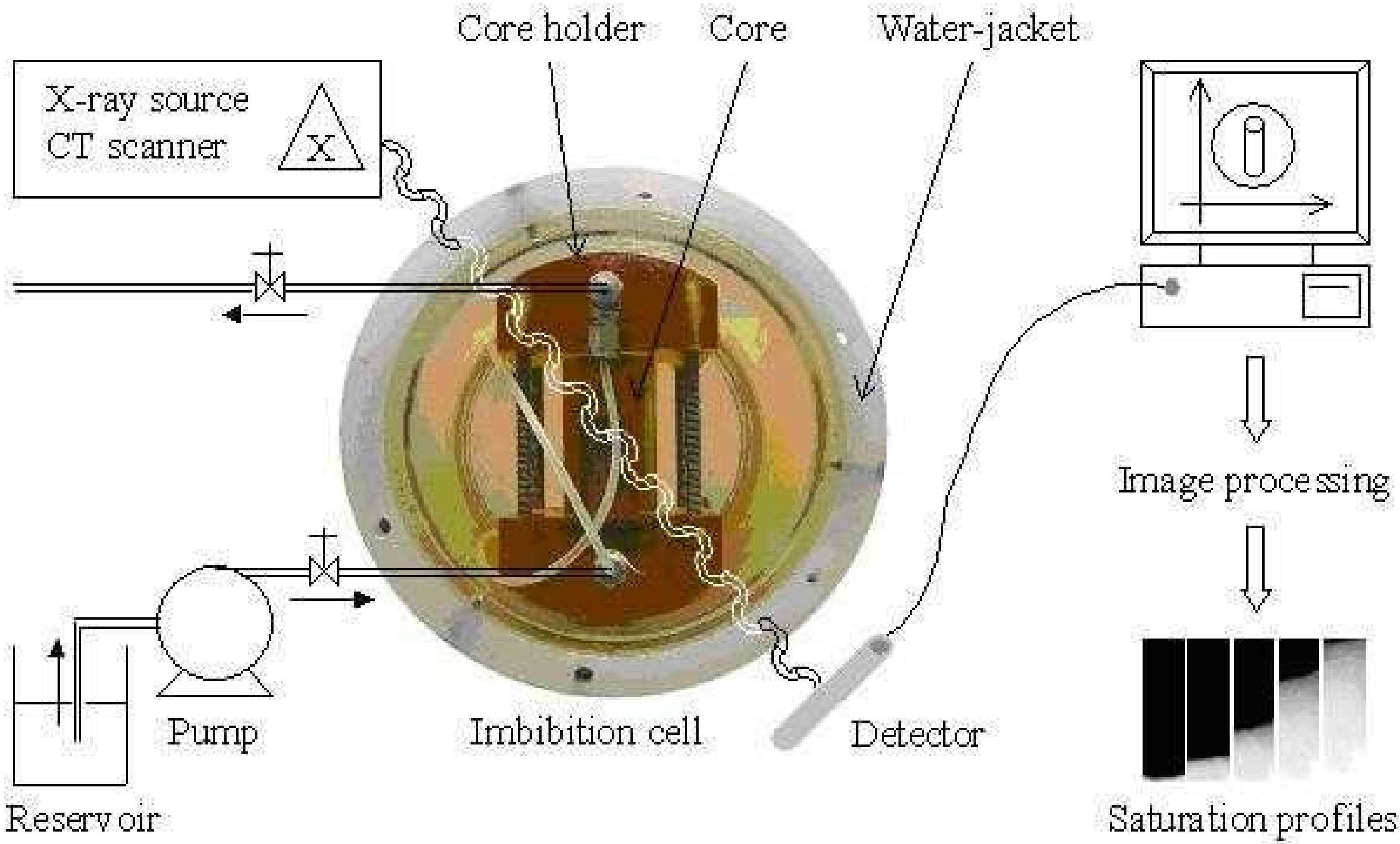
- X-ray computerized tomography (CT) scanner
  - X-ray radiation through the core captured by detectors
  - More dense materials/fluids yield greater attenuation

- Porosity, saturation calculations
  - Porosity $$\phi = \frac{CT_{wet} - CT_{dry}}{CT_{water} - CT_{air}} = \frac{V_{void}}{V_{rock}}$$
  - Saturation $$S_w = \frac{CT_{obj} - CT_{dry}}{CT_{wet} - CT_{dry}} = \frac{V_w}{\phi V_{rock}}$$

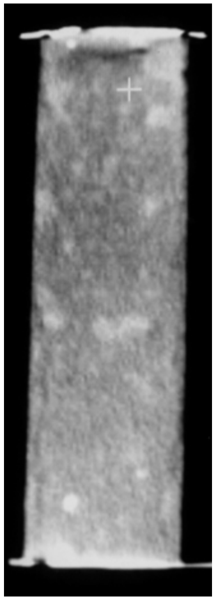




CT Scanning Process

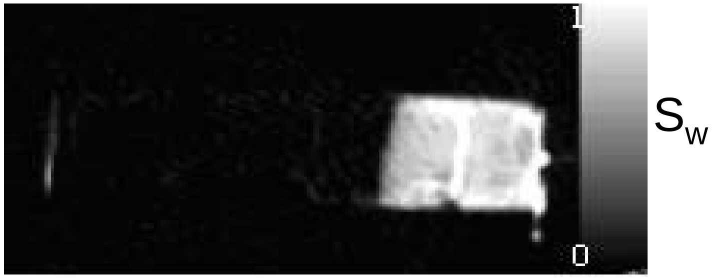


"Core" Preparation

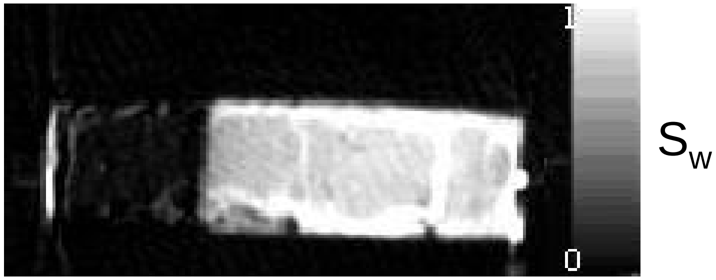


Spontaneous Water Imbibition

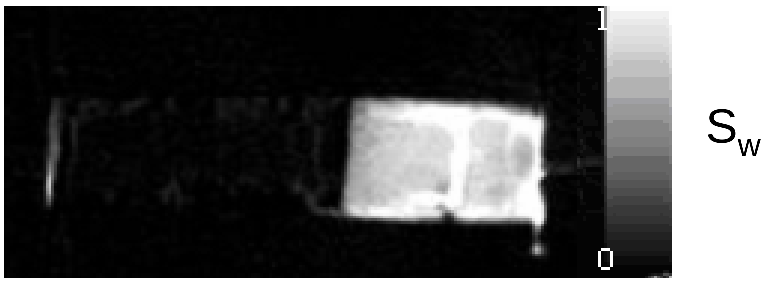
pH=2



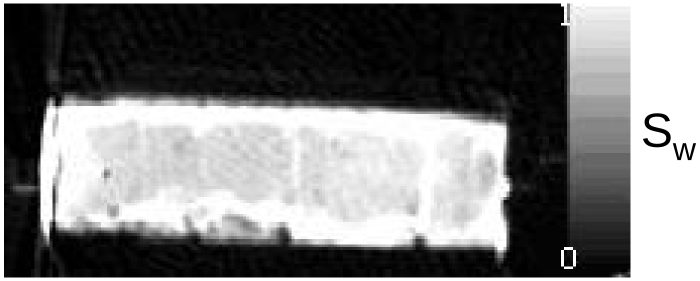
15 mins



180 mins

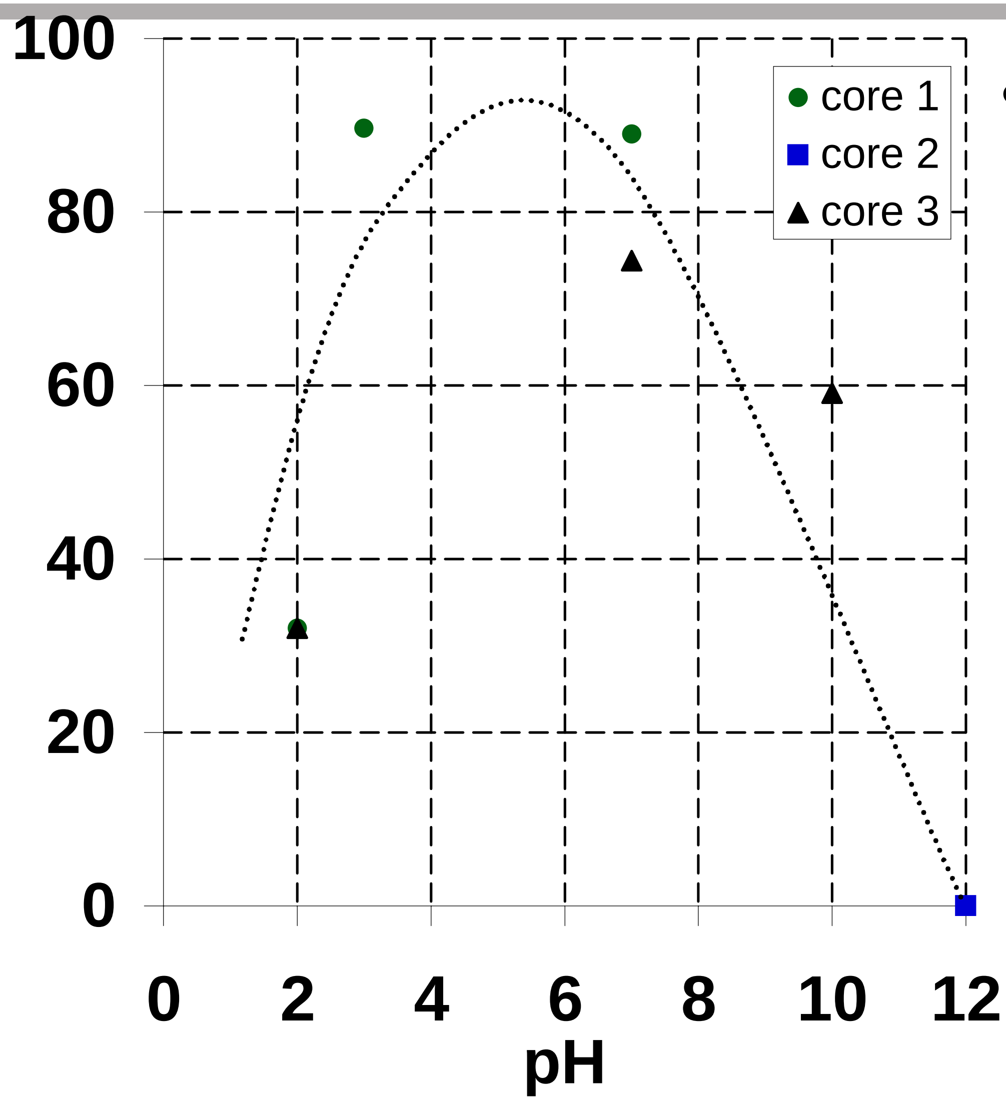


60 mins

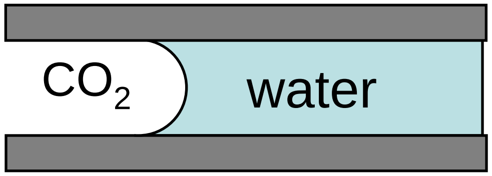


post forced imbibition

Wettability Aspects



- coal wettability varies with pH and CO_2 content



Relative Permeability is Foundational to Modeling

$$\frac{\partial G_i}{\partial \tau} + \frac{\partial H_i}{\partial \xi} = 0$$

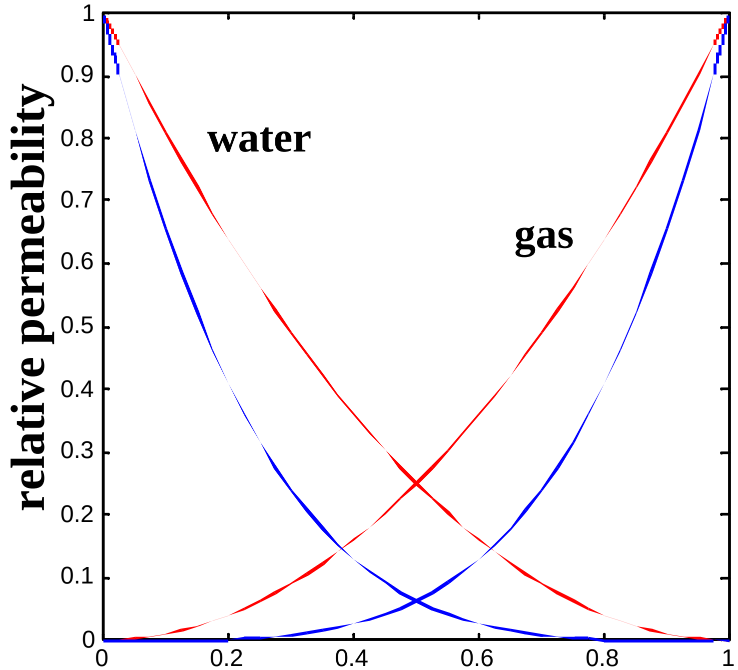
$$G_i = \rho_{DG} y_i S_g + \rho_{DL} x_i S_L + \frac{1-\phi}{\phi} a_{iD}$$

$$H_i = \left(\rho_{DG} y_i u_g + \rho_{DL} x_i u_L\right)$$

$$u_\beta = -\frac{k k_{r\beta}}{\mu_\beta} \nabla p_\beta$$

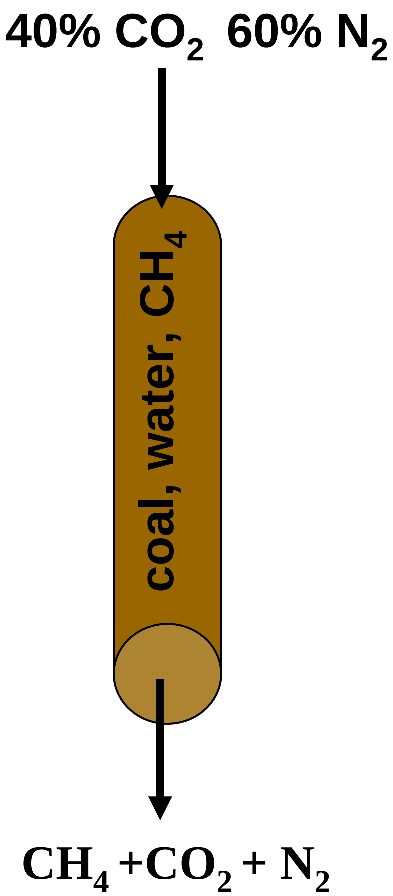
assumptions

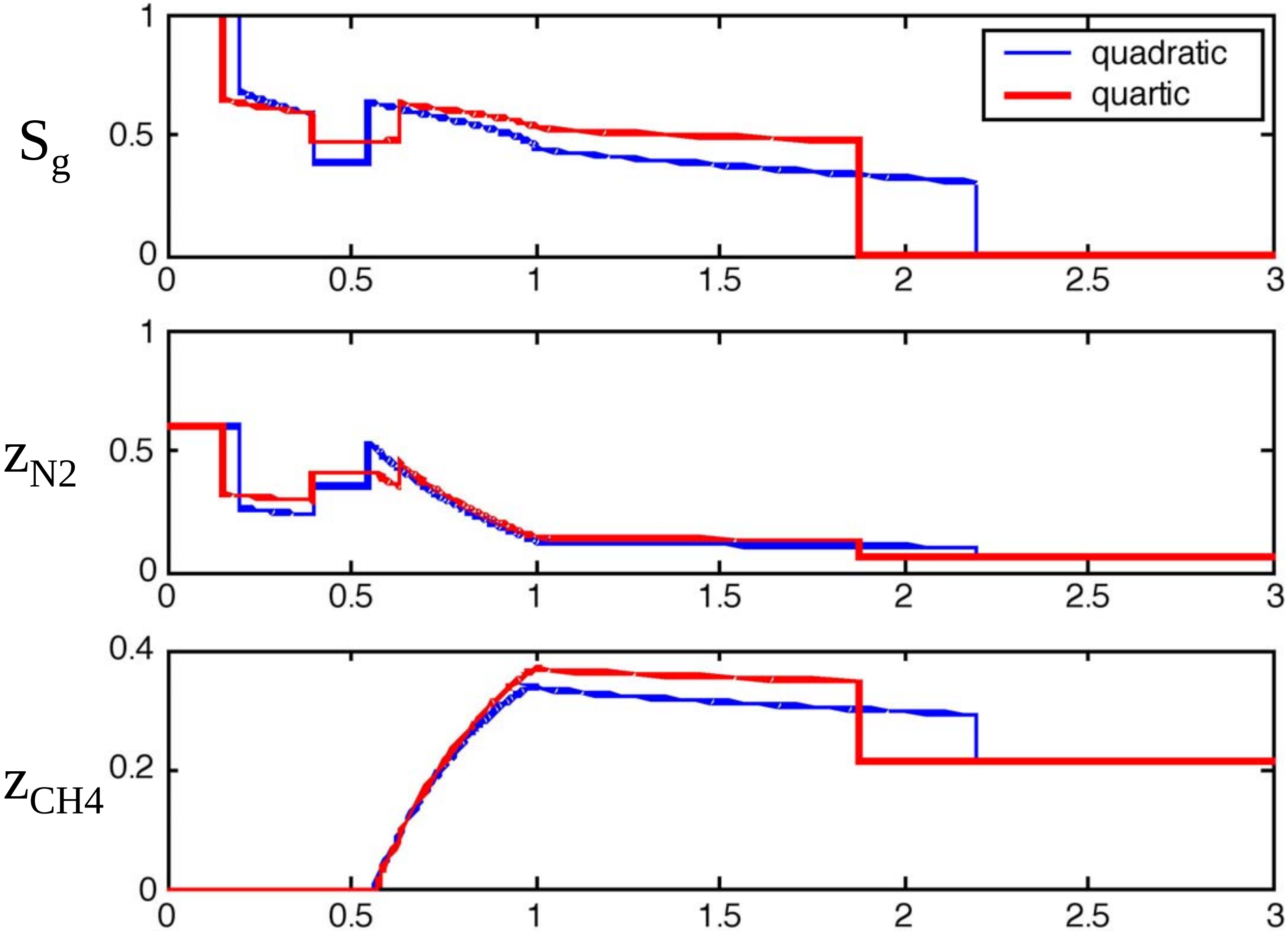
- 1D flow
- local equilibrium
- no dispersion or diffusion
- homogenous porous medium
- negligible gravity or capillary forces



slide: C.J. Seto

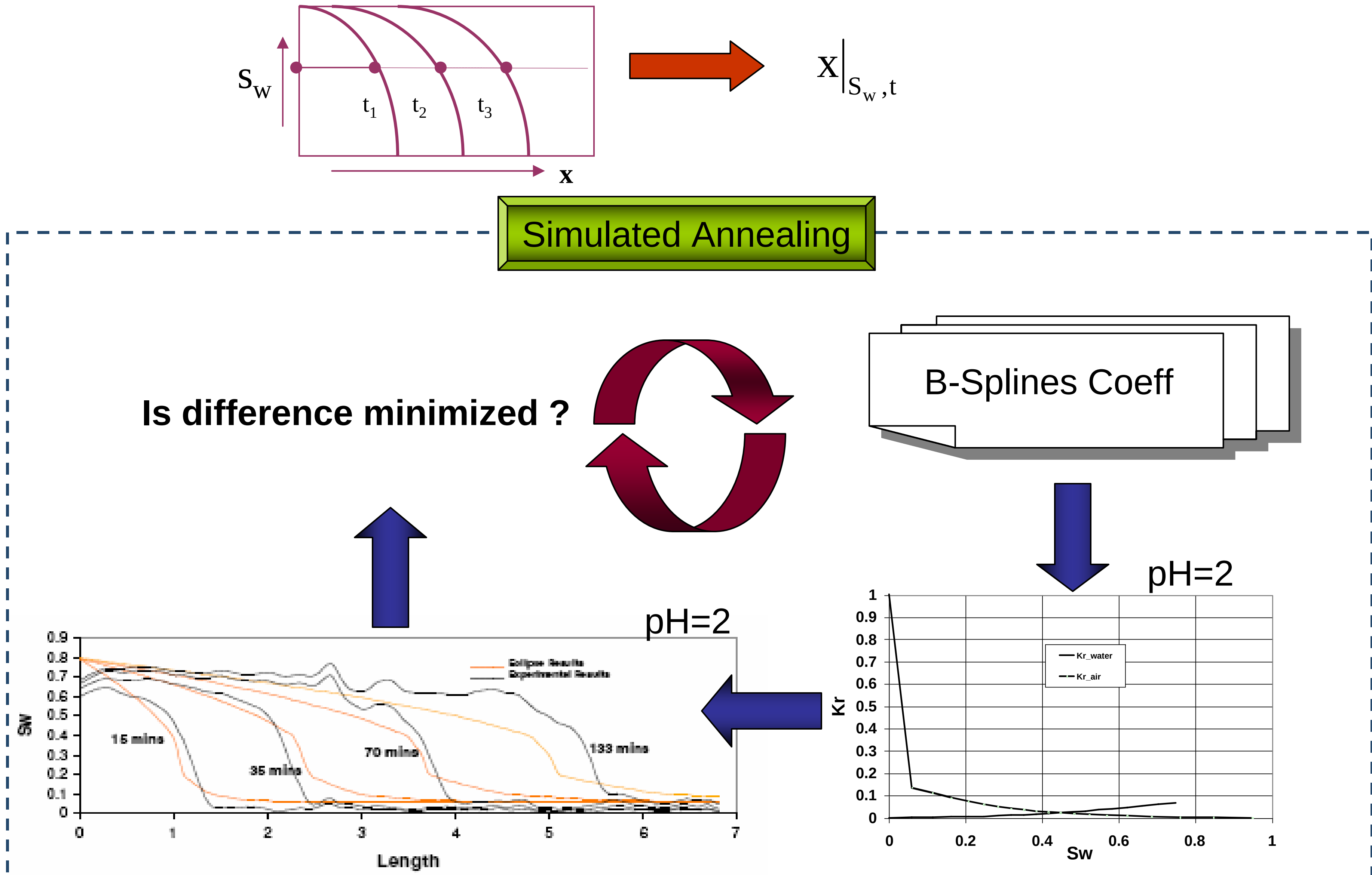
Sensitivity to Rel-Perm



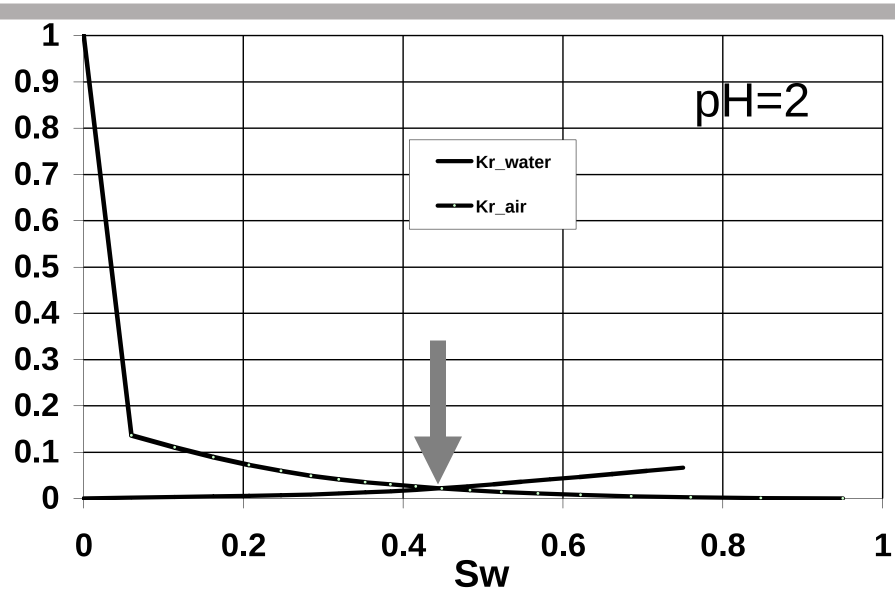


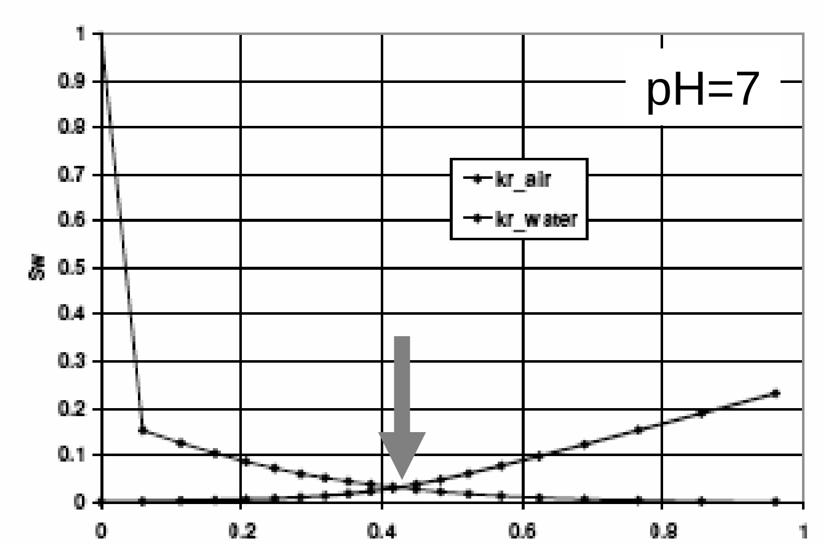
slide: C.J. Seto

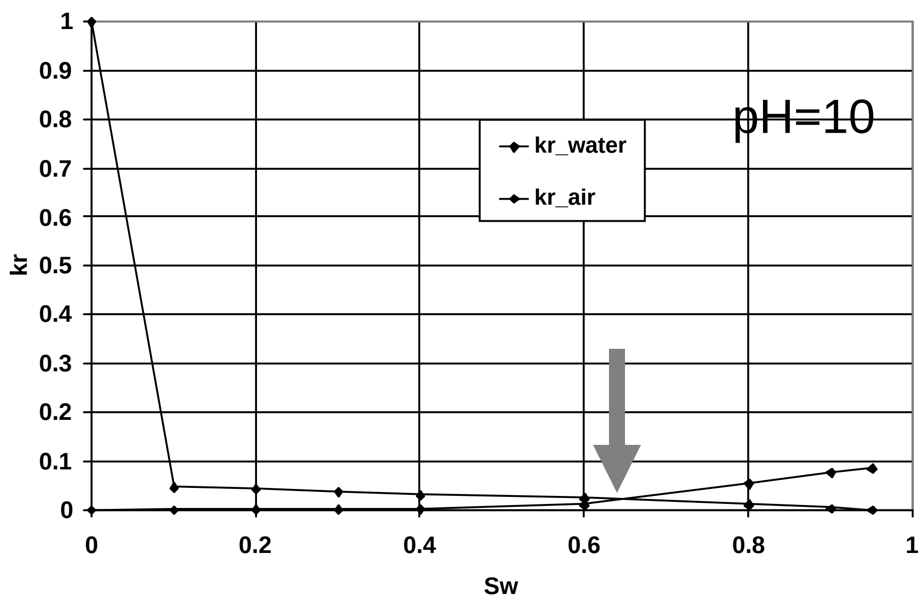
Relative Permeability from Imbibition Data



Relative Permeability vs pH





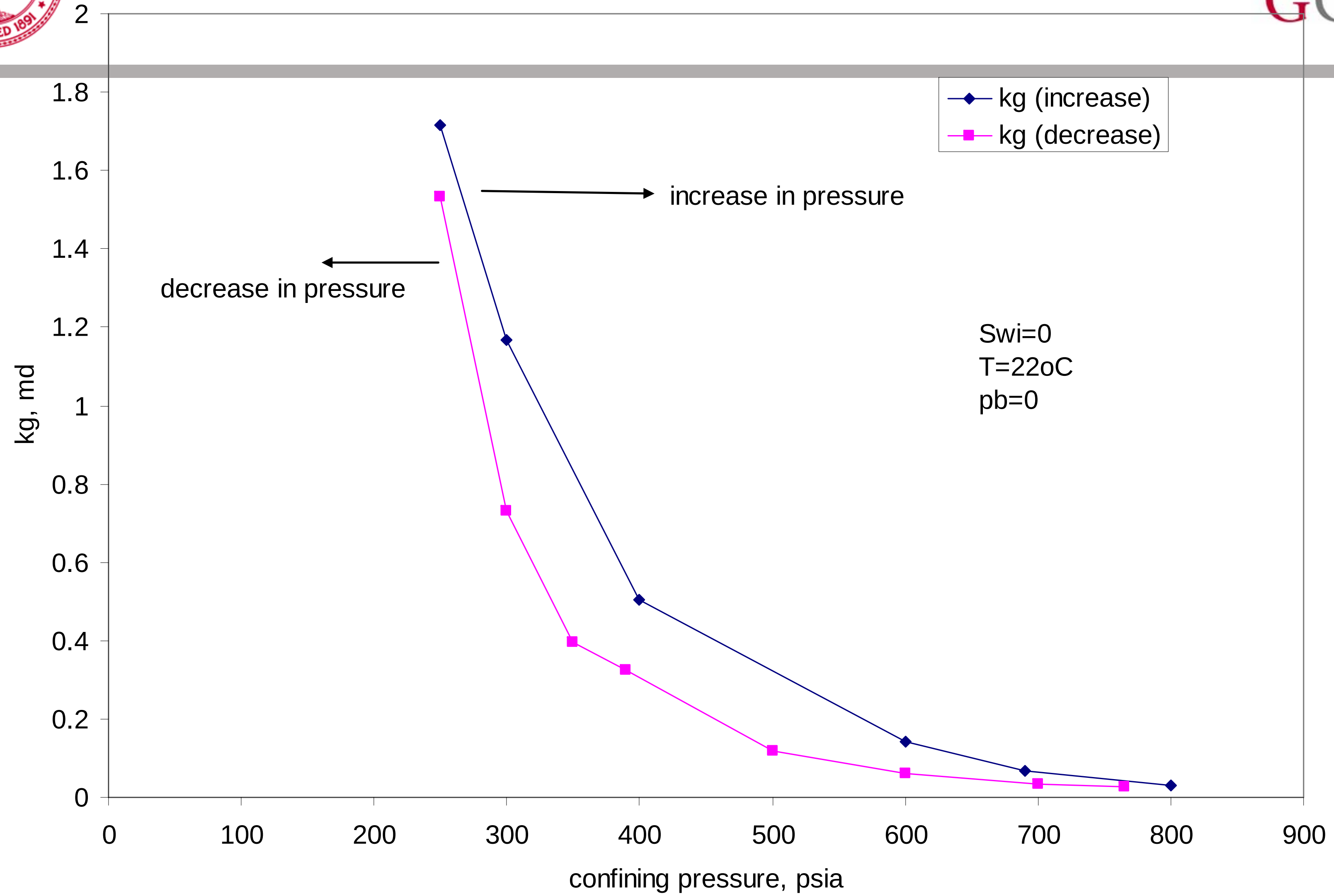


Summary

- Gas injection enhances CBM recovery significantly (at least 94% OGIP)
- Coals demonstrate rich dynamical behavior that is sensitive to
  - gas adsorption
  - temperature
  - adsorption hysteresis
  - water pH
- Permeability reduction during CO_2 flow is less severe in intact core samples
- Wettability of coal surfaces varies with the amount (pressure) of CO_2

Acknowledgement

- GCEP
- Collaborators: Tanmay Chaturvedi, Kristian Jessen, Wenjuan Lin, Lynn Orr, Carolyn Seto, Tom Tang.



Effect of confining pressure on permeability to Helium

Why are we studying coalbeds?

methane/CO_2 storage/acid gas disposal

- **win / win / win ?**

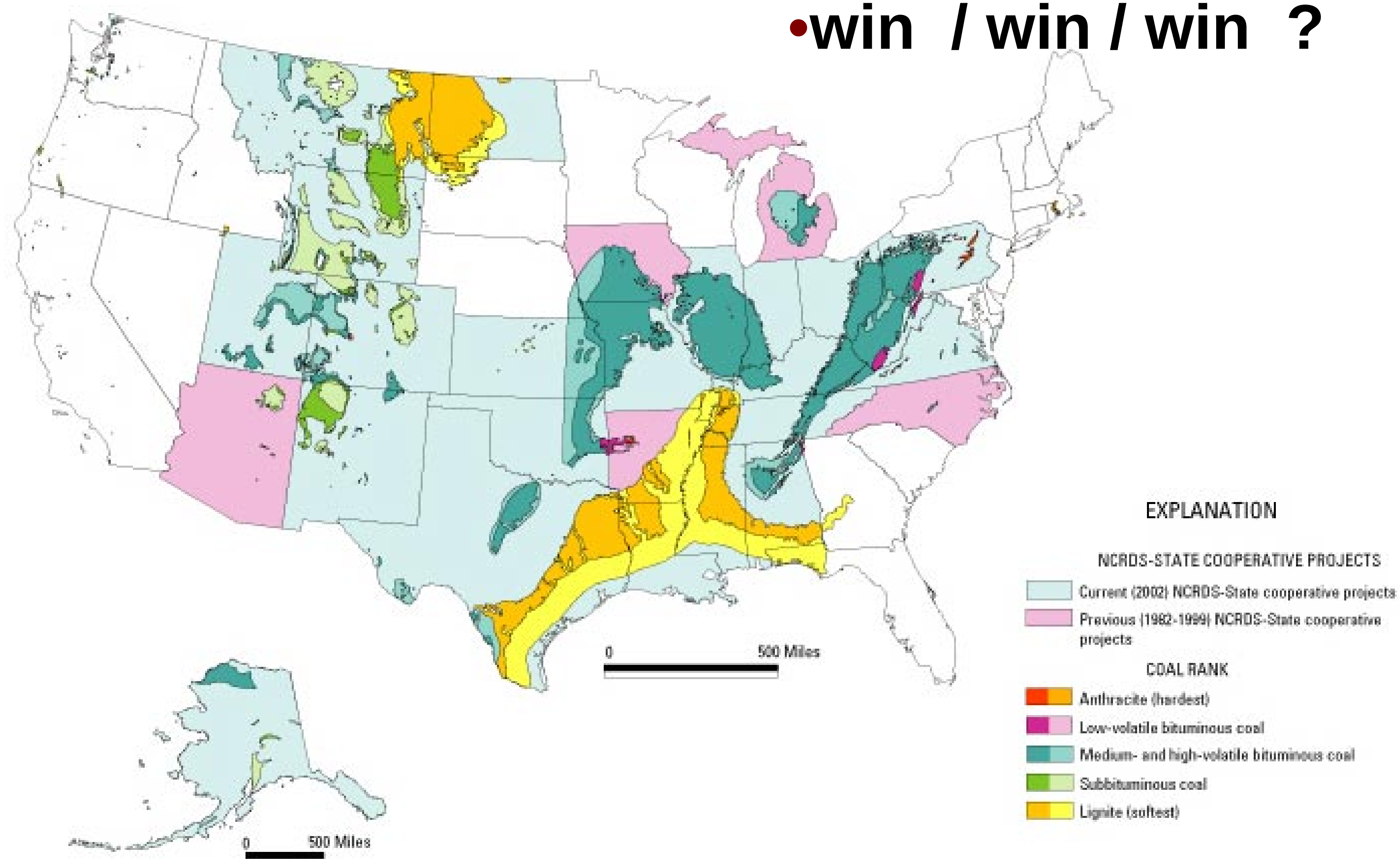


image source: USGS