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Reducing Greenhouse Gas Emissions: Geological Storage of CO_2

Tara C LaForce, Imperial College London

4th Dec. 2007 Second Nature

Global Warming is:

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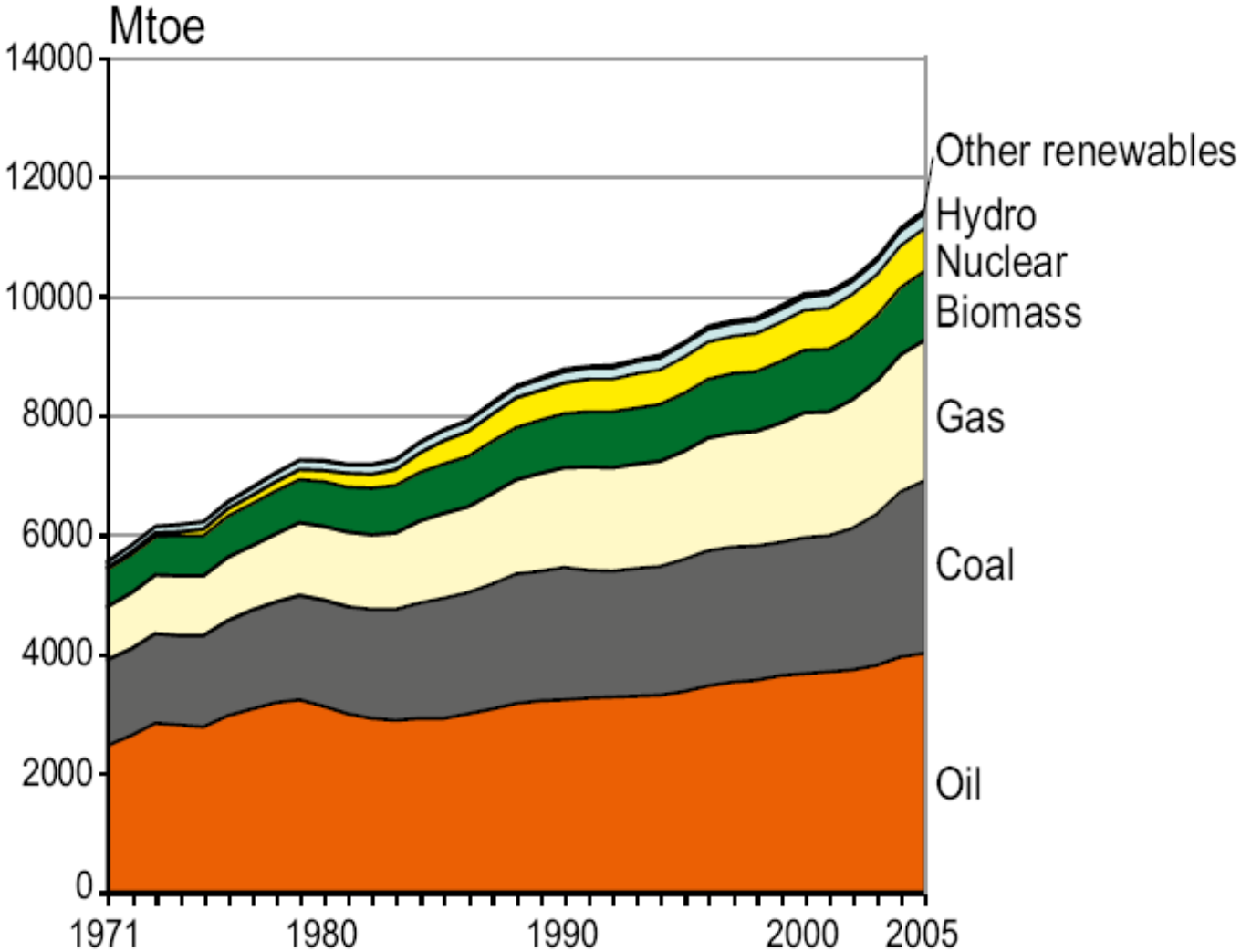
World Primary Energy Consumption



http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-ts.pdf

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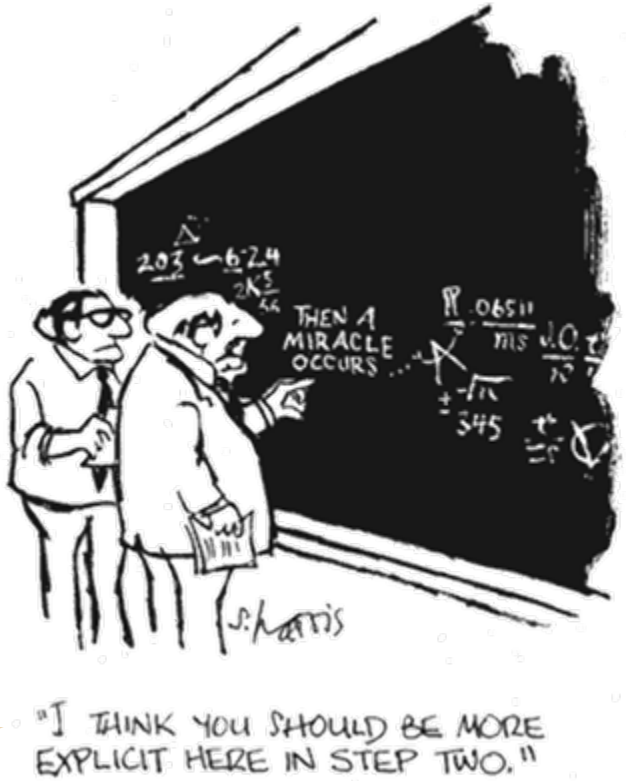
But Aren't We Going to Run Out of Oil?

Yes! But we are not going to run out of coal…

- Coal has a reserves-to-production ratio of 164
- Coal is the second-largest source of energy-related CO_2 emissions, with 39% in 2004
- Coal is projected to become the largest source of CO_2 emissions by 2010
- World coal consumption is predicted to increase by 74% from 2004 to 2030
- China and India account for 72% of the increase

http://www.eia.doe.gov/oiaf/ieo/coal.html

What Can We Do About It?



Why Geological Storage?

- Technology already established – many carbon dioxide injection projects in the world
- Allows smooth transition away from a fossil fuel economy
- Economic benefit of enhanced oil/gas recovery
- Has potential to have a large impact on carbon dioxide emissions quickly
- Low emission option for developing countries – e.g. China and India

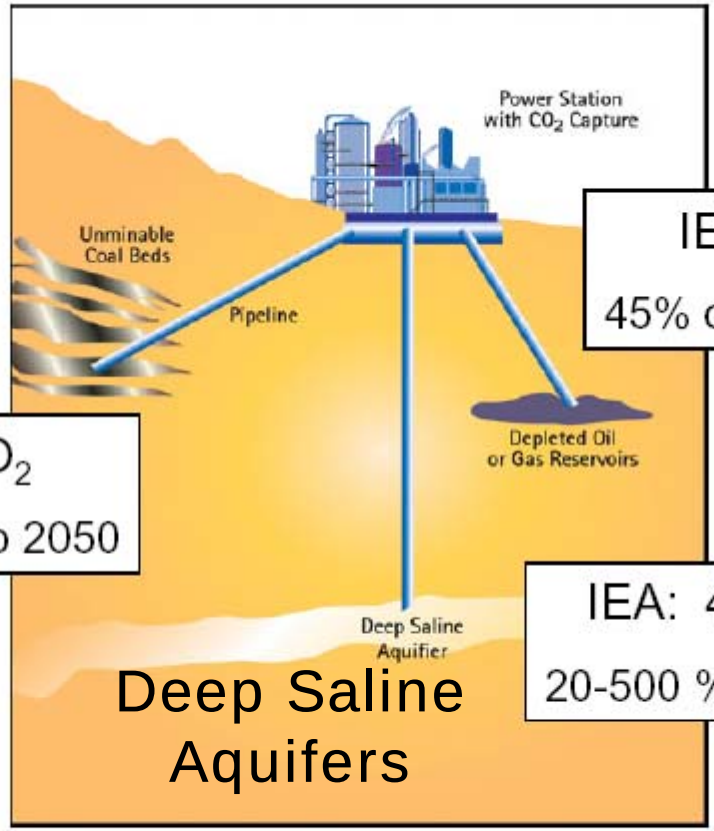
Geologic Storage Options

Unminable Coal Beds

IEA: 40 Gt CO_2

<2% of Emissions to 2050

Parson & Keith: 370-1100 Gt CO_2



Hydrocarbon Reservoirs

IEA: 920 Gt CO_2

45% of Emissions to 2050

Parson & Keith: 740-1850 Gt CO_2

Deep Saline Aquifers

IEA: 400-10 000 Gt CO_2

20-500 % of Emissions to 2050

Parson & Keith: 370-3700 Gt CO_2

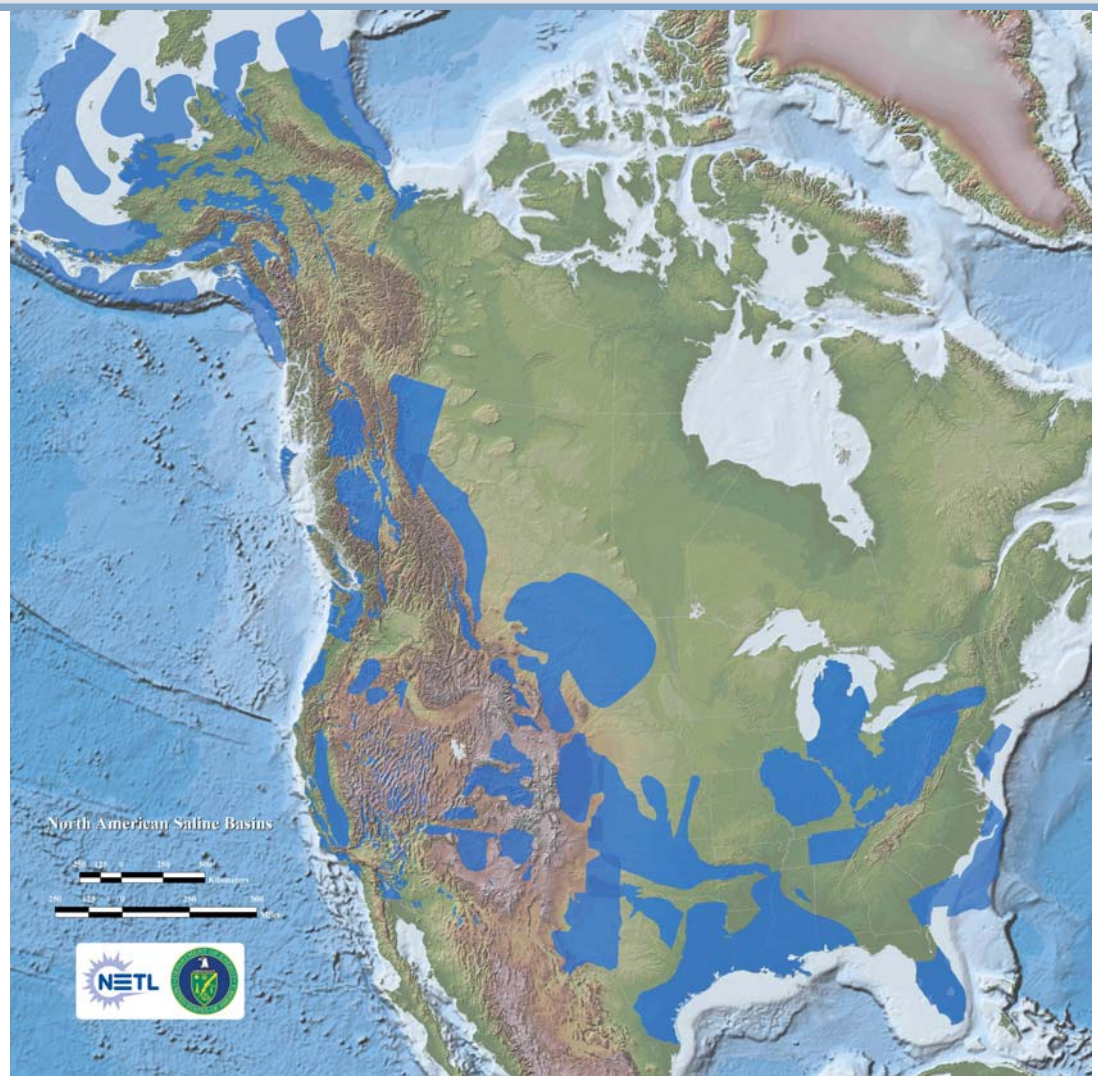
But do we know that it will stay trapped?

Questions We Must Answer

- How could the CO_2 escape?
- How far does the injected CO_2 spread?
- How long does it take to immobilize the CO_2?
- What is the ultimate fate of the CO_2?
- How we design injection processes that reduce the potential for leakage?

Storage in Aquifers

- By far the largest volume of potential storage space
- Poorly-characterized geology



Source: S.M. Benson, GCEP

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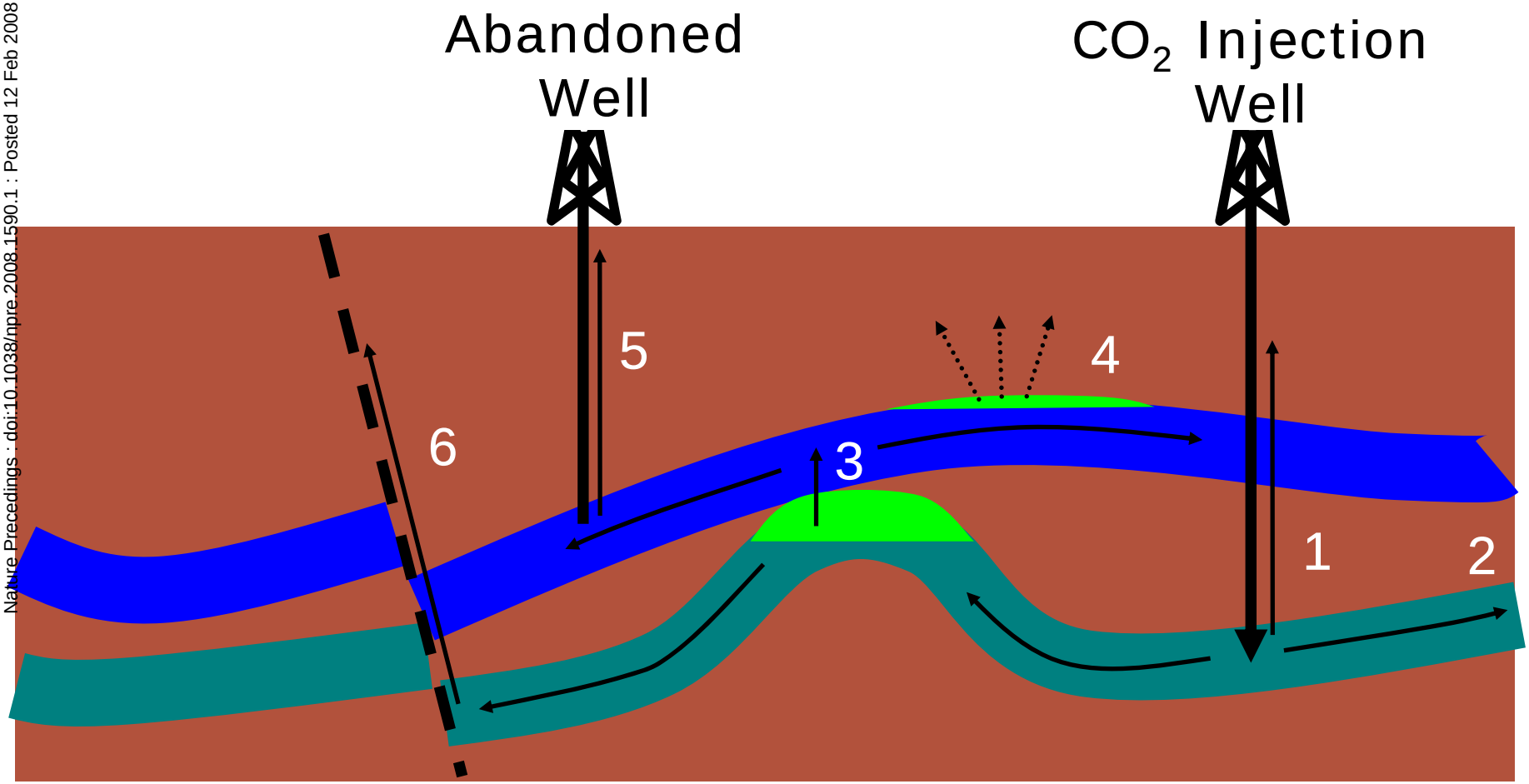
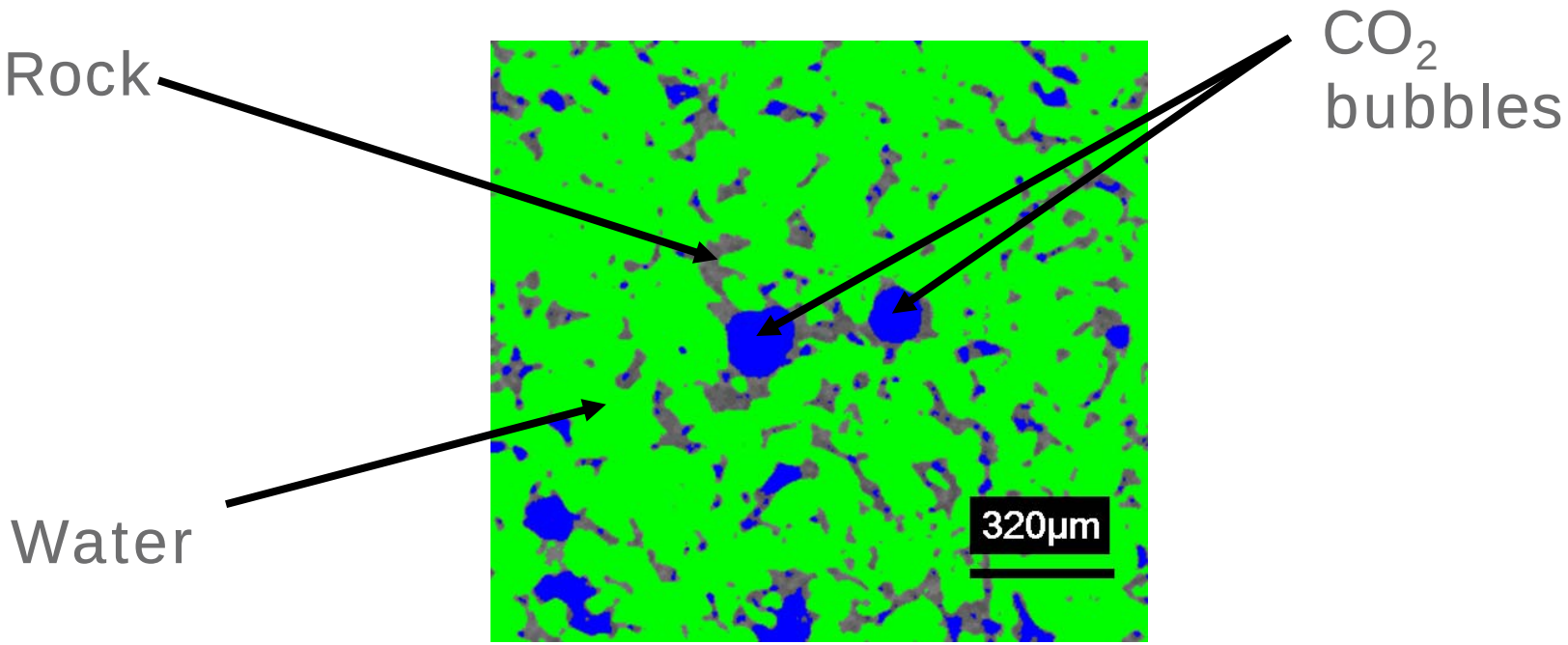
How Could the CO_2 Escape?



How Far Does the CO_2 Spread?

As CO_2 migrates through the rocks, it is trapped in tiny bubbles that can not move further



(photo courtesy of Hu Dong)

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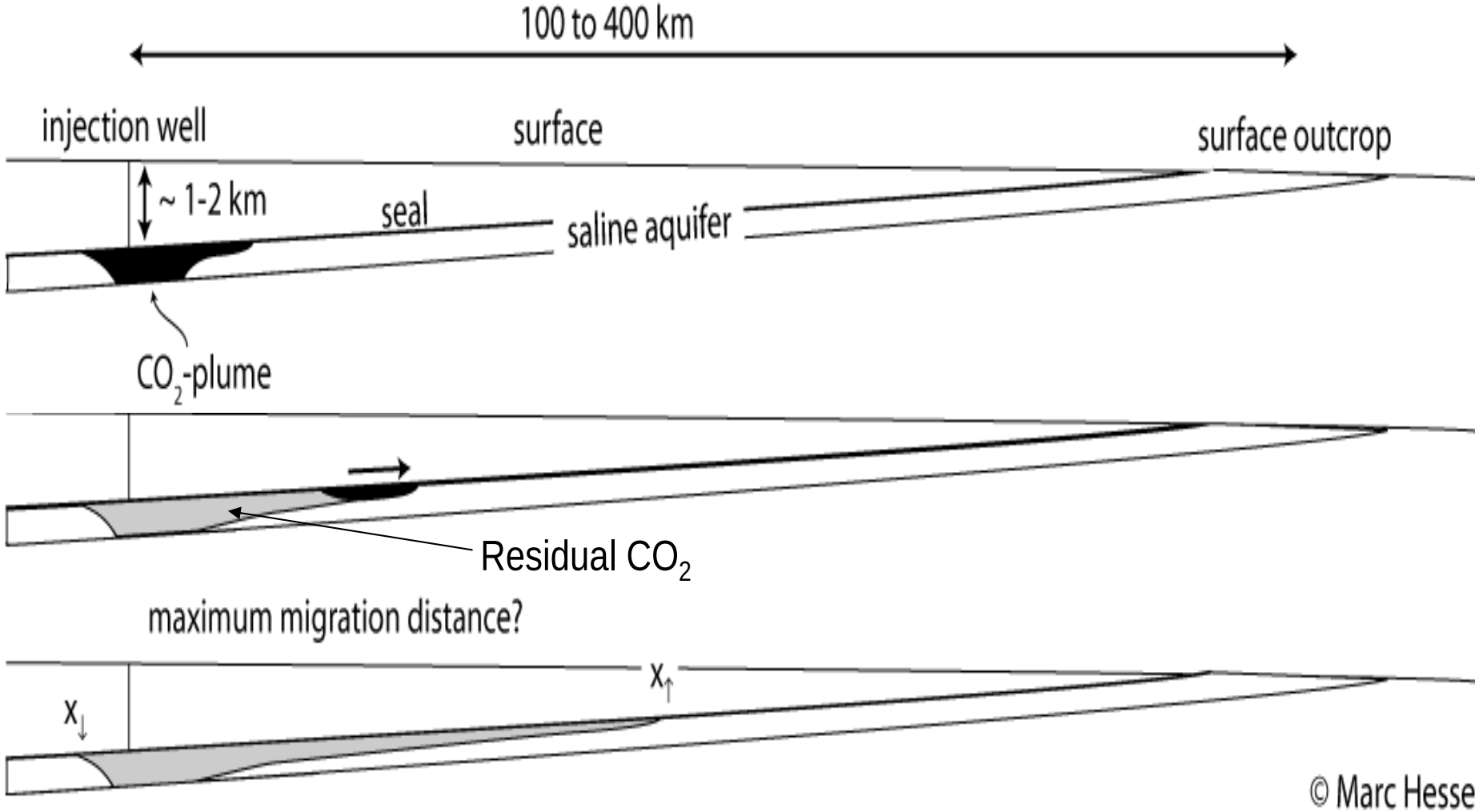
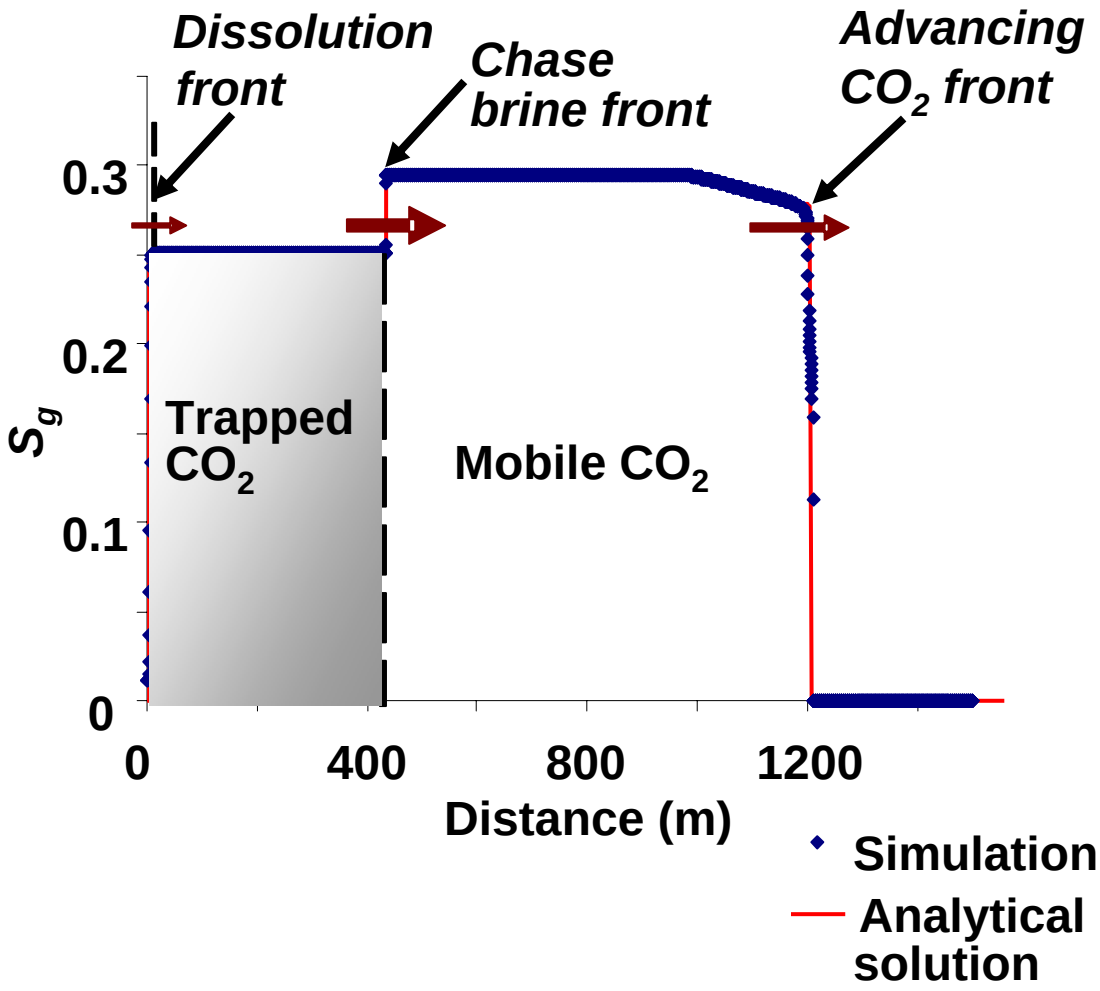


Hesse et al., SPE 102796

How Long to Immobilize the CO_2?

Depends on injection strategy and geology

- 1,000-2,000 years if CO_2 is injected alone
- Faster if water is injected after CO_2 to speed up trapping



Qi et al., SPE 109905

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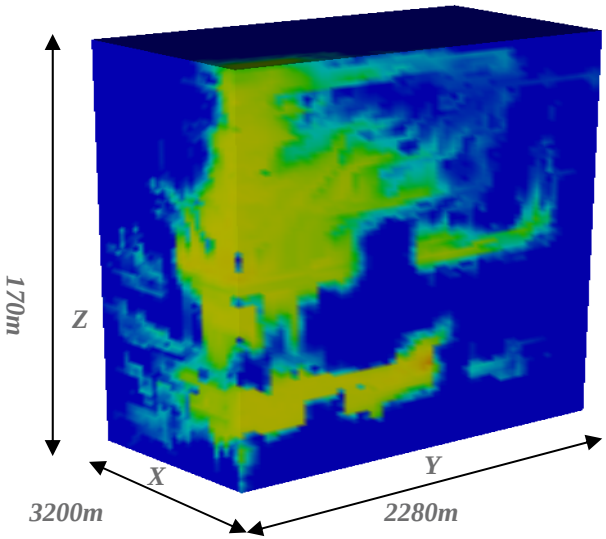
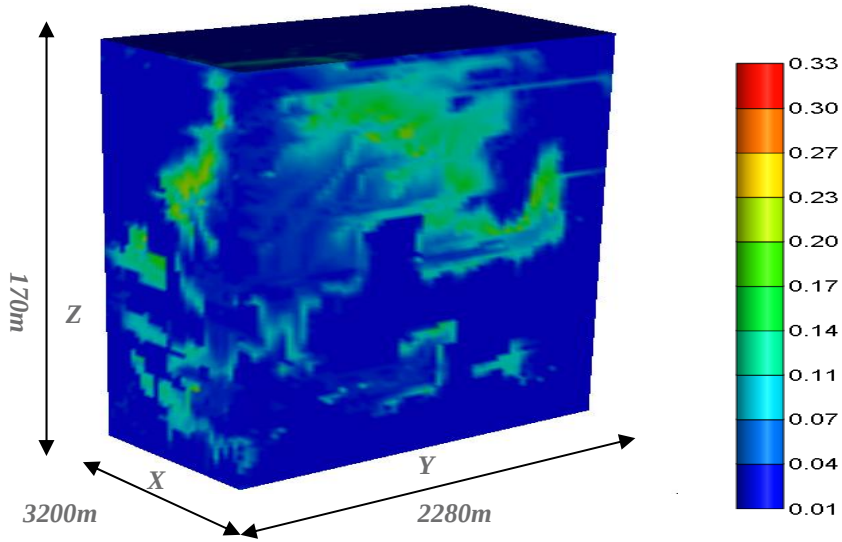
How Long to Immobilize the CO_2?

20 years of water and CO_2 injection followed by 2 years of water injection in realistic geology

95% of CO_2 trapped after 4 years of water injection



Trapped CO_2 saturation



Mobile CO_2 saturation

Qi et al., SPE 109905

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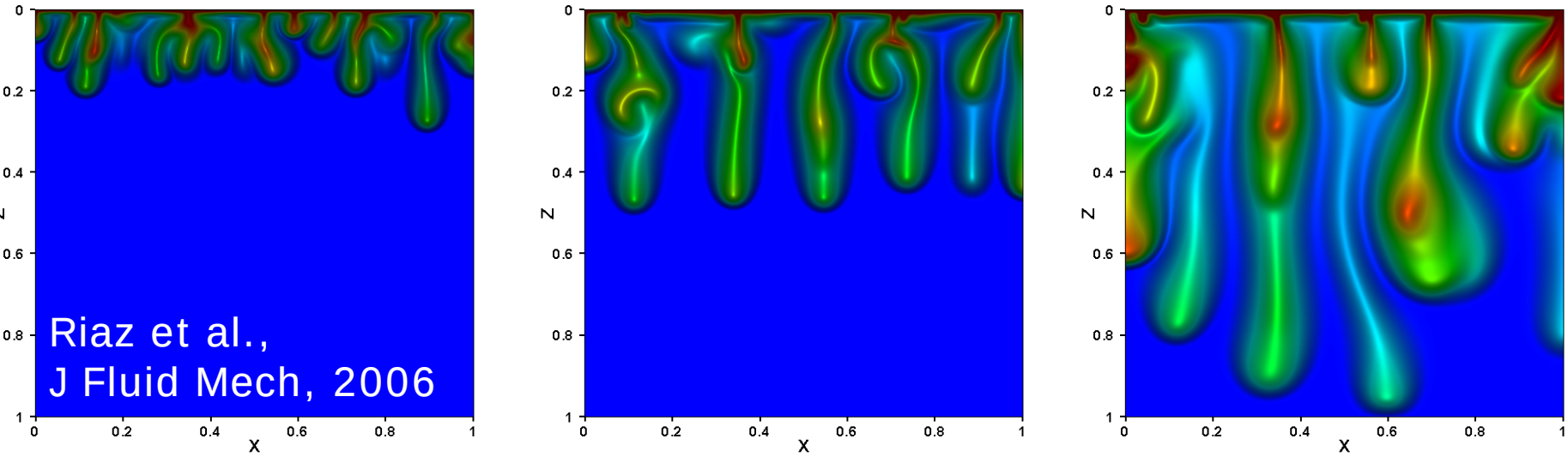
What is the Ultimate Fate of the CO_2?

- CO_2 dissolves into the water and sinks over 10^3 years



- CO_2 can combine with minerals in the water and form calcium carbonate (limestone) over 10^3-10^9 years

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

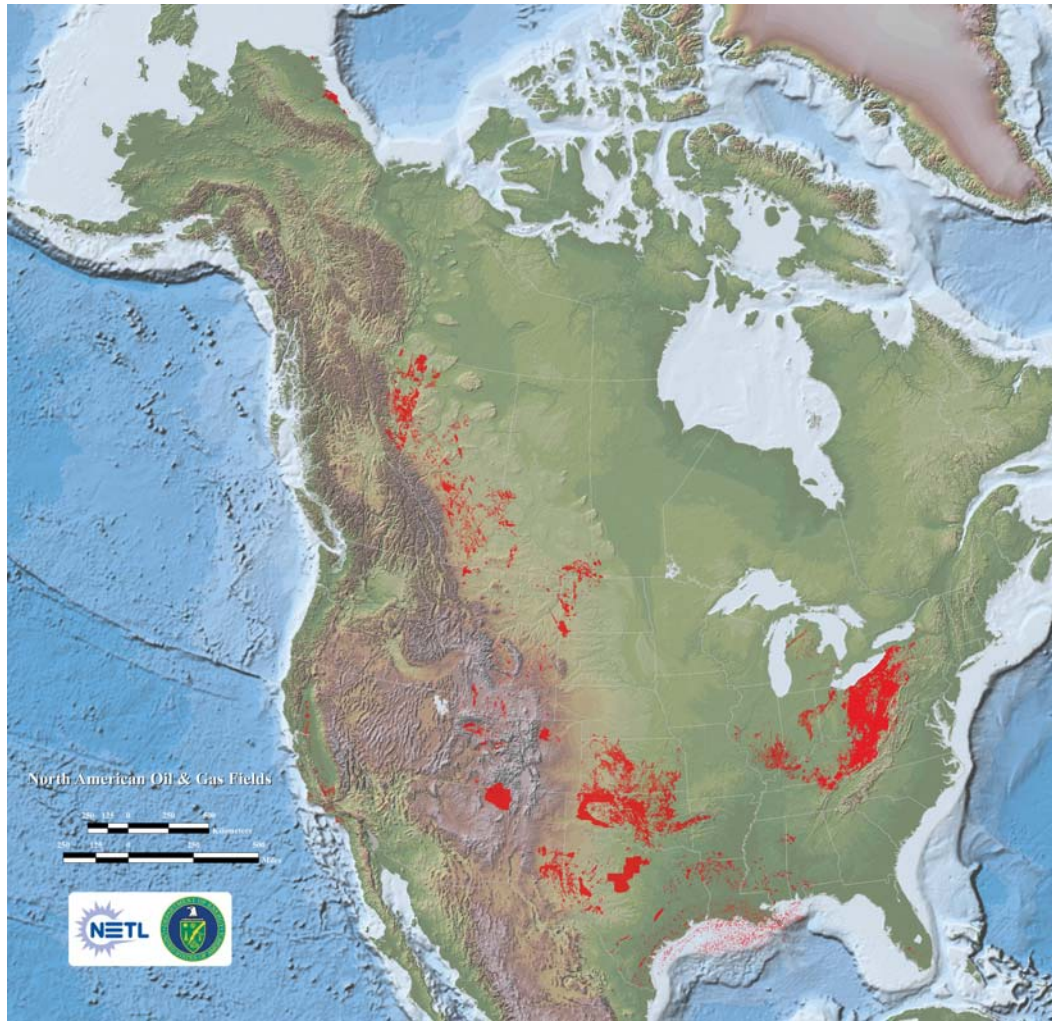
$$Ca^{2+} + 2HCO_3^- \leftrightarrow CO_2 + H_2O + CaCO_3$$

Reduce the Potential for Leakage?

- Know the geology!
  - How well aquifer is sealed at the top?
  - Far away from outcrops that are potential leaks?
- Inject chase water
  - Pushes CO_2 away from injection well
  - Traps CO_2 as tiny bubbles
- Storage security increases with time, so early time monitoring is critical

Storage in Oil and Gas Reservoirs

- Existing infrastructure
- Practical experience injecting CO_2 into oil reservoirs
- Detailed knowledge of geology
- Far from emission sources



Source: S.M. Benson, GCEP

Questions We Must Answer

- How could the CO_2 escape?
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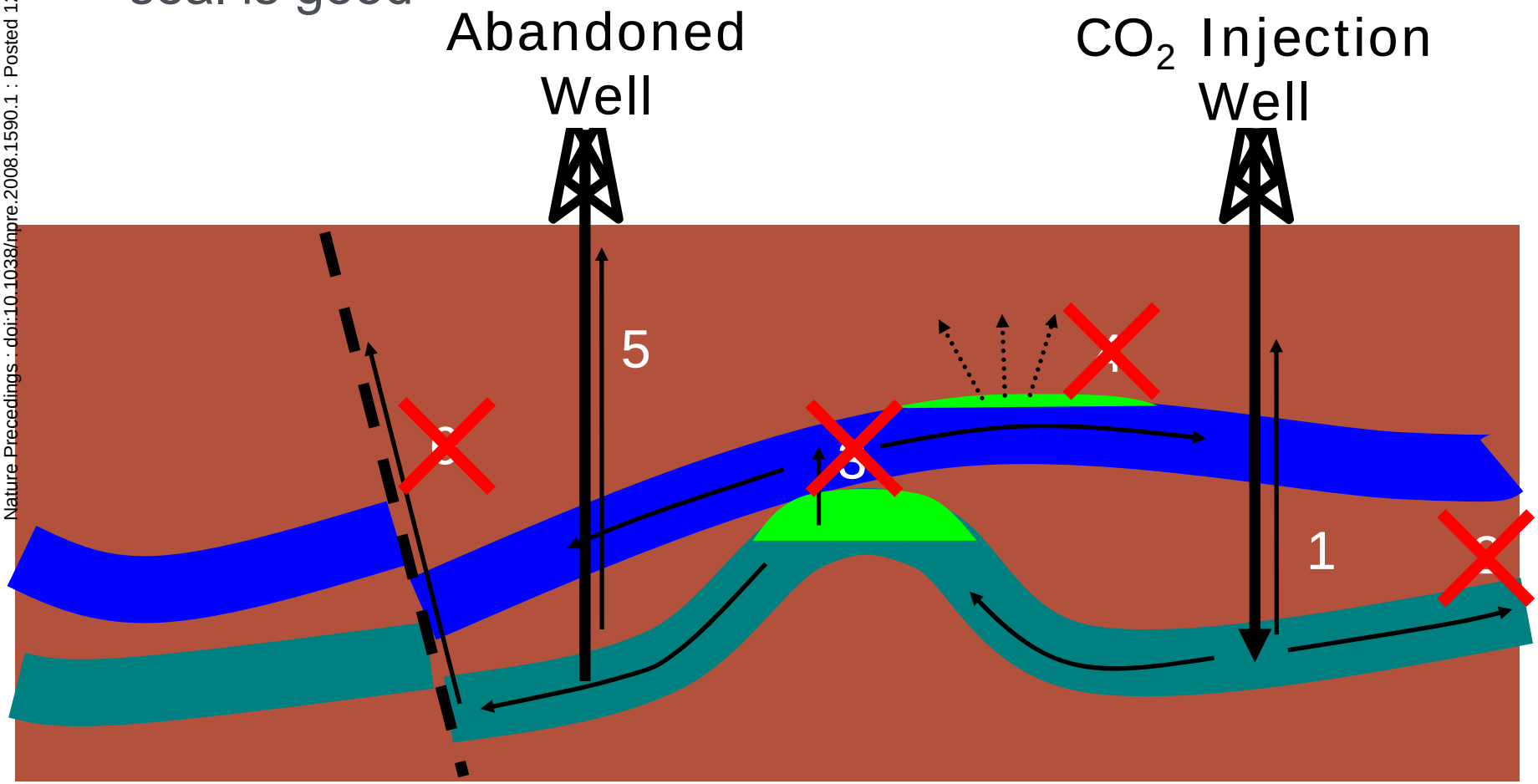
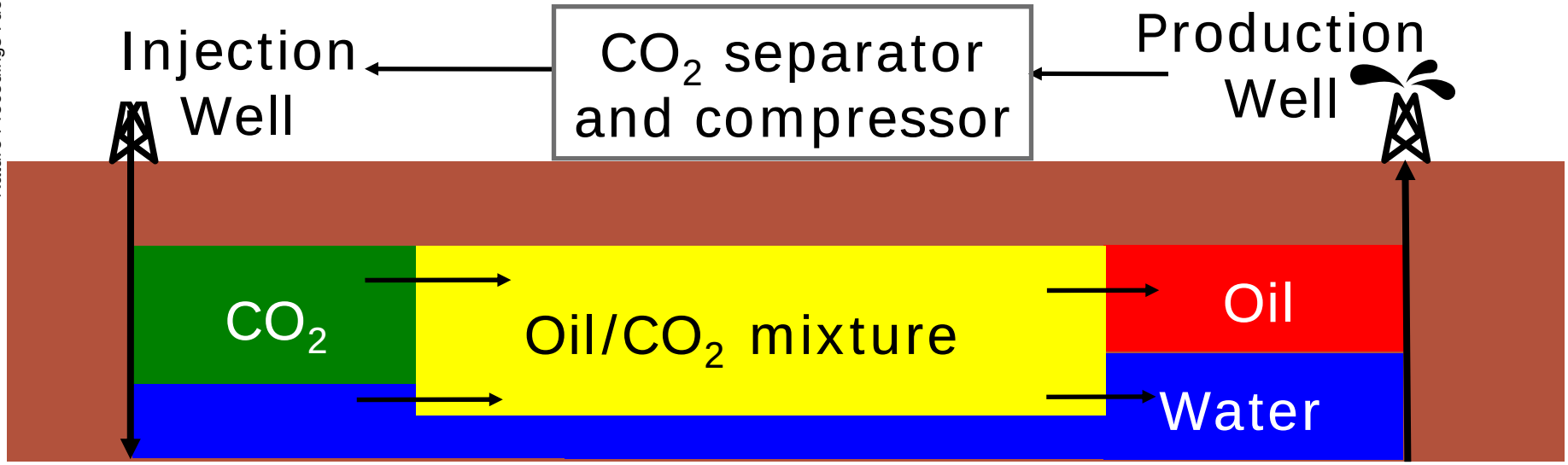
How Could the CO_2 Escape?

Presence of hydrocarbons indicate that the geologic seal is good



How Far Does the CO_2 Spread?

- As CO_2 migrates through the rocks, it will be trapped in tiny bubbles (just like in an aquifer)
- CO_2 can also mix with oil
  - Spread throughout reservoir
  - Increases oil recovery
  - May be produced with oil



CO_2 Storage for Enhanced Oil Recovery?

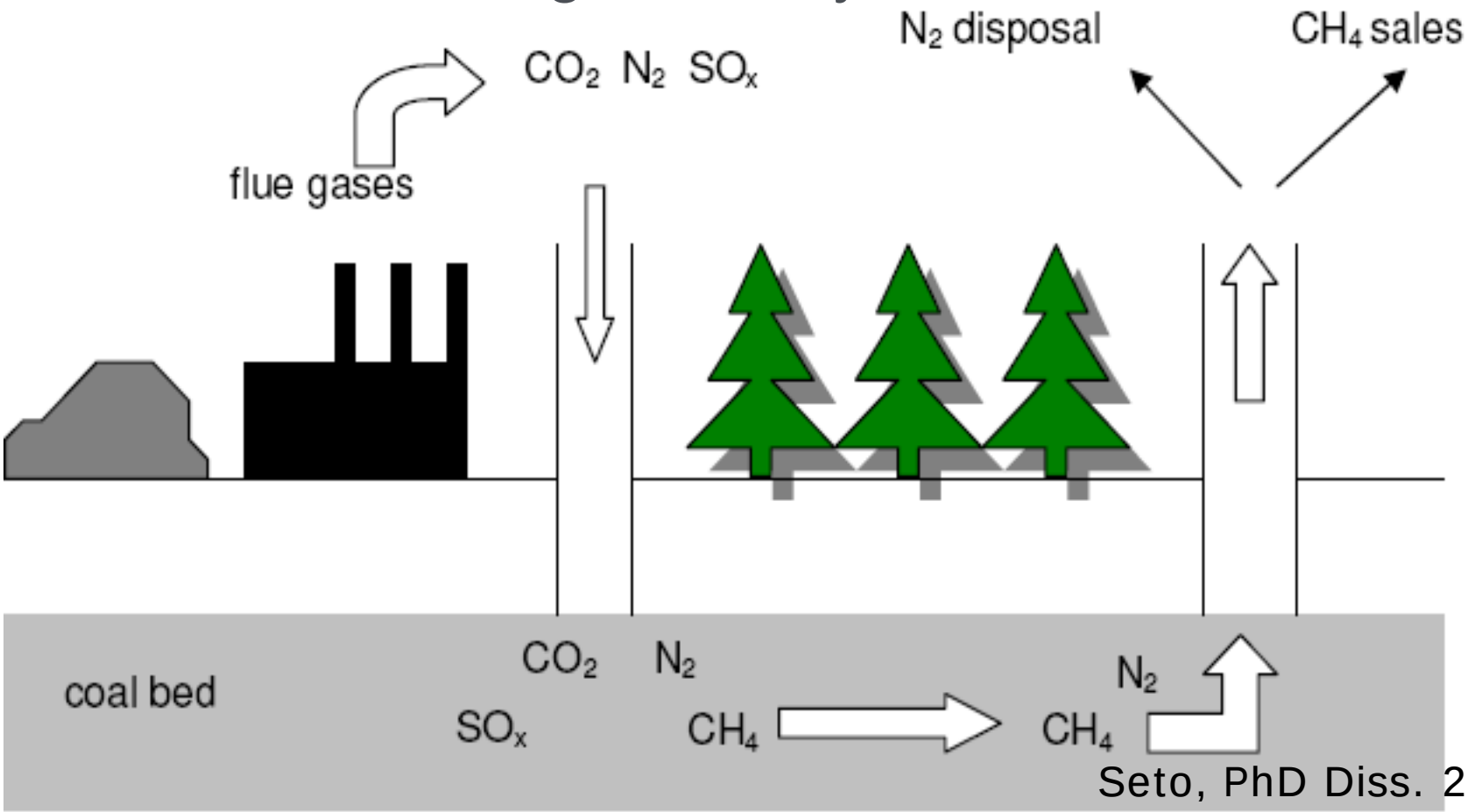
- CO_2 injection is a very effective EOR technique that has been used since the 1960's
- Doesn't that defeat the purpose of CO_2 injection? Partly, but…
  - Increased oil recovery offsets the cost of capture, making CO_2 storage more economic
  - Only a small fraction of injected CO_2 is produced
  - Technology and infrastructure already in place
  - If CO_2 is available oil companies will do this anyway

Questions We Must Answer

- How long does it take to immobilize the CO_2?
- What is the ultimate fate of the CO_2?
  - CO_2 will be immobilized in the same way as in an aquifer
- How we design injection processes that reduce the potential for leakage?
  - Make sure all wells are properly sealed
  - Inject chase water to ensure CO_2 trapping

Storage in Unmineable Coal Seams

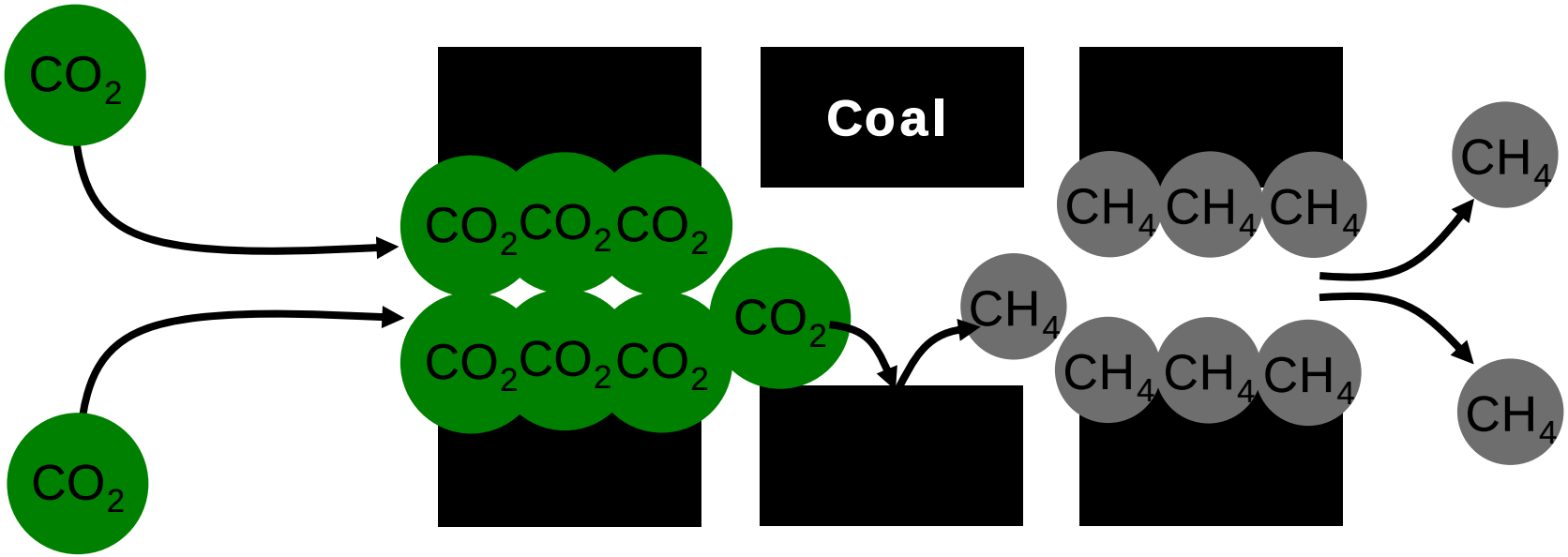
- Smallest volume of potential storage space
- Excellent storage security



Seto, PhD Diss. 2007

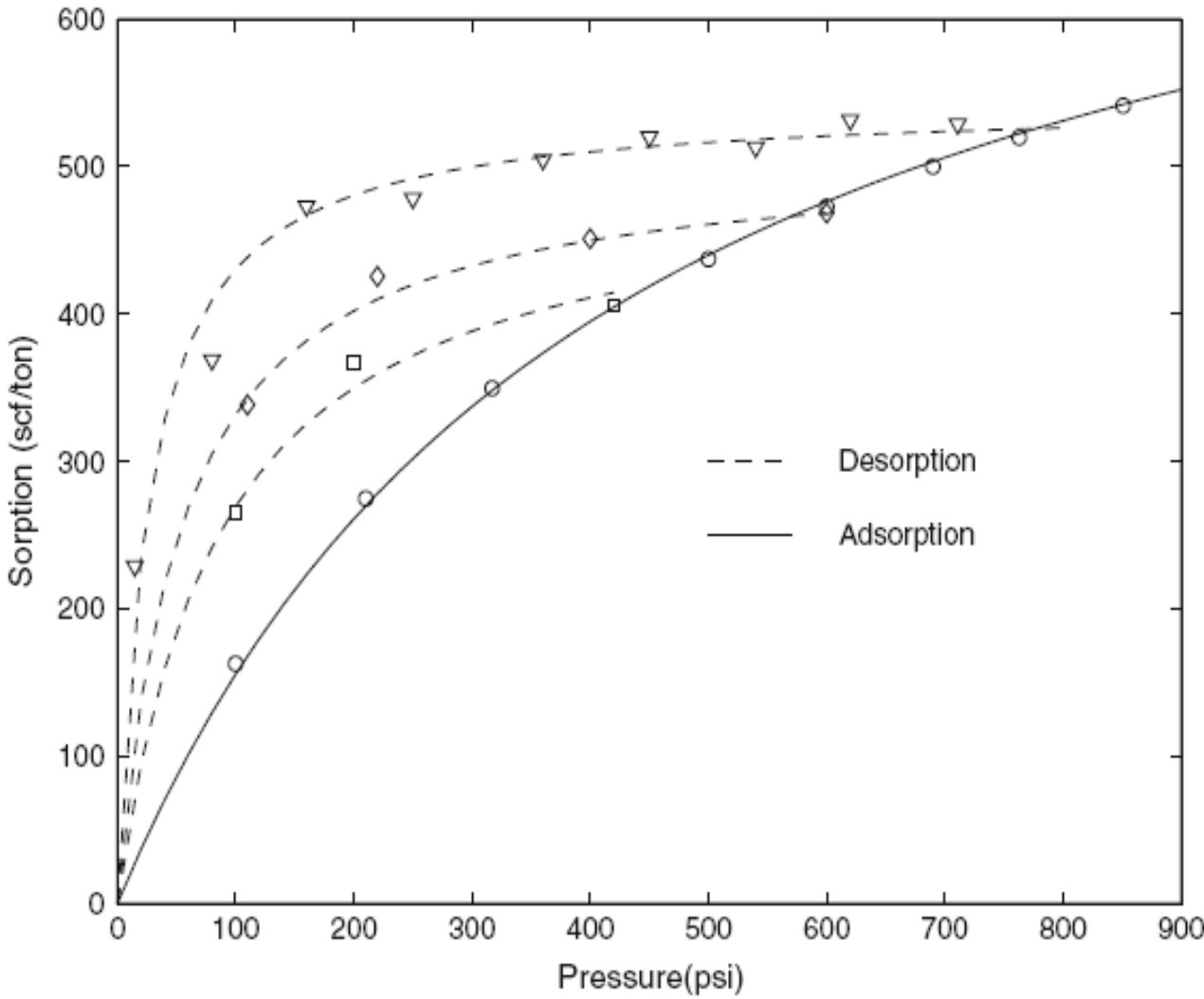
How Long to Immobilize CO_2?

- CO_2 is immobilized during injection
- Coal adsorbs CO_2 and releases methane
- Coal surface swells as CO_2 is adsorbed



CO_2 Adsorption

- Adsorption is a reversible process
- But has hysteresis, i.e. once CO_2 is attached to the coal surface it is hard to get it to detach



Jessen et al., TIPM 2007

Questions We Must Answer

- How could the CO_2 escape?
- How far does the injected CO_2 spread?
  - If CO_2 is not adsorbed during injection it could flow out of cracks in the coal seam
- How long does it take to immobilize the CO_2?
  - CO_2 should be immobilized during injection
- What is the ultimate fate of the CO_2?
- How we design injection processes that reduce the potential for leakage?
  - CO_2 will stay on coal surface indefinitely

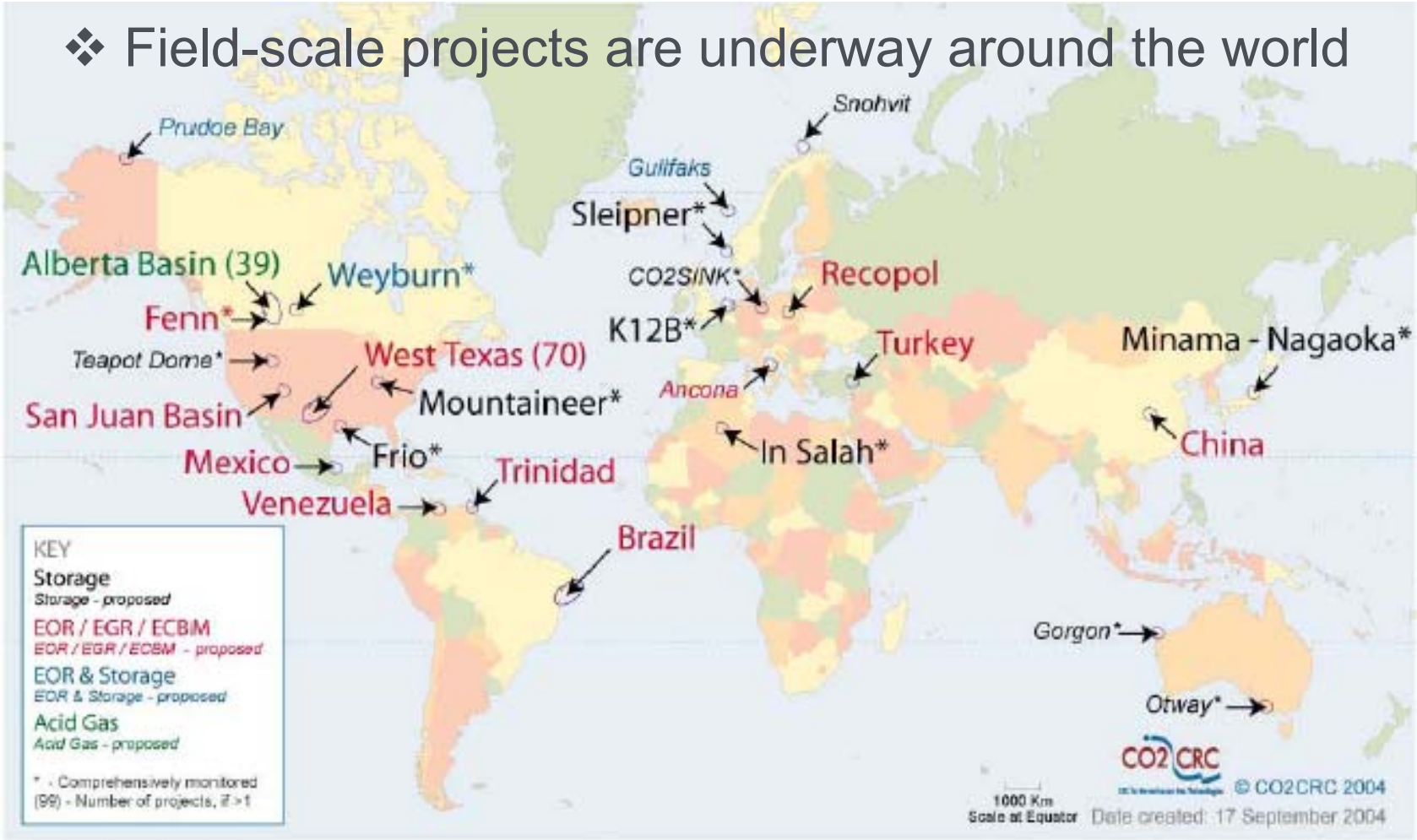
What Does This All Cost?

- CO_2 capture and compression is the expensive part
  - $20 to $74 (2002 US$) per tonne of CO_2 avoided
  - Much of this cost is for extra power required by separators
  - Typical efficiencies for the solvent/amine separations are about 15%. A breakthrough in separations technology would make a big difference
- Cost of injection (2002 US$ per tonne of CO_2)
  - Saline aquifers $0.2 to $ 30.2
  - Depleted Oil Fields $0.5 to $4.0
  - Enhanced Oil Recovery $-92 to $66.7
  - Enhanced Coalbed Methane Recovery $-20 to $150

Source: IPCC Special Report on CCS, 2005

Conclusions

- All of these issues are areas of active research
- Field-scale projects are underway around the world



Source: Peter Cook, CO2CRC

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Many Thanks To:

- Stanford, Dept. of Energy Resources Engineering/Global Climate and Energy Project:
  - Prof. Franklyn Orr, Jr., Marc Hesse, Carolyn Seto
- Imperial College London, Dept of Earth Sciences and Engineering
  - Prof. Martin Blunt, Ran Qi, Erica Thompson
- Dr. Kristian Jessen, Dept. of Chemical Engineering and Material Science, University of Southern California

- Research Sponsors
  - Grantham Institute for Climate Change
  - Shell Grand Challenge on Clean Fossil Fuels

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Slide 7: Parson and Keith, Science, **282**, 1053-1054, 1998.

Slides 9, 17:" Carbon Sequestration Atlas of the United States and Canada," National Energy Technology Laboratory, US DOE, 2007, http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/index.html

Slide 11: Unpublished data courtesy of Hu Dong

Slide 12: Hesse, M.A., H.A.Tchelepi and F.M. Orr, Jr., "Scaling Analysis of the Migration of CO2 in Aquifers", SPE 102796, Presented at the 2006 SPE Annual Technical Conference and Exhibition, San Antonio, TX, 24-27 Sept 2006

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