Geology (and policy) matters: The challenging case for carbon storage, U.S. Mid-Atlantic margin

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RUTGERS Energy Institute

Rutgers Symposium on Carbon Capture and Sequestration

Rutgers Energy Institute (http://rei.rutgers.edu/)

Date: Monday, October 27th, 2008

Session-1: The Global and National Scene
Convener: Ken Miller

8:30 – Paul Falkowski, Rutgers University
Carbon cycle – why we can't fix our problem easily or cheaply

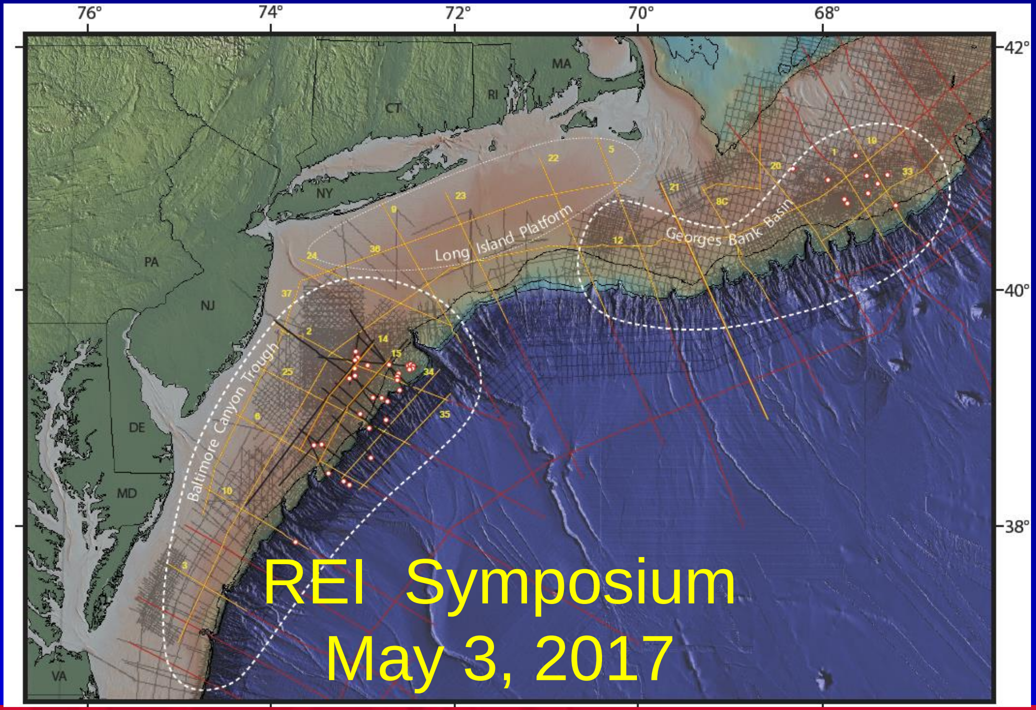
9:00 – Mike Trachtenberg, Carbozyme, Inc.
Social-Economical-Political Landscapes of CCS

9:45 – Dan Schrag, Harvard University
Grand Science Challenges of CCS

2008

U.S. DEPARTMENT OF ENERGY

Battelle
The Business of Innovation



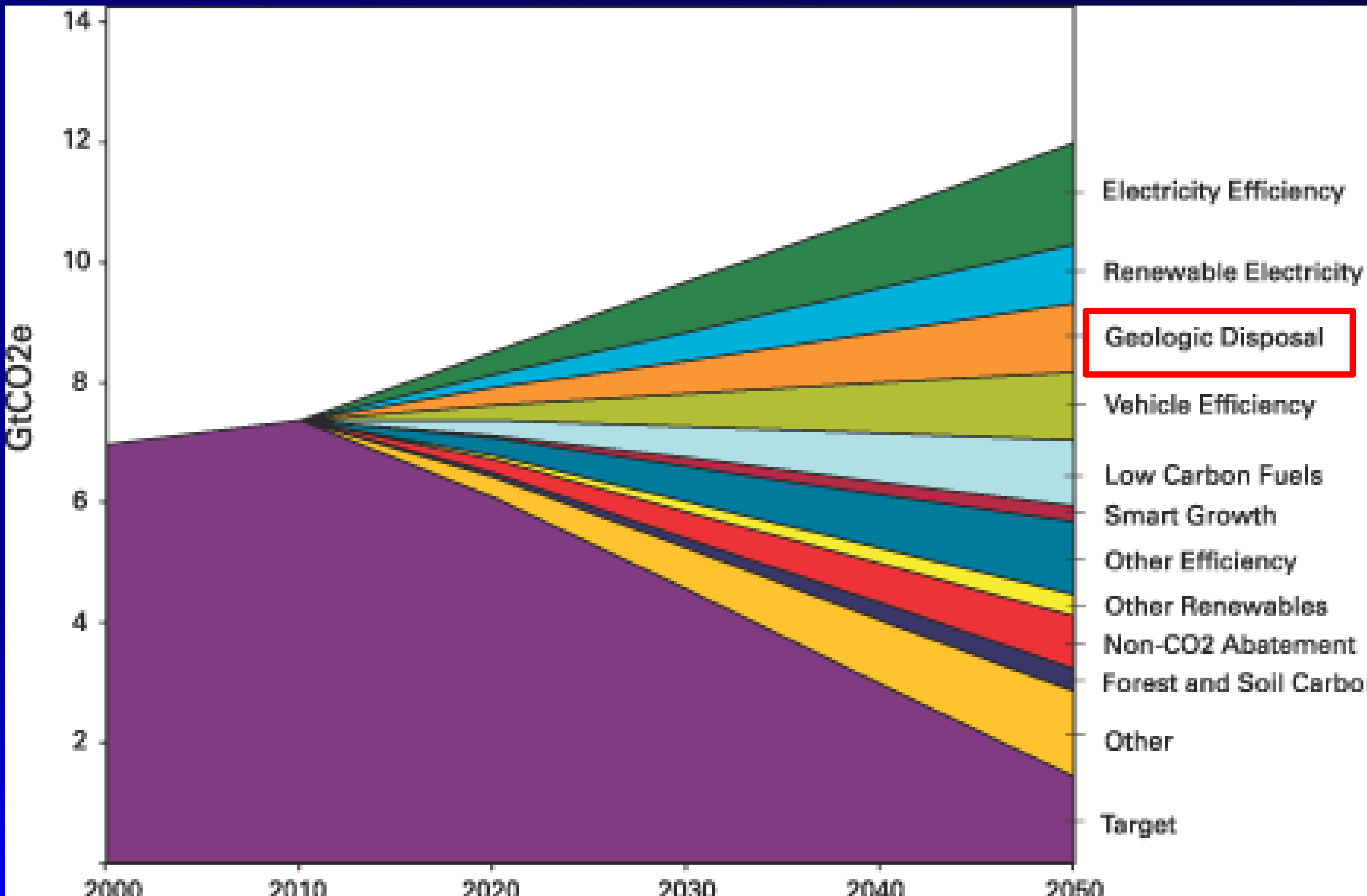
MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

MID-ATLANTIC U.S. OFFSHORE CARBON STORAGE RESOURCE ASSESSMENT PROJECT

NPR Morning Edition, May 1 2017
Environmentalists, Coal Companies Rally Around Technology To Clean Up Coal:

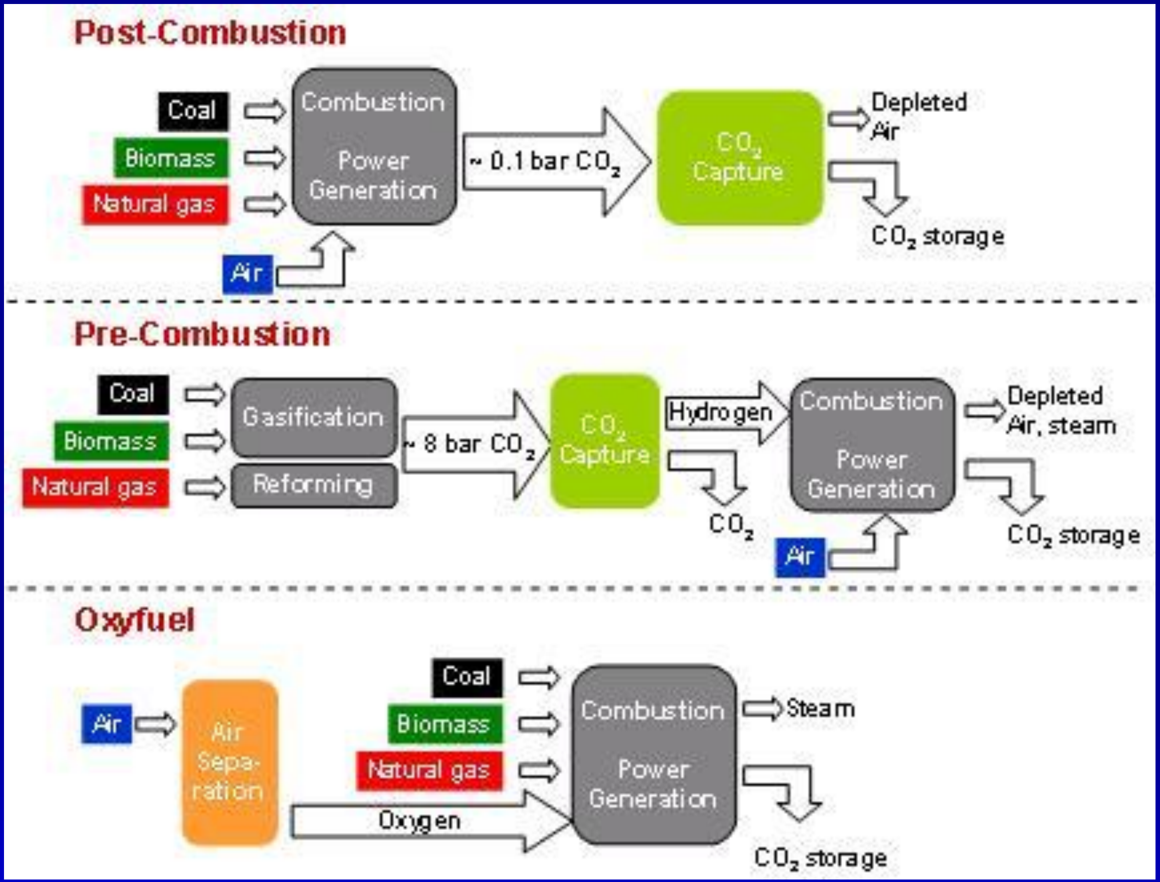
Solution: All of the above

Energy stabilization wedges Pacala & Socolow (2011)



Carbon Capture from large point sources

1,000 stationary sources account ~30% of global CO_2 emissions
Pre-, Post-, or Oxyfuel capture, compression, and pipe away



http://ceramics.org/ceramic-tech-today/doe-awards-millions-for-carbon-capture-storage-and-for-solar-grid-integration

Post-combustion: capture CO_2 solvent/membrane

Pre-combustion: gassify coal/biomass/CH_4 burn H_2

Oxyfuel: burn in O_2 with flue gas H_2O and CO_2

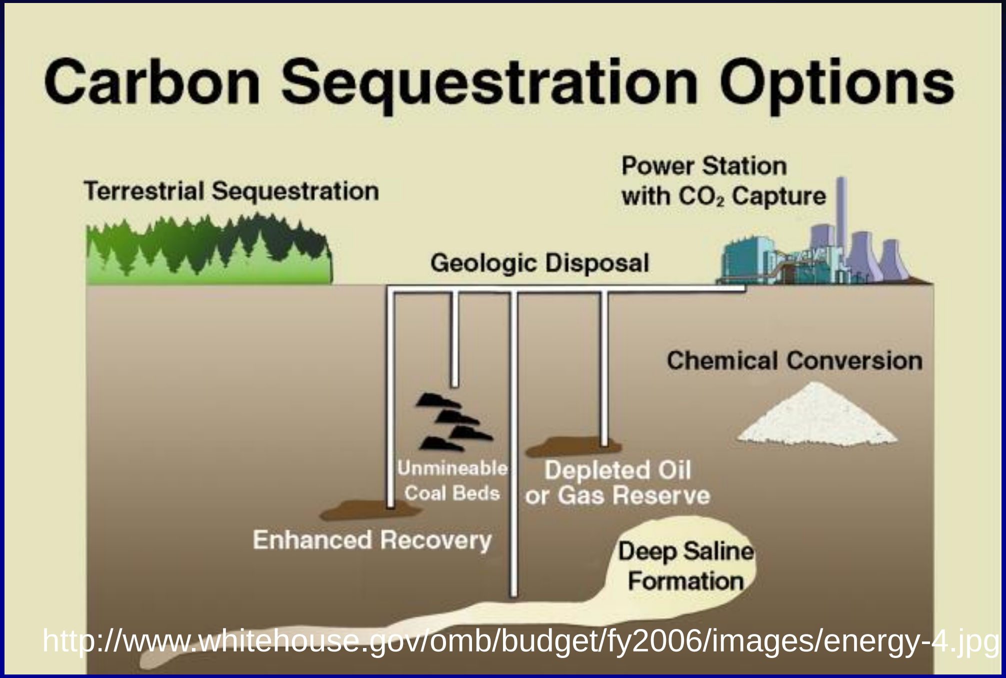
Negative CO_2 if use Bio-energy with carbon capture and storage (BECCS) or air capture (e.g., Klaus Lackner)

CCS = carbon capture and storage/sequestration

Carbon storage options:

1) Biological storage
- (re)forestation
- aquatic biomass

0.4 Gt/yr Pacala & Socolow (2011)



http://www.whitehouse.gov/omb/budget/fy2006/images/energy-4.jpg

2) Geological storage
- inject CO_2 into ocean (a very bad idea)
- accelerated weathering (see Keleman & Matter)

  http://www.ldeo.columbia.edu/gpg/projects/carbon-sequestration
- subsurface storage of supercritical CO_2

  ~1.5 Gt/yr Pacala & Soccolow. 300 power plants


Madin, *Oceanus*, 2010

[SHOW CAPTION]

Should We Inject Carbon Dioxide into the Deep Ocean?

Study finds that some seafloor life may be harmed by high CO_2 levels

By Kate Madin :: Originally published online December 22, 2009 : In print Vol. 48, No. 1, Jun. 2010

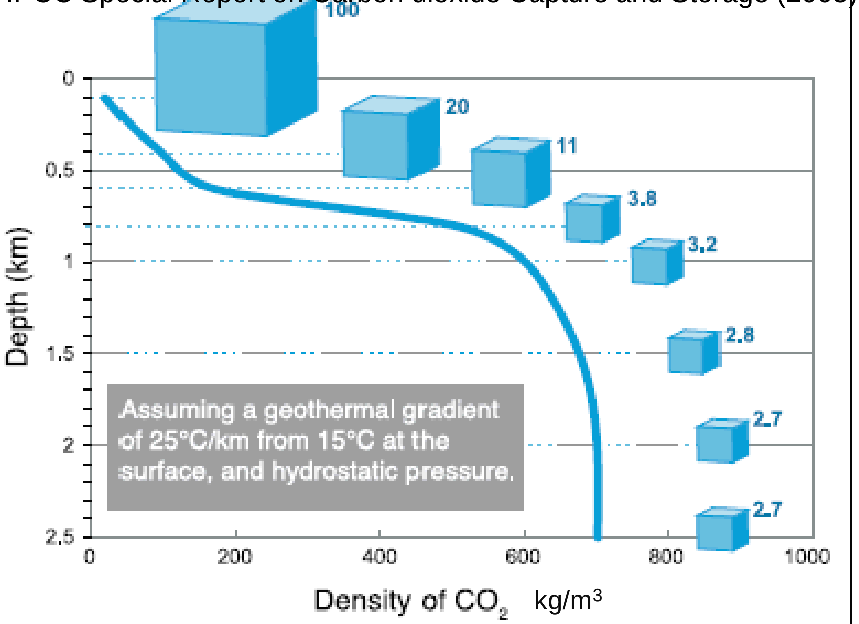
TOPICS: OCEAN ACIDIFICATION

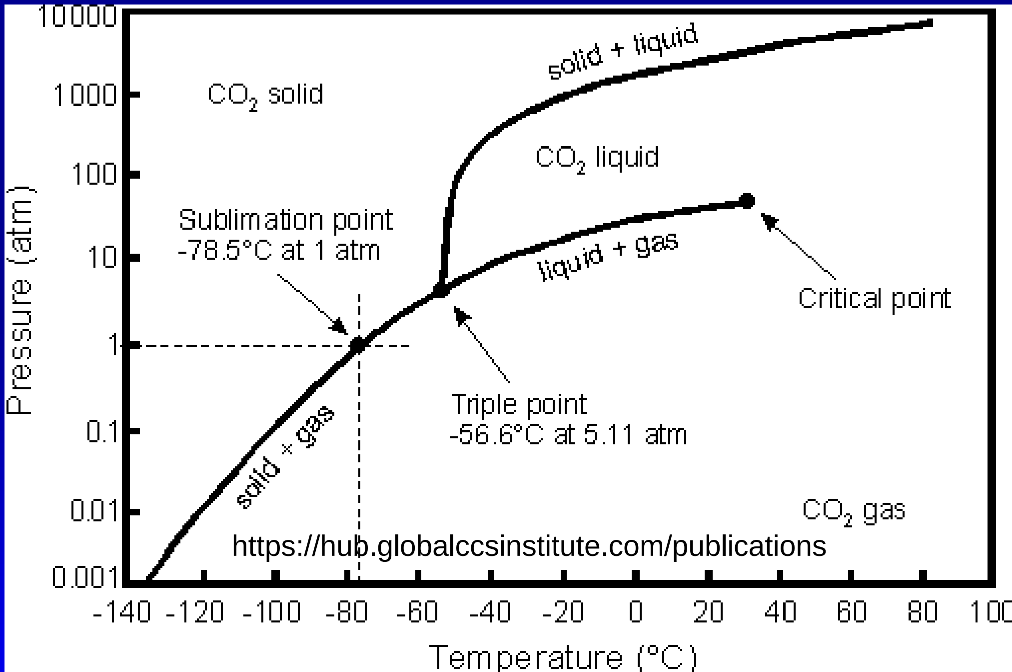
Carbon sequestration: Supercritical storage

Advantage of injecting CO_2 in supercritical state
Increases volume that can be stored in a reservoir
Supercritical state @ pressure >8 Mpa (80 bars), T >32°C
Compress to supercritical and store > 800 m burial depth

Requires a reservoir and seal (Geology matters)

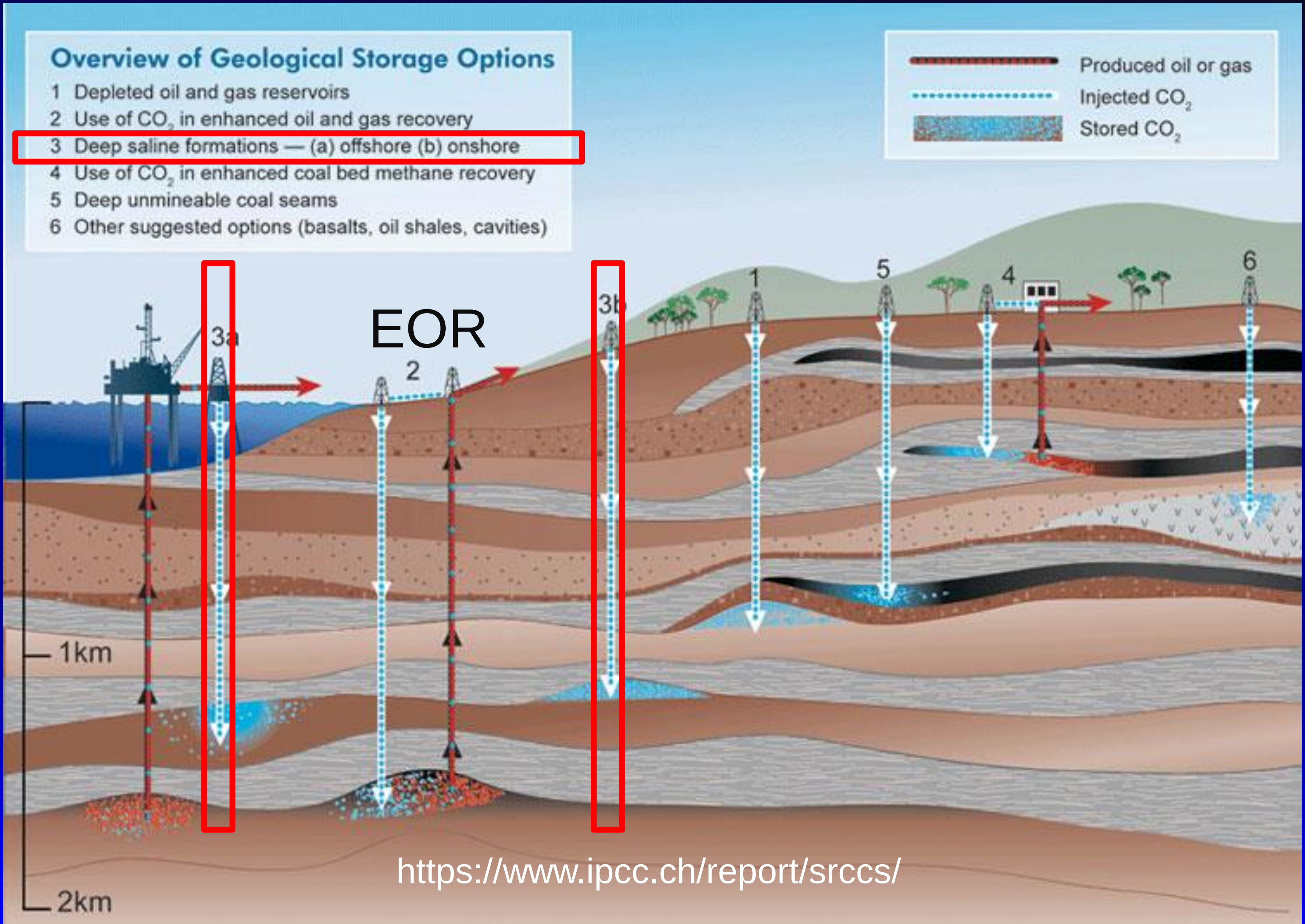
IPCC Special Report on Carbon dioxide Capture and Storage (2005)





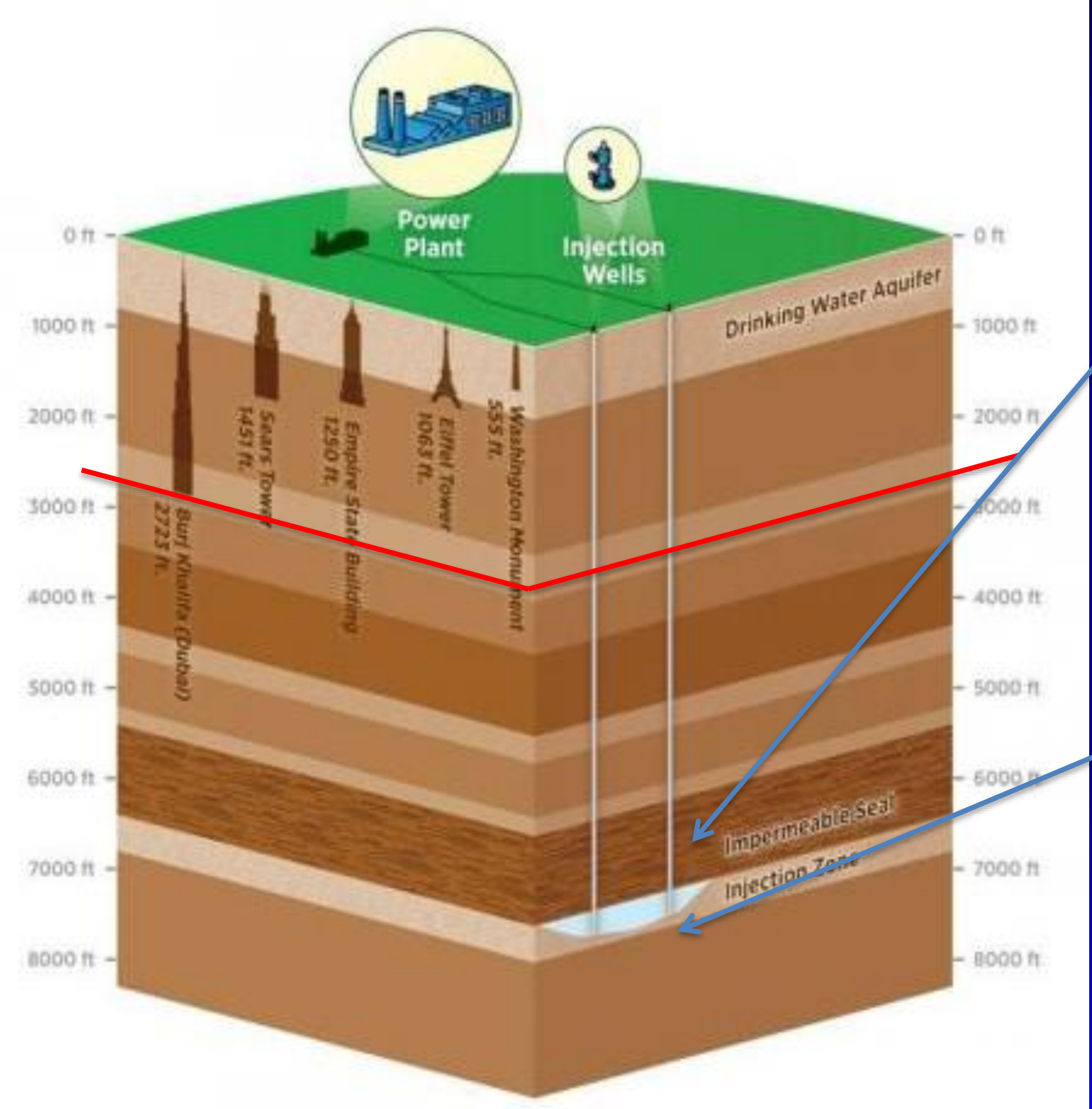
https://hub.globalccsinstitute.com/publications

Geological Storage supercritical CO_2



https://www.ipcc.ch/report/srccs/

Geology Matters: Geological Storage CO_2



Reverse Petroleum 101

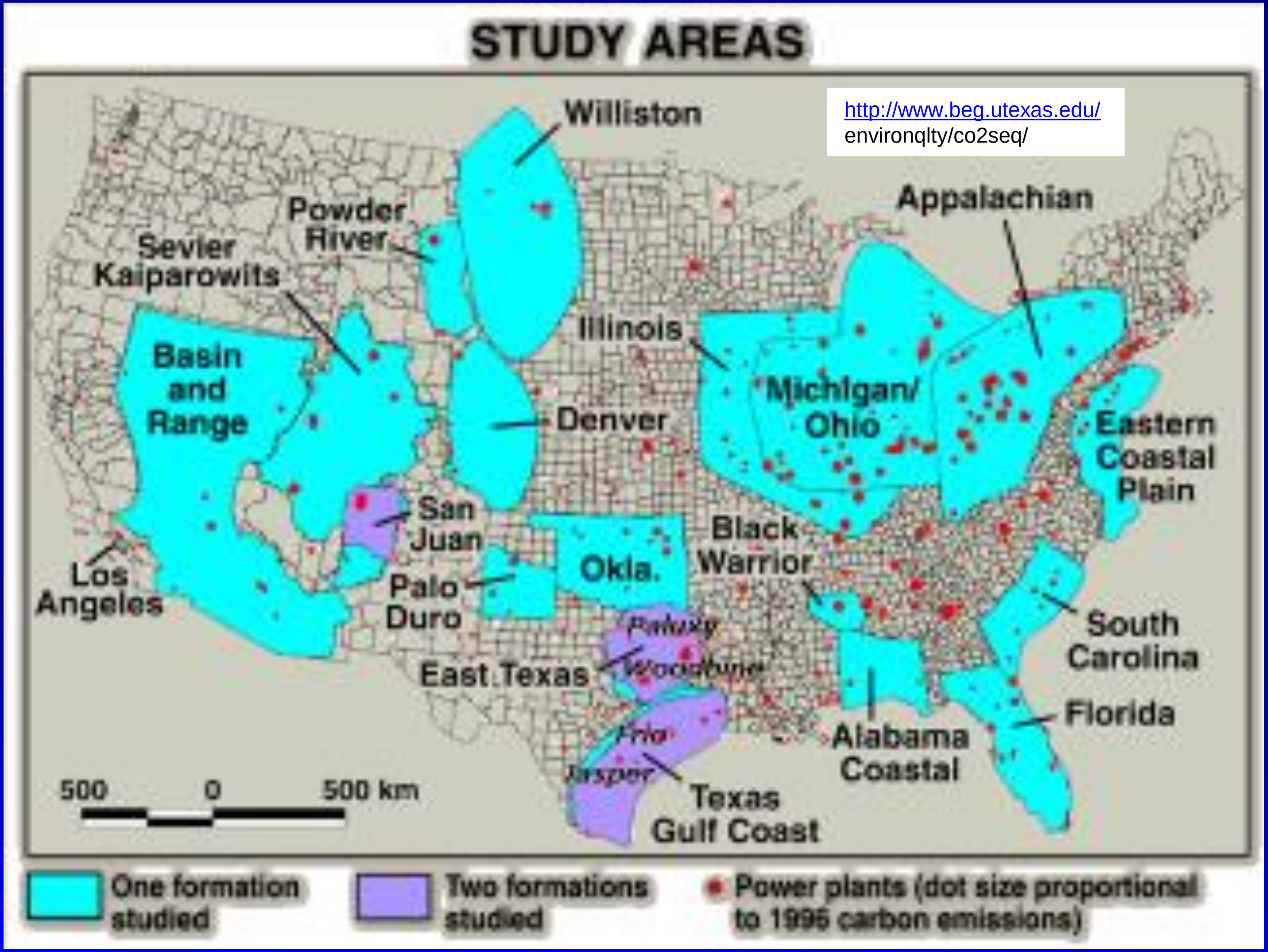
Seal = "Caprock"
Confining Unit
Impermeable
"tight" shales

Reservoir:
porous (20-30%),
permeable (>100 mD)
sandstones, limestones
saline water reservoirs
(not potable water)

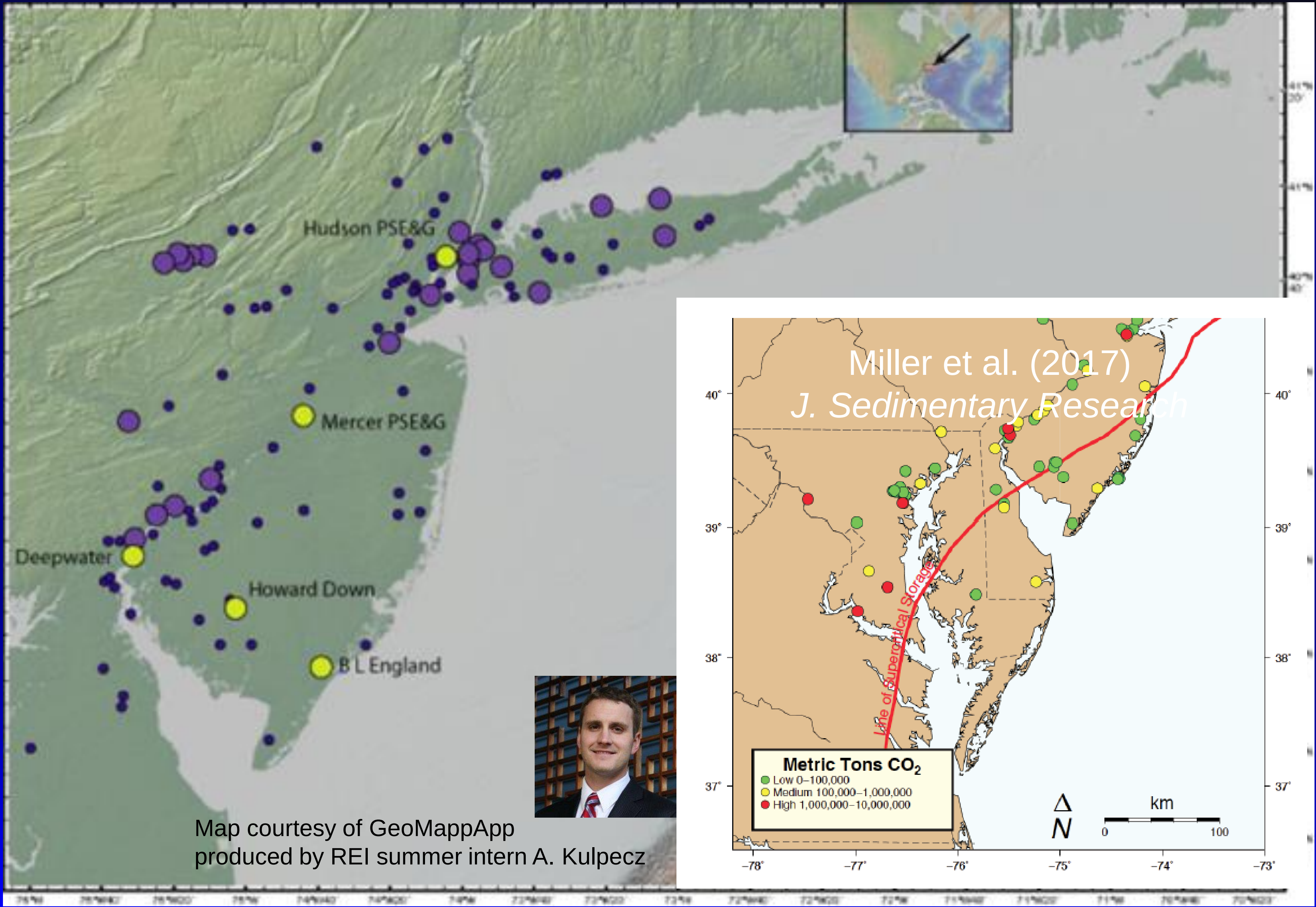
https://www.epa.gov/climatechange/carbon-dioxide-capture-and-sequestration-overview

U.S. Mid-Atlantic region for CCS

one of ~dozen suitable U.S. targets identified
strata sufficiently deep, porous, permeable, & hydraulically isolated from fresh aquifers
several major CO_2 producers in this region.



1 NJ & 1 Delaware coal power plants suitable

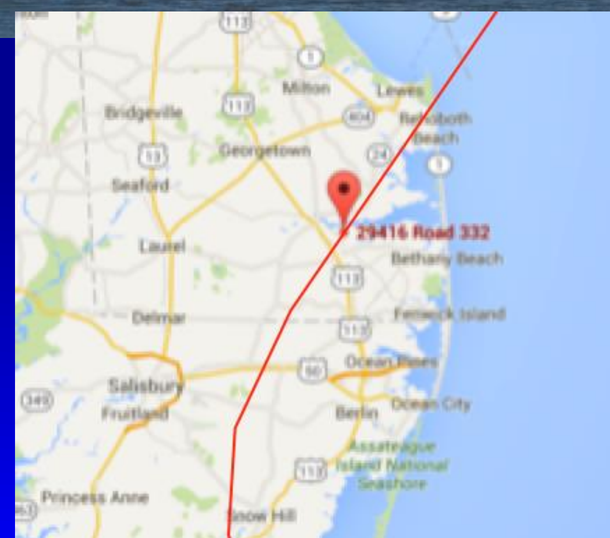


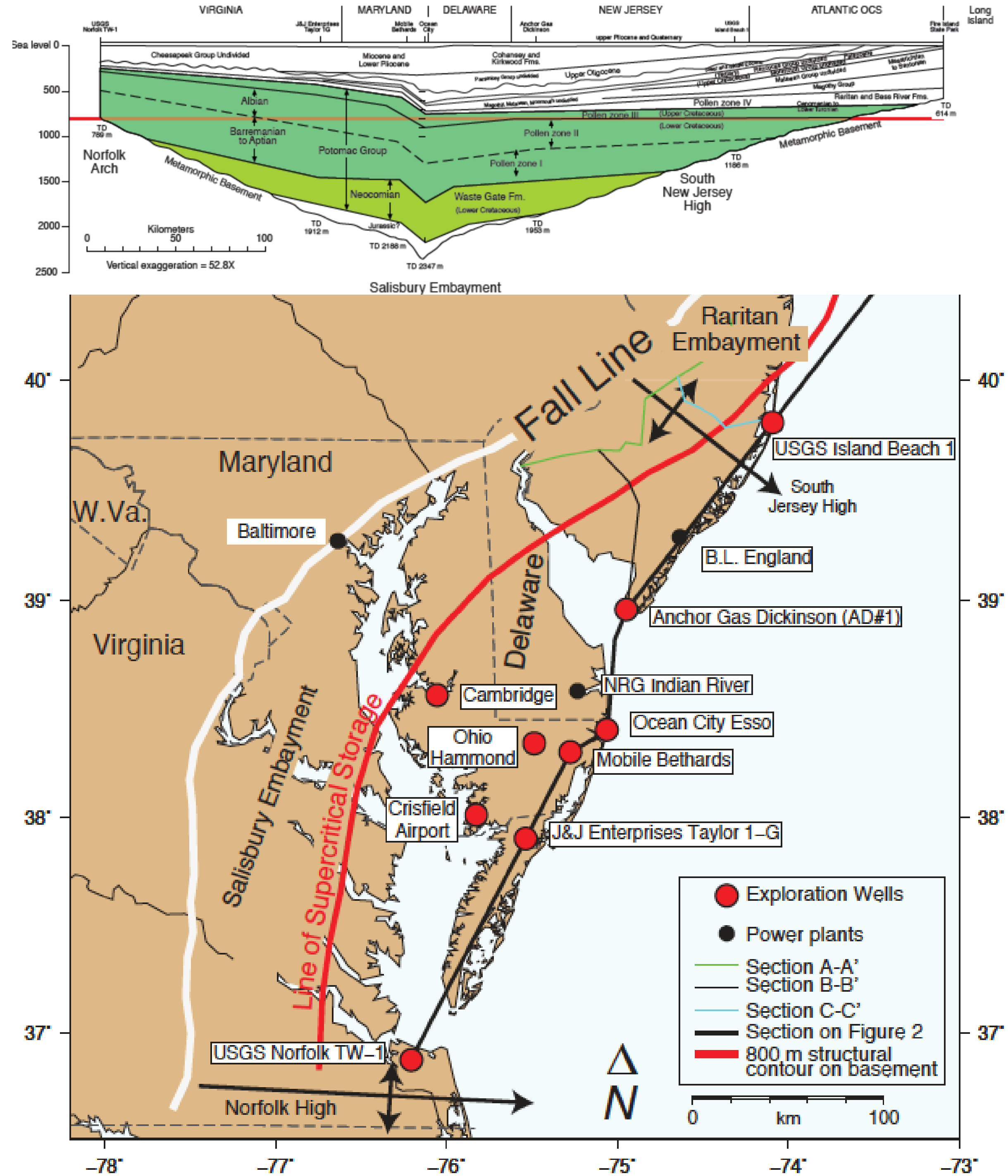
Map courtesy of GeoMappApp
produced by REI summer intern A. Kulpecz

Future onshore possibilities

BL England, Beesley’s Pt., NJ

Indian River power plant Delaware
Thick (6500 ft to basement)
Waste Gate/Potomac I target
Politically less difficult than NJ



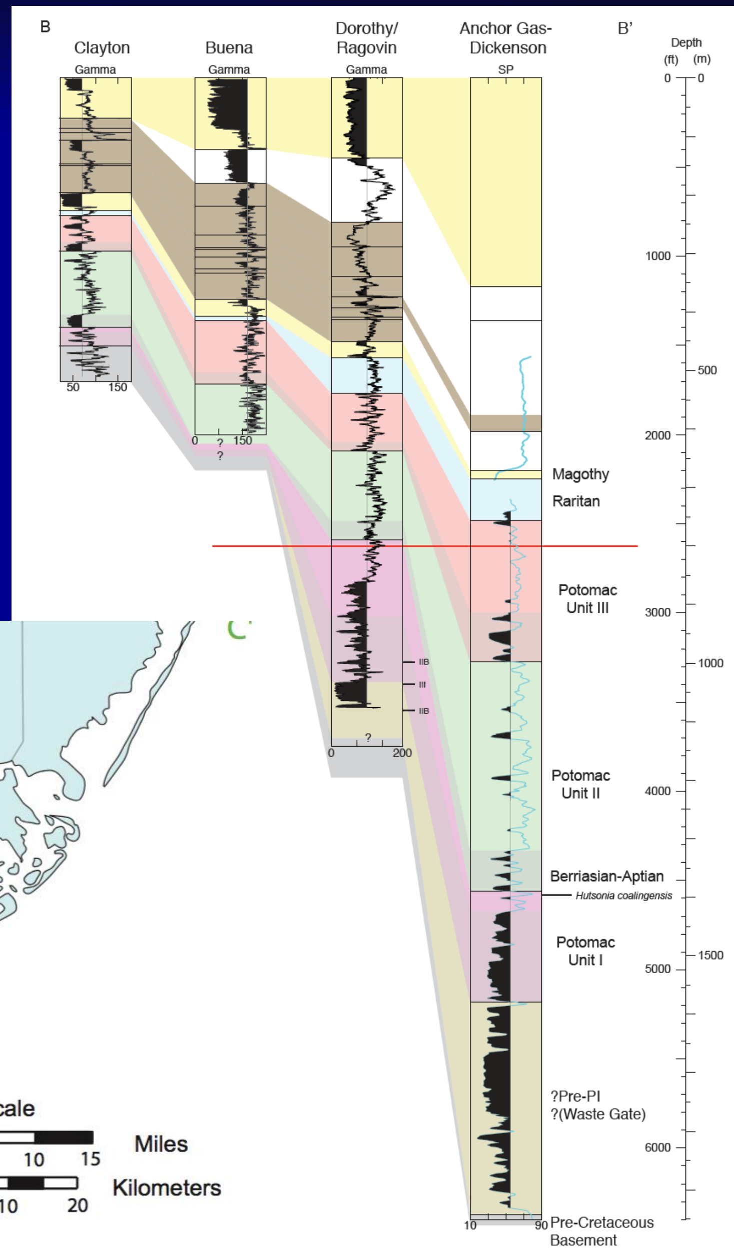


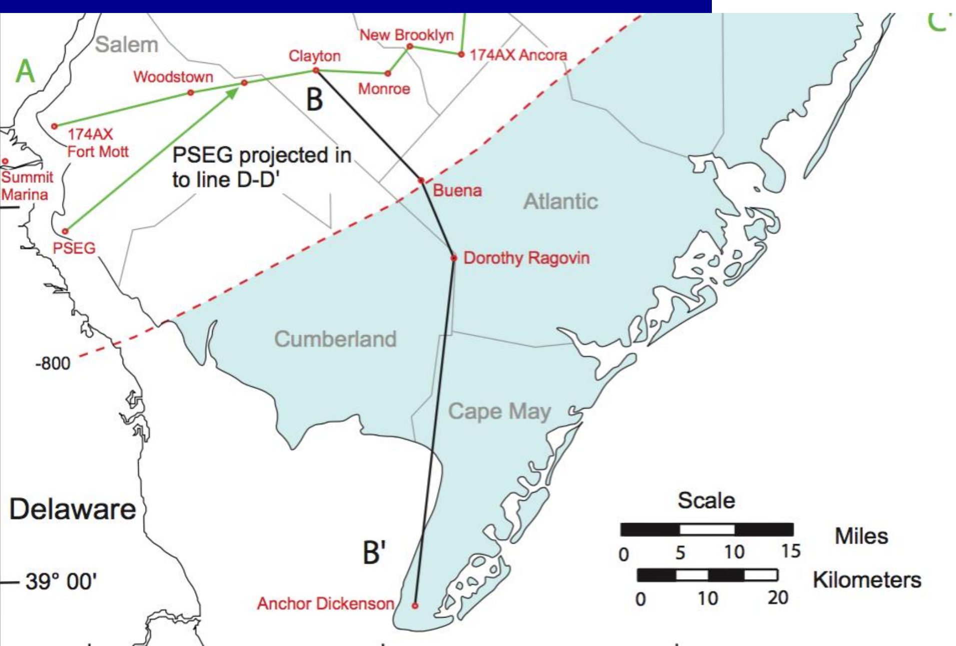
Onshore coastal plain storage

Miller et al. (2017)
J. Sedimentary Research

Onshore storage in Waste Gate and Potomac I Sands

After Sugarman et al. (2011) updated by Miller et al. (2017)





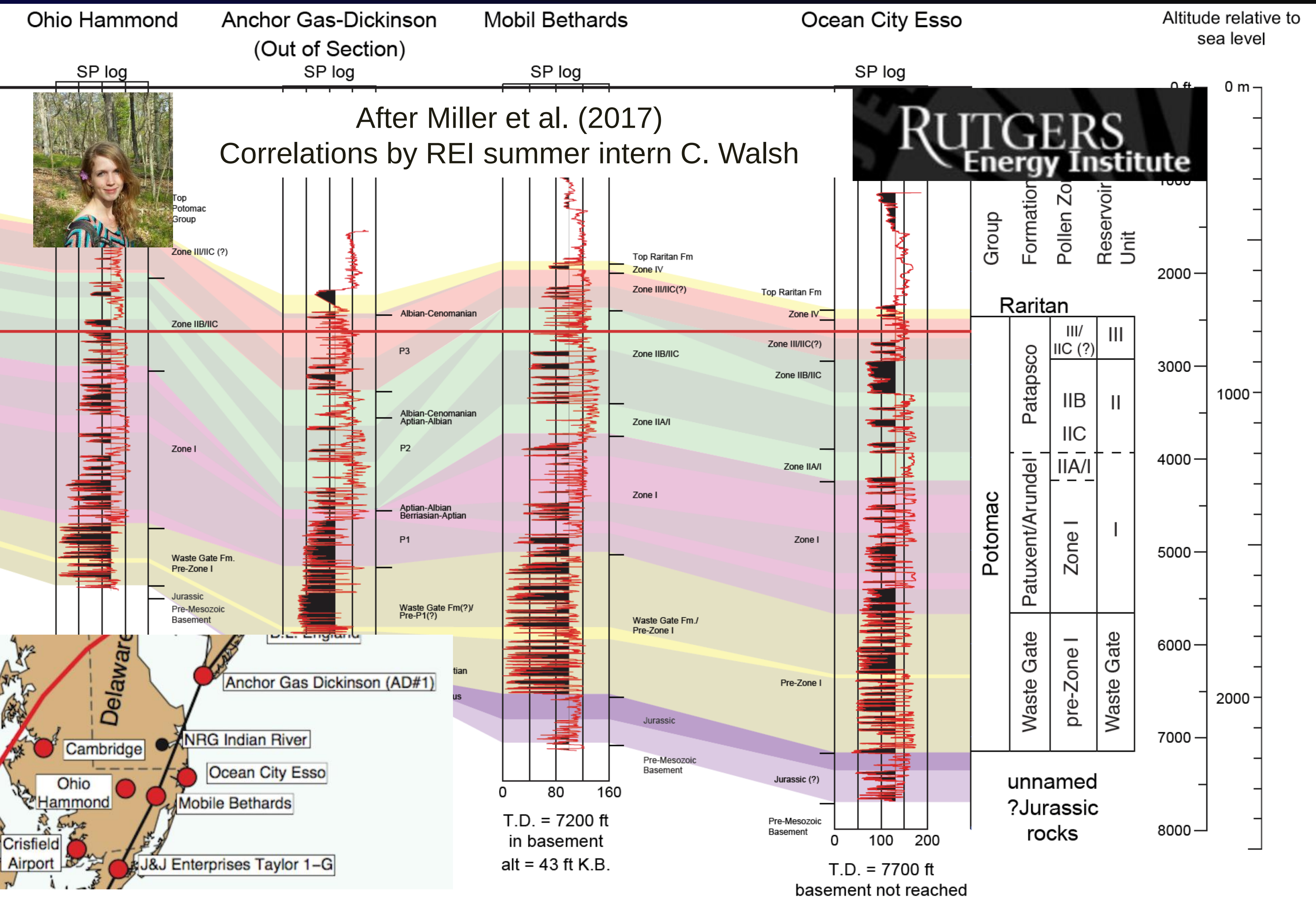
Composite Confining Unit

Potomac I Formation

Waste Gate Formation

Onshore storage in Waste Gate and Potomac I Sands

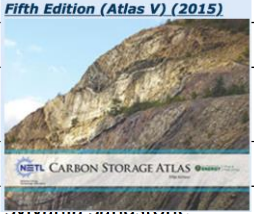
After Miller et al. (2017)
Correlations by REI summer intern C. Walsh



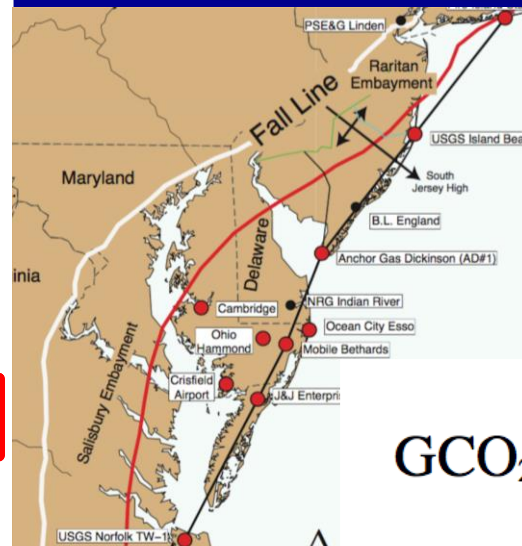
Onshore CO_2 storage capacity ~21 Gt C

Potential CO_2 Storage Resource* (million metric tons)			
Deep Saline Formation	**Low**	**Medium**	**High**
Mount Simon Sandstone	16,900	42,200	67,600
St. Peter Sandstone	8,800	22,000	35,200
	6,100	15,300	24,400
	4,500	11,300	18,100
	4,000	10,000	16,000
	1,560	3,900	6,040
Sylvania Sandstone	1,510	3,800	3,500
Oriskany Sandstone	720	1,800	2,880
Onshore Mid Atlantic	8,400	21,000	33,500
Dundee, Waste Gate, Conasauga, Potsdam, Rome Trough Sandstone	1,630	4,080	8,770

Carbon Storage Atlas – Fifth Edition (Atlas V) (2015)



21 Gt C (= 77 Gt CO_2) equivalent to 0.6 to 2.4 years of current U.S. emissions



MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

After Miller et al. (2017)

$$GCO_2 = A_t H_g \phi_t \rho_{CO2res} E_{saline} \quad (1)$$

GCO_2 mass of CO_2 storage resource in Gt C

ρ_{CO2res} density of CO_2 under reservoir conditions

ϕ formation total porosity (assumed 20% here)

A_t is the total area of the formation

H_g is the gross thickness of the prospective formation

E_{saline} is the storage efficiency factor (% of the total formation fluid displaced) low (1%), intermediate (2.5%) high (4%) (DOE/NETL, 2010).

mean reservoir depths are ~1500 m, geothermal gradient = 23°C/kms

Why the offshore Mid-Atlantic?

Good storage location: Thick, porous sands & confining beds <10,000 ft (3.4 km, lo porosity below)

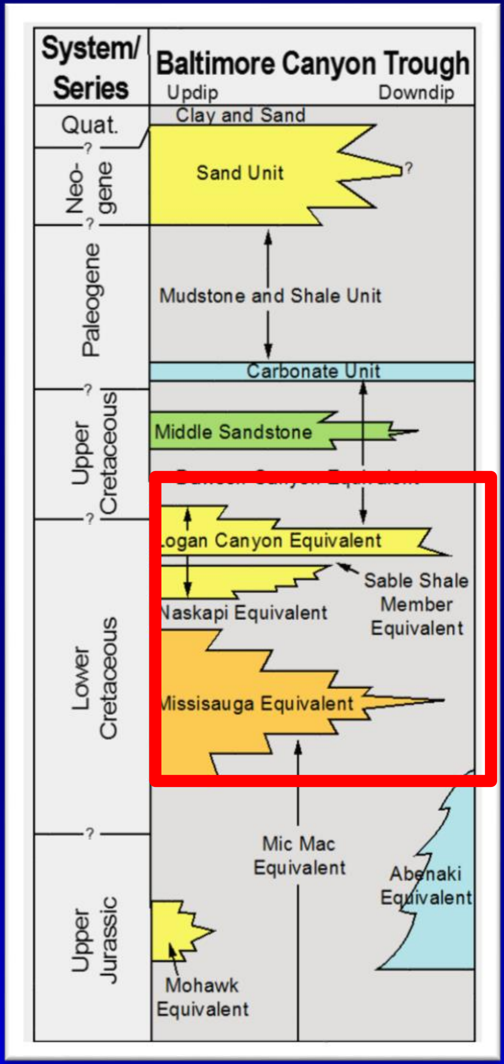
Preliminary estimates offshore storage 22-87 Gt (Monteverde et al., 2011)

Doesn't conflict with oil and gas resources: No CH_4 in Logan Canyon Sands, most of Mississauga

Avoids public perception concern of storage beneath populated area (Not Under My Backyard; Van Noorden, 2010)

Mitigates concerns regarding earthquake stimulation:(Zoback and Gorelick, 2012): supercritical CO_2 into the poorly indurated Logan Canyon will not exceed lithostatic pressures and cause fracturing and earthquakes

Targets
Logan Canyon &
Mississauga Formations



Libby French (1984)

Mid-Atlantic Offshore
Carbon Storage Resource Assessment Project
Geological Characterization

MID-ATLANTIC U.S. OFFSHORE
CARBON STORAGE RESOURCE
ASSESSMENT PROJECT

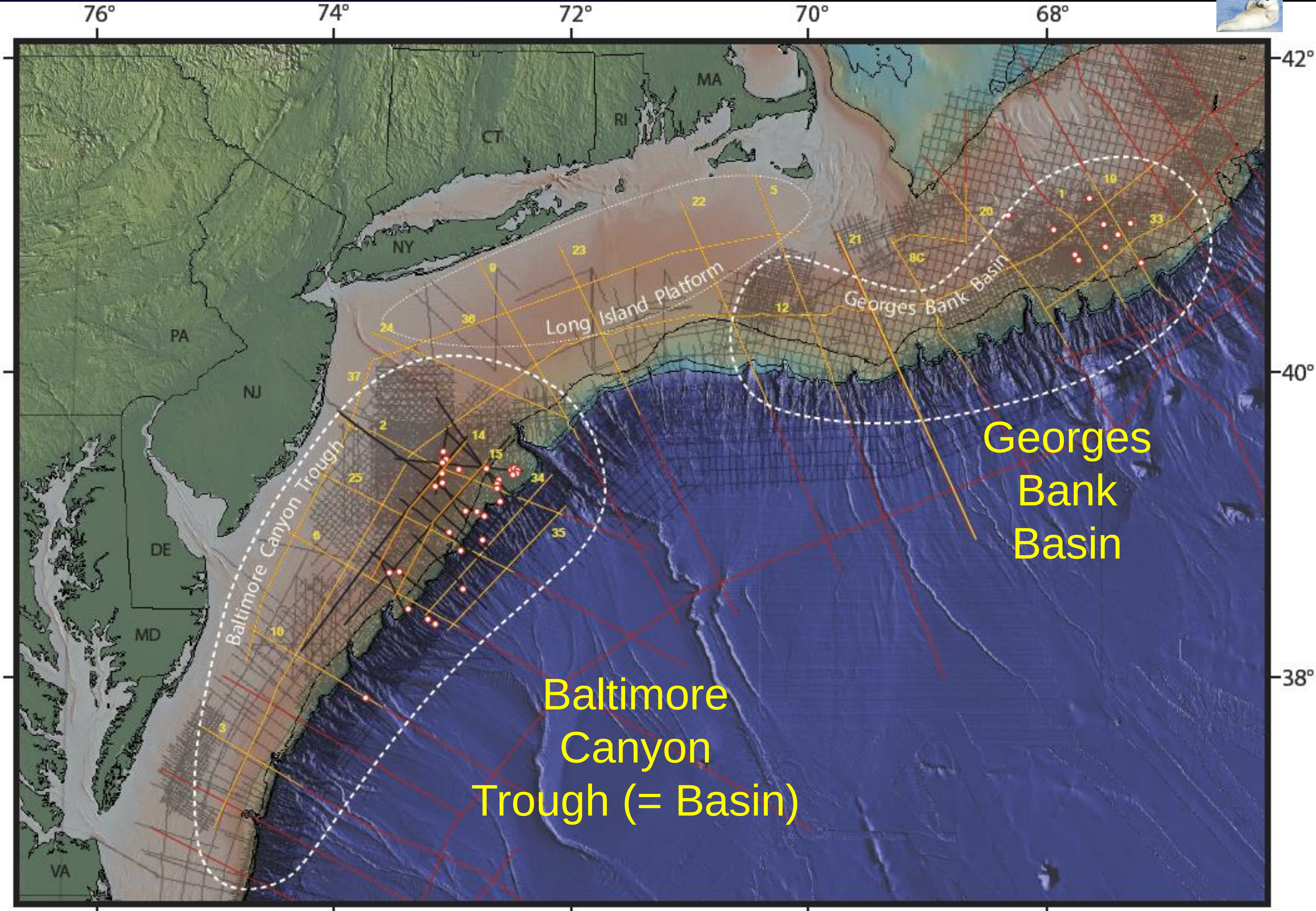
MRCSP
MIDWEST REGIONAL
CARBON SEQUESTRATION
PARTNERSHIP

MRCSP onshore New Jersey to Maryland: onshore reservoirs and traps and previous MRCSP onshore work: Miller, Browning, Thornburg

Geological evaluation offshore new project:
Log-sample evaluation of offshore reservoirs and traps
- Northern BCT: Chris Lombardi, Miller, Schmelz
- Eastern Georges Bank Basin: Stephen Graham logs
- Southern BCT: John Schmelz

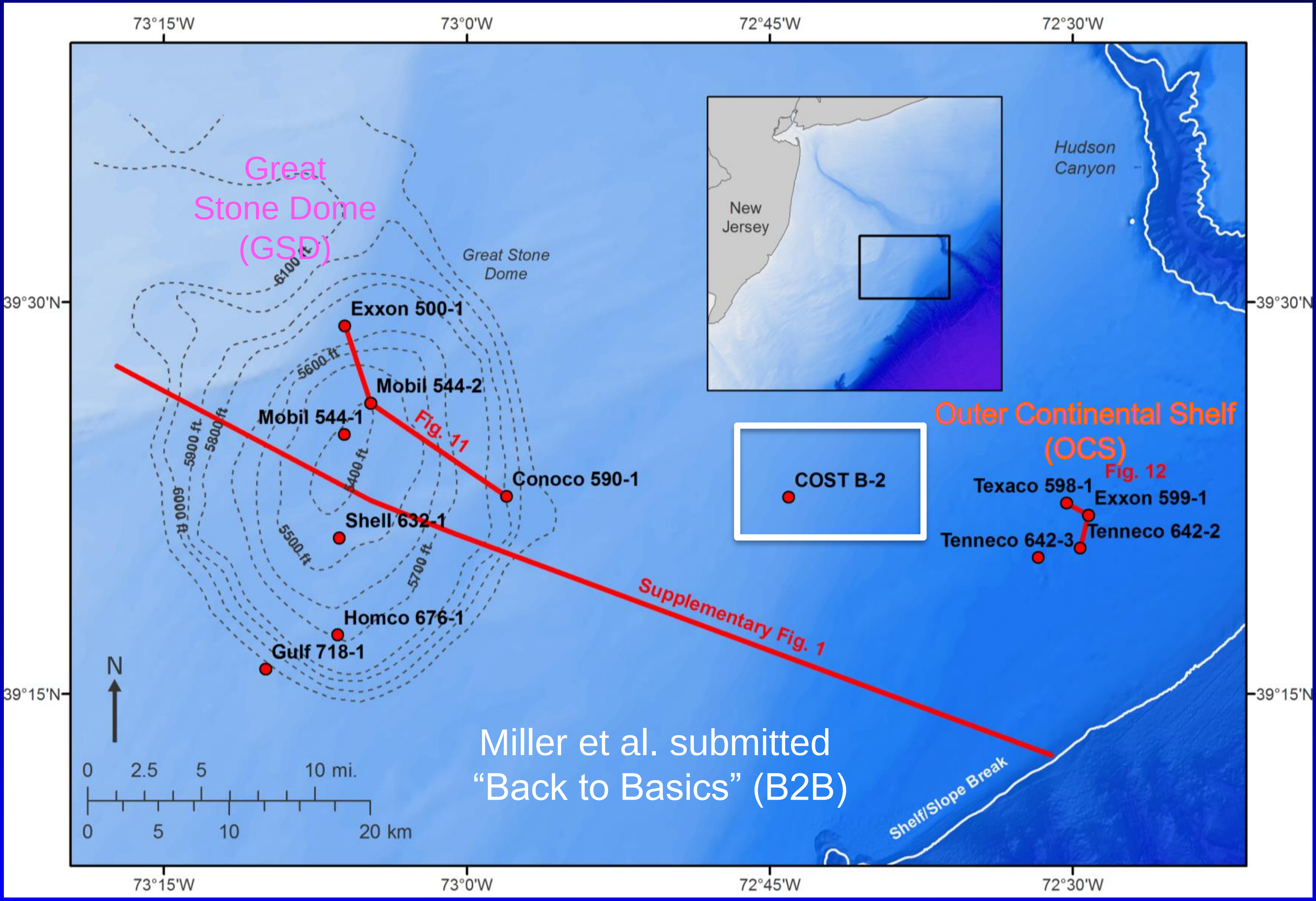
Seismic Evaluation: Mountain, Miller Baldwin, Schmelz, Graham, Adams

Rutgers focus: BCT & GBB sand reservoirs and shale seals



Well log transects: GSD & OCS

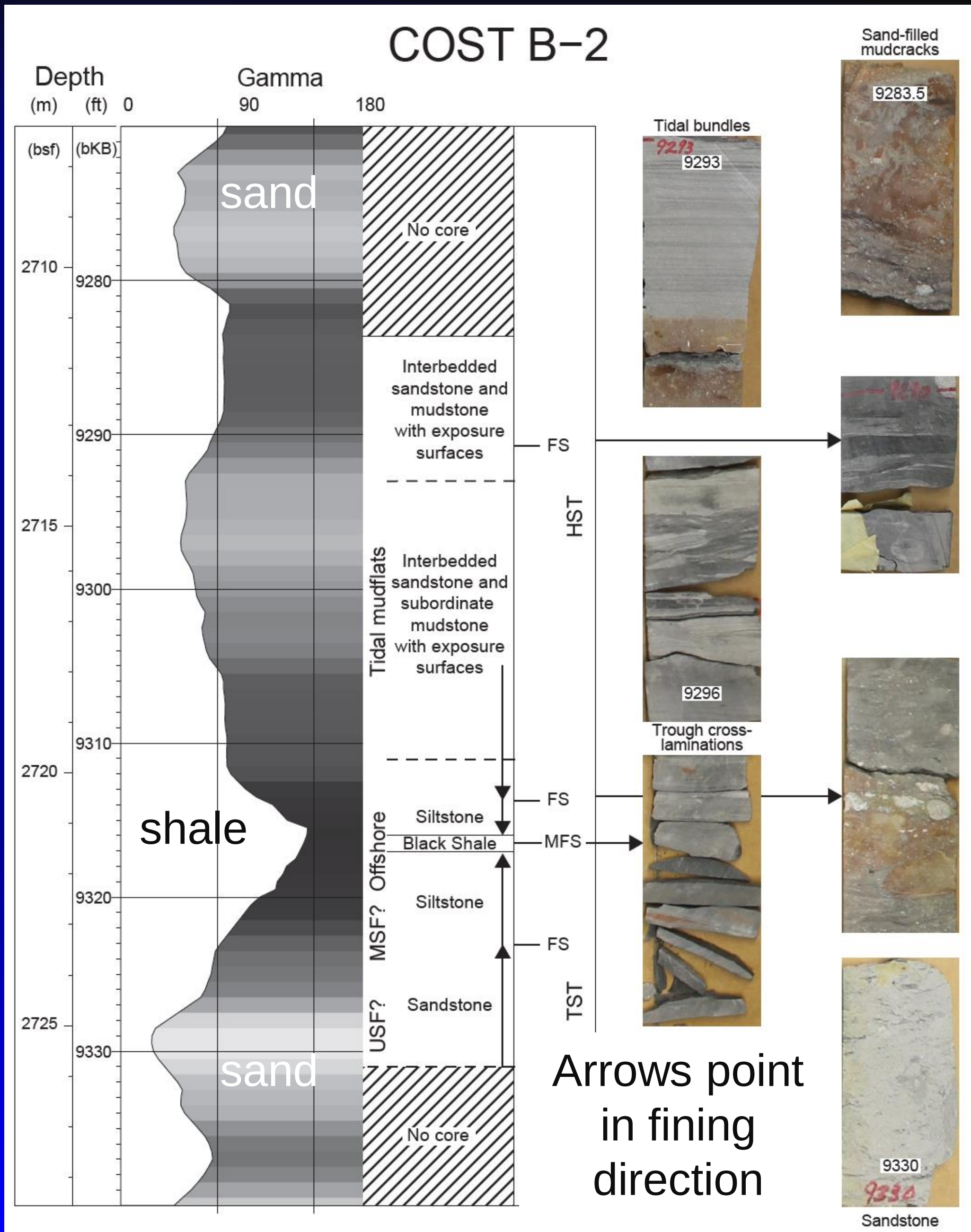
Continental Offshore Stratigraphic Test (COST) B-2 well industry-government consortium; Scholle (ed.) 1980



Miller et al. submitted “Back to Basics” (B2B)

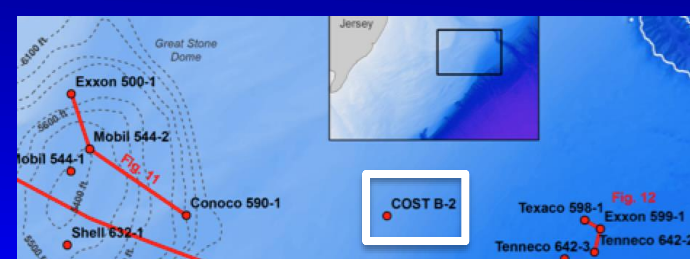
Miller et al. submitted (B2B)

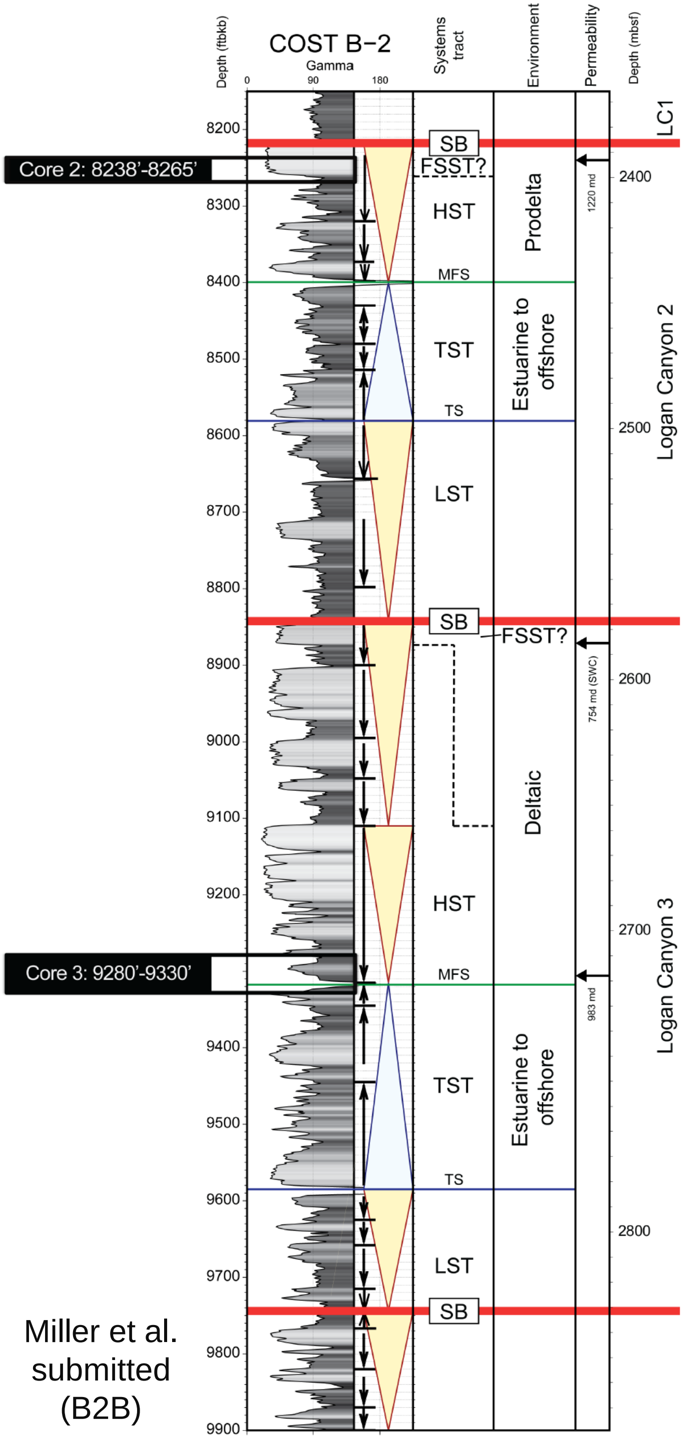
COST B-2 Core Ground truth



Register downhole logs to cores

Look at vertical changes on logs to infer sequences (unconformity bounded units)





Miller et al. submitted (B2B)

COST B-2 sequences

Logan Canyon 3 sequences (1 is the youngest)

Sequences predict sands are correlatable
Individual beds or most parasequences are not traceable, but sand prone appear at same level and and likely connected reservoirs

High porosity (>30%)

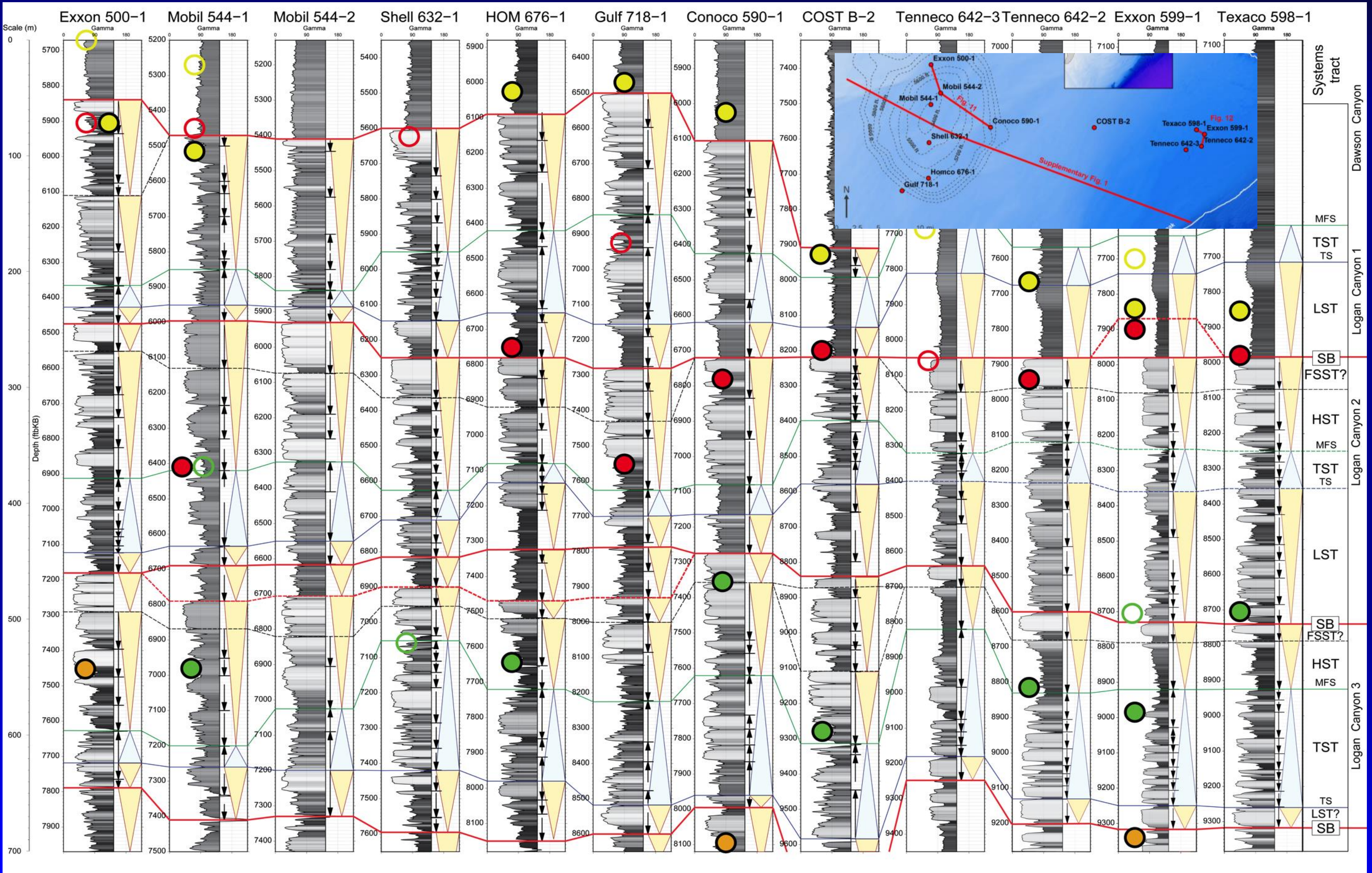
High permeability (>1000 mD)

Excellent reservoir

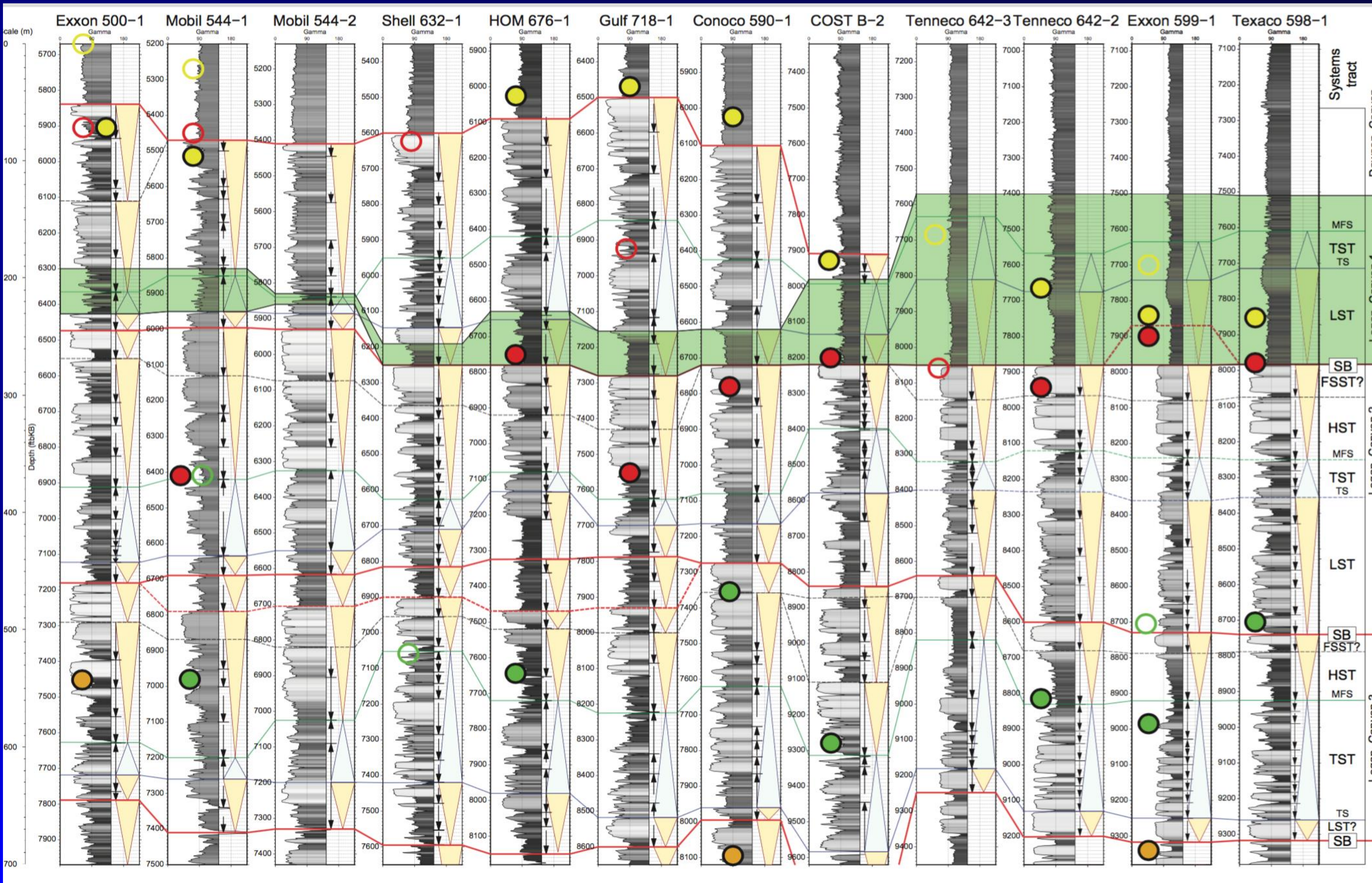
Sands are confined not only by overlying sequences, but by thick shales

Sequences & biostratigraphic correlations

Miller et al. (in review)

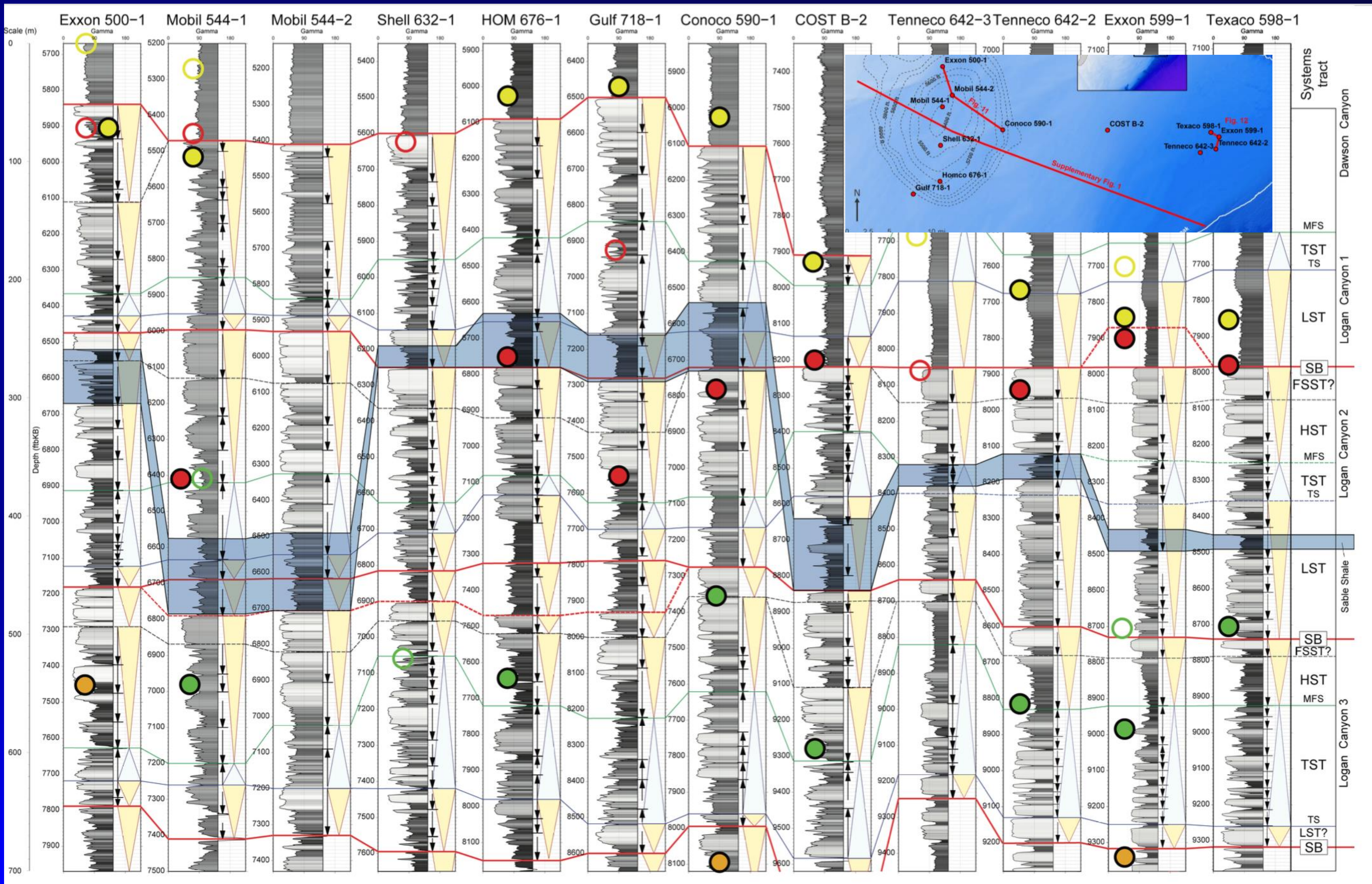


Sequence stratigraphy informs reservoirs and seals

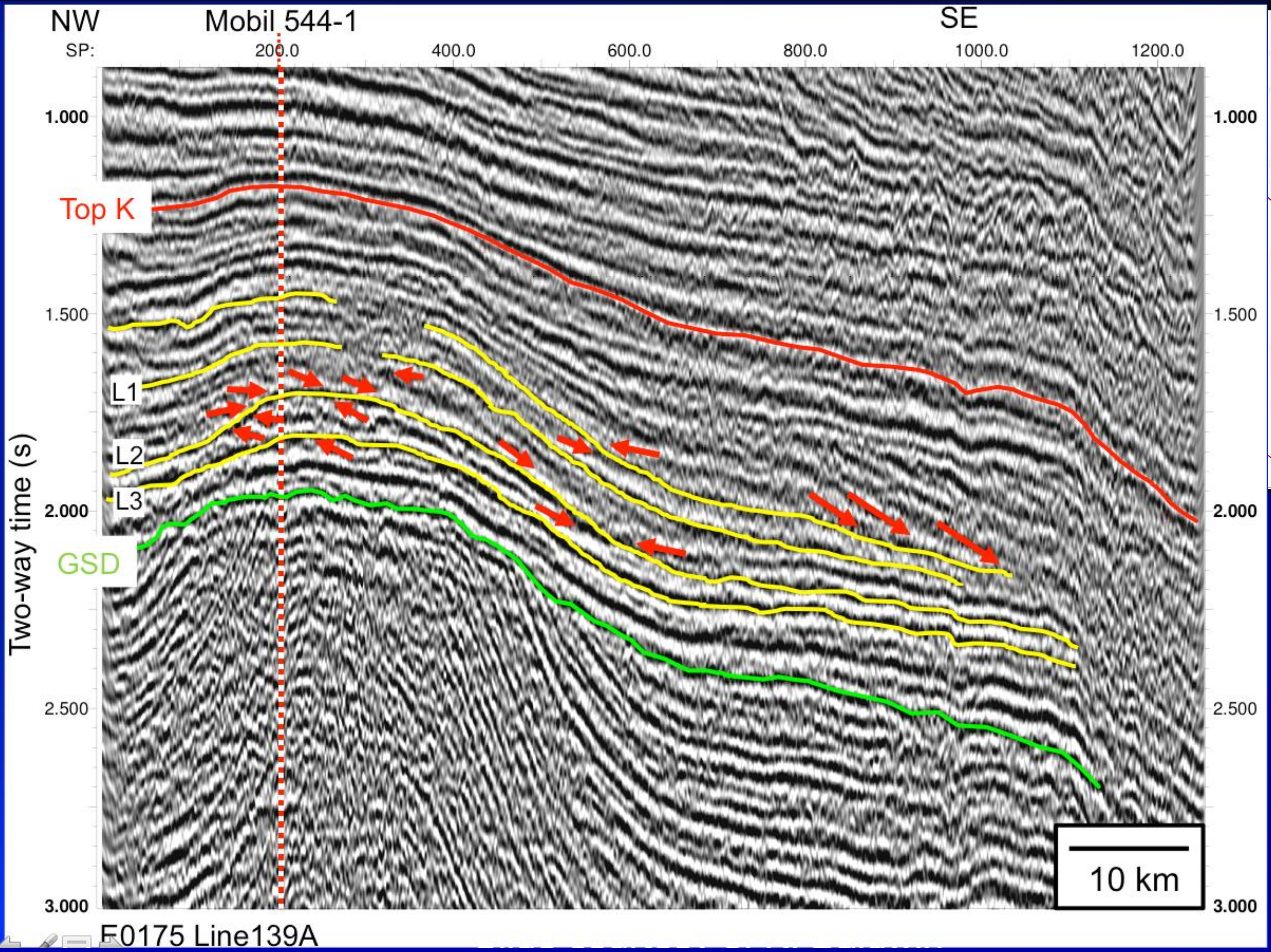


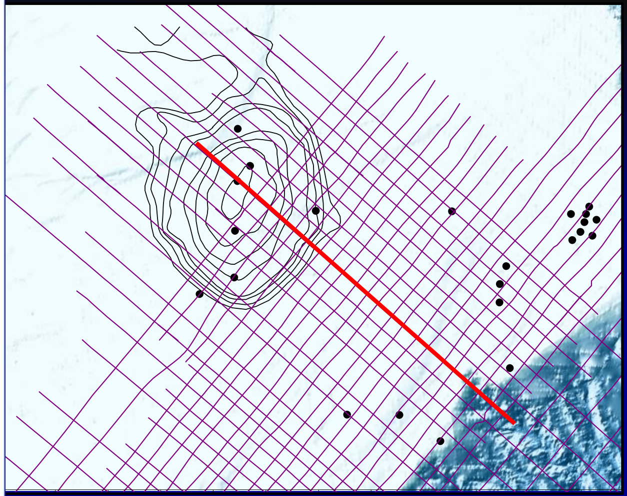
Lithocorrelation violates sequences & biostrat

Sable Shale of Libby French (1981) separating up & lo Logan Canyon placed both above and below basal LC1 sequence boundary, though generally LST of LC2 (note section hung on top LC2)



Seismic profiles "sonograms of the Earth"





Allows recognition of geometry of strata (layers)
Identification of sequences provides increased prediction
Map the units
Recognize faults that would be potential hazard
Slide from K. Baldwin

Geology is ready offshore Mid-Atlantic

✓ Good reservoirs

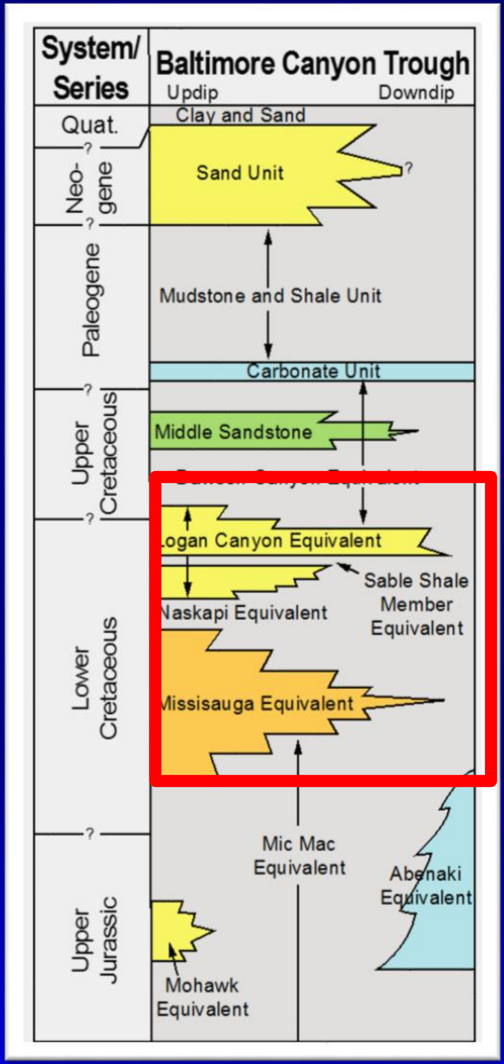
✓ Good seals

✓ Local CO_2 point sources

What next?

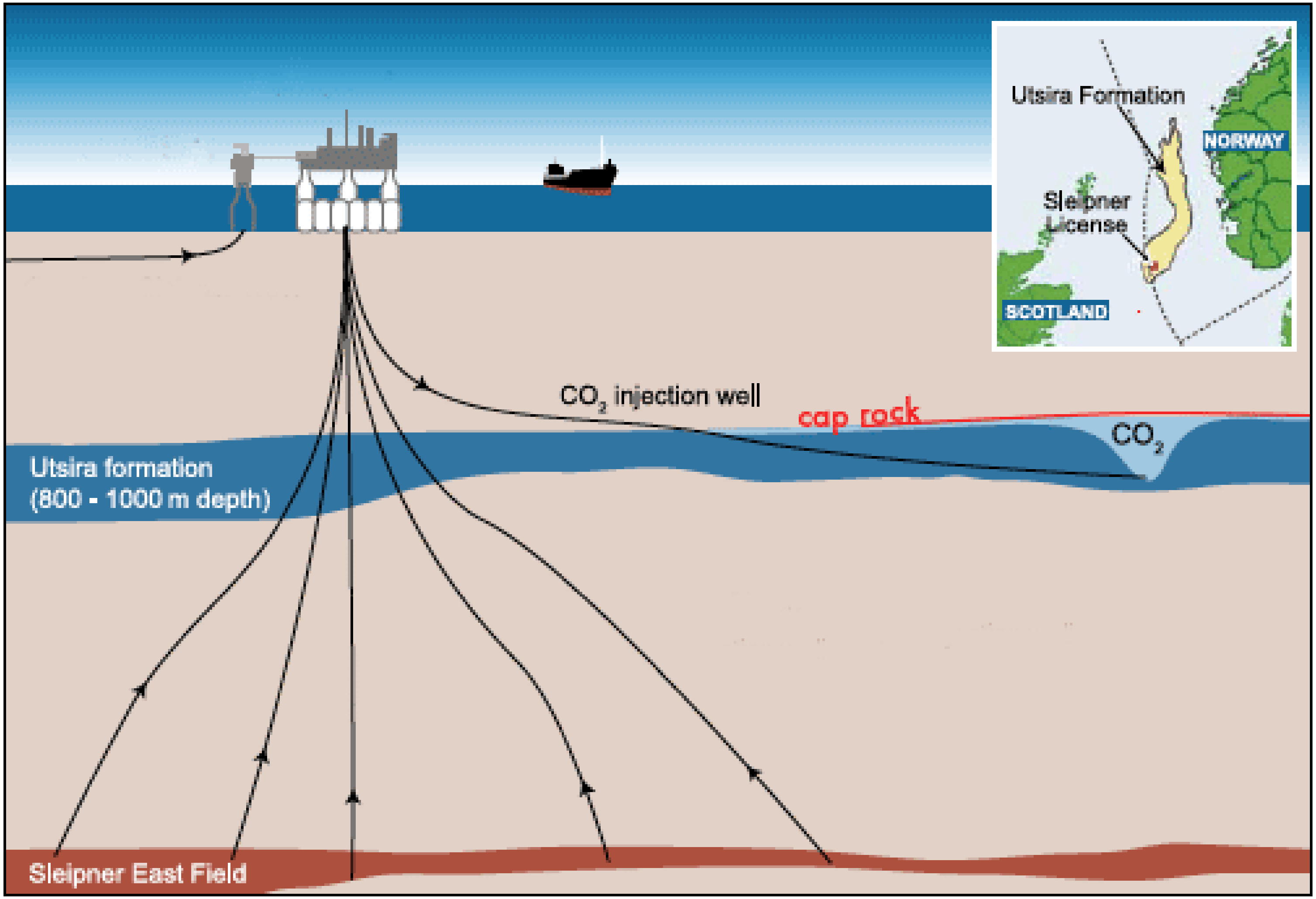
What are the political and economic challenges in previous & current projects?

Targets
Logan Canyon &
Mississauga Formations



Libby French (1984)

Sleipner Project, Norwegian North Sea (Statoil)
CCS since 1996



The Sleipner area gas field Central North Sea, Norway sector

CO_2 content of “wet” gas 4-9%

Statoil spurred by carbon tax to capture & store CO_2 in a saline reservoir

Injection rate of almost 1 Mt/yr

reservoir Utsira Formation (sandstone) at 800-1,100 meters

A Plan for U.S. Emissions to Be Buried Under Sea

By KATE GALBRAITH
Published: April 17, 2009

D. Schrag

In an ambitious proposal to counter global warming, an upstart power developer wants to build a coal-fired electric plant on the outskirts of New York City that would capture its emissions of carbon dioxide and pump the pollutant 70 miles offshore. The gas would be injected into sandstone a mile beneath the ocean floor in the hope that it would stay there for eons.

Enlarge This Image

Daniel Sannum Lauten/Agence France-Presse

Experts have thought for years that capturing the emissions from power plants will be a crucial technology for limiting climate change. But high cost projections and scientific uncertainty have meant that progress on the technique has been limited, even as the effects of global warming are starting to be felt around the world.

The New York Times

A key to the plan is an industrial site in Linden, N.J.

SCS ENERGY

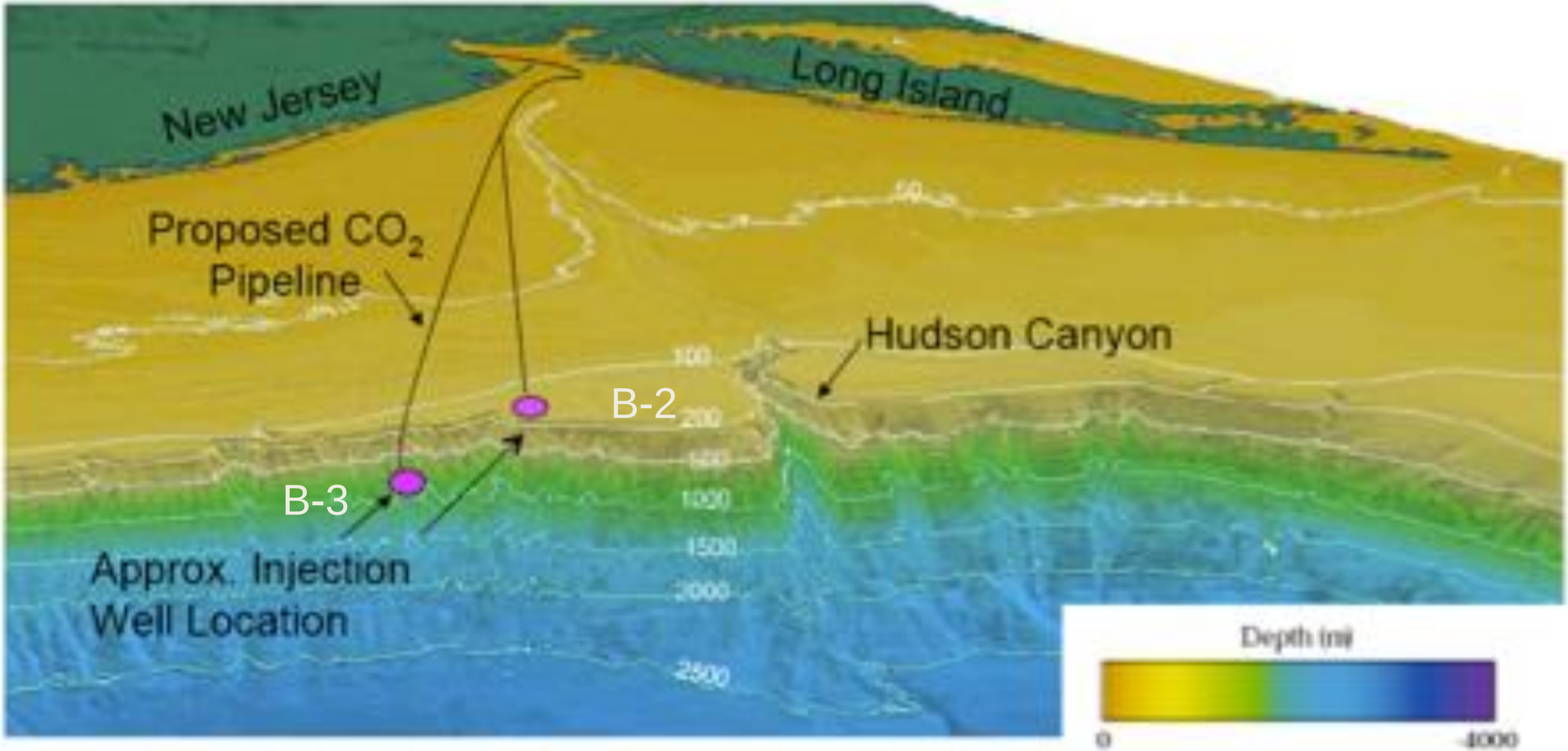
Welcome to SCS Energy

SCS Energy is a private power plant development company that prides itself on exceeding investor's expectations. We concentrate on high value projects that lead the industry in environmental stewardship and climate change mitigation.

Purgen (SCS Energy LLC) 2008

- Build new Linden coal plant, very high efficiency (can't retrofit; loss ~25%; need high 40% efficiency plant, need infrastructure of trains, power lines)
- 90% capture
- 500 megawatt plant, 5 MtCO_2/year (plan to store 200 Mt)
- First large scale commercial power plant w/ CCS
- 3-5 b$ of private capital (no government $)
- Business plan: make fertilizer/H_2 fuel at night

PurGen Storage Area



The locations of the pipeline and injection well area are based on an interpretation of the image and have not been geo referenced.

Courtesy of D. Schrag

Social-Political Reac[...]wards of PurGen's [...]eployment

- Opposition fro[...] key lo[...] officials, gras[...]oots activists in Li[...]en, and se[...]al statewi[...] environmenta[...]roups who o[...]sed th[...]lant on environmental [...]stice and publi[...]ealt[...]grounds
  - A CCS plant bu[...]25-40% more coa[...]
  - CO_2 leakage: Not [...] My Back[...] (NUMBY)
- Economic Feasibility
  - an unfavo[...]oal
- Failure of ex[...]ge legislation
- Political Aspe[...]
  - Opposition [...]
  - Environmen[...]gy

Corie Hlavaty
REI intern
Kopp-Miller

RUTGERS Energy Institute

SIERRA CLUB FOUNDED 1892 New Jersey Chapter

Also Cancelled: SCS EOR in California

The Project

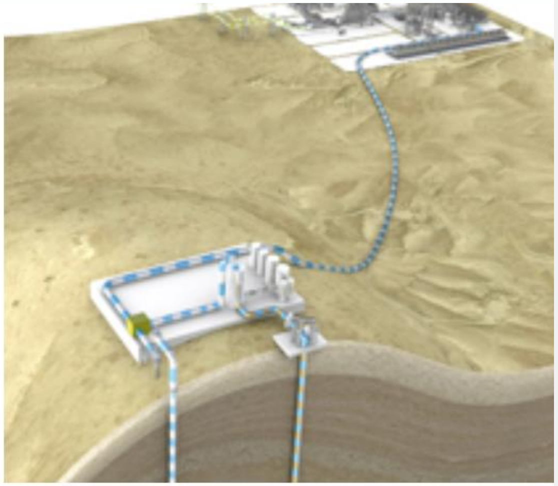
Hydrogen Energy California (HECA) is a clean and reliable alternative energy solution that will provide significant economic and environmental benefits to Kern County and the State of California, while advancing California's long term climate strategy.

As one of the first projects of its kind, HECA will bring together safe and commercially proven technologies into a single, multi-purpose operation that will generate a stable and predictable new source of clean, low-carbon electricity using hydrogen; minimize greenhouse gases released into the atmosphere; capture, store and utilize carbon dioxide (CO_2) for enhanced oil recovery; and produce a much needed local source of low-carbon fertilizer.

OGOS Energy LLC
www.OgosEnergy.com

PIONEERS IN RENEWABLE ENERGY DEVELOPMENT

SCS Energy / OGOS Energy Strategic Alliance



"David has slain Goliath" - $4 billion Kern HECA project dies

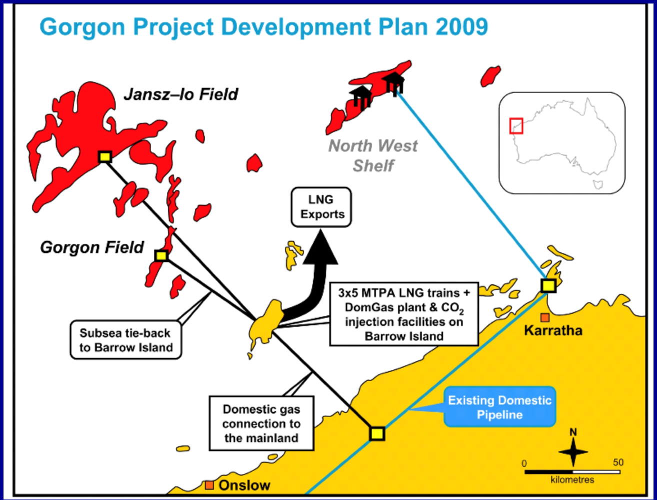
By: MIKE TRIHEY

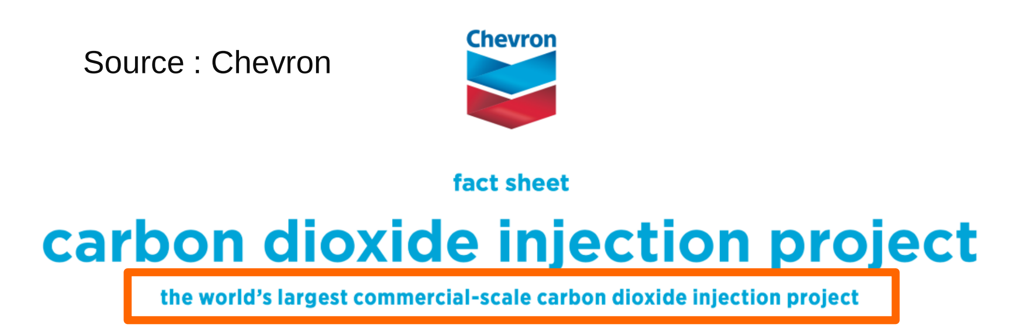
Mar 3, 2016

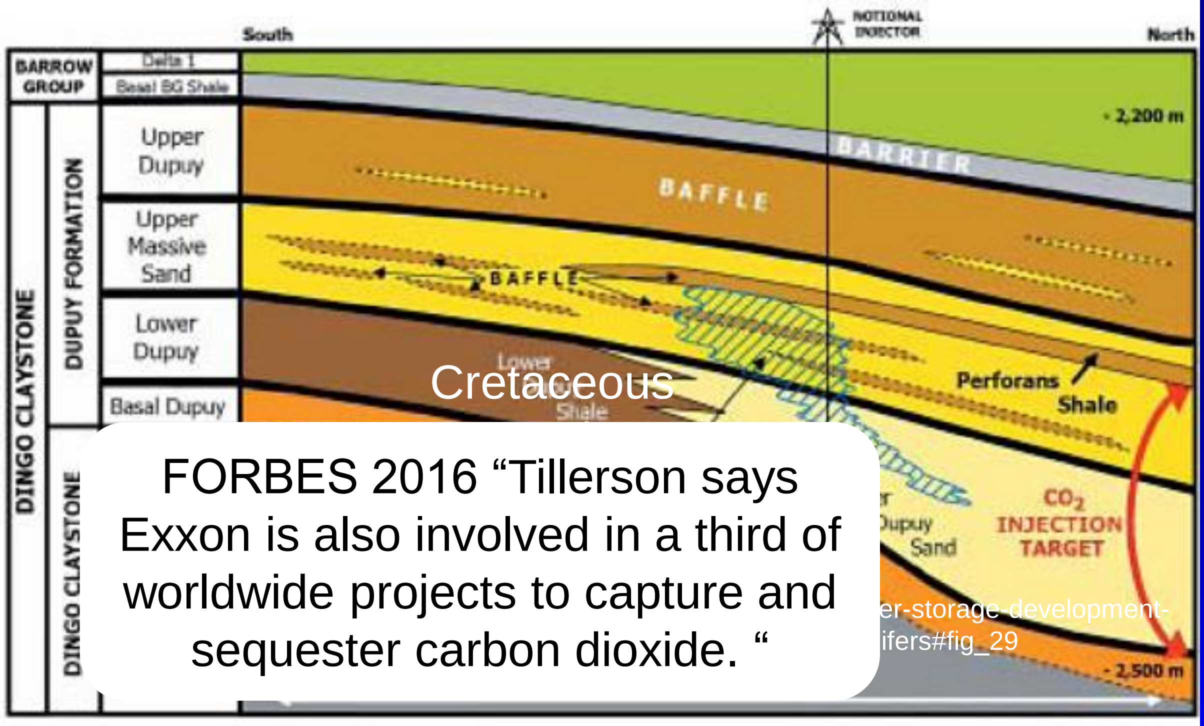
BAKERSFIELD, Calif. - Developers of the $4 billion Hydrogen Energy California project officially withdrew plans late Thursday afternoon for the controversial west Kern County project. Although they left room for a possible

Other projects under construction: largest Gorgon

Gorgon field NW Australia "wet" (14% CO_2) gas field
Project plans to inject 1 Mt Carbon/year
Cost $2 billion, Australian government $60 million







FORBES 2016 "Tillerson says Exxon is also involved in a third of worldwide projects to capture and sequester carbon dioxide. "

REI summer intern
A. Kulpecz
Chevron Perth

ExMob President
Steve Greenlee
Indonesian CCS

Working Project: Petra Nova EOR political reality

Petra Nova, Paris, TX Generating Station commercial-scale post-combustion carbon captures more than 90% of CO_2 sequestration of 1.6 Mton/yr

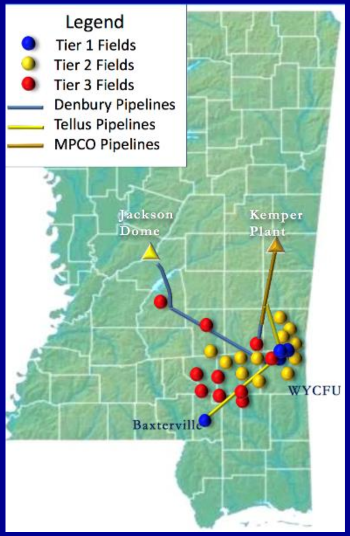
Captured CO_2 used to enhance production at the West Ranch oil field, from ~300 to 15,000 barrels per day

190m$ Clean Coal Power Initiative Program

Constructed on time and on budget and performing to spec

Other projects under construction: Kemper

Kemper Project, Mississippi
EOR 100 m$ pipeline to
Denbury and Tellus oil fields



http://iogcc.ok.gov/Websites/iogcc/images/2014Biloxipresentations/IGOCCC_052014_Final2_Bowman.pdf

Lignite-fired electrical generating station using gasification & capture
President Obama's Climate Plan "clean coal"
DOE 270 m$ grant & 13 m$ tax credits
Cost of $2.4 billion increased to $7.1 billion due to cost overruns
Project management issues delayed May 2014 opening

Working project: Boundary Dam, Saskatchewan

Operational July 2014; first plant to capture carbon on an industrial scale
Sells CO_2 for EOR in Weyburn Field to offset costs
Costs: 1.4 b$C, 240 m$C Canadian government

ENERGY & ENVIRONMENT | SPECIAL REPORT: OIL & MONEY

Companies Struggle to Make Carbon Capture Viable

By MARK SCOTT OCT. 5, 2015

https://www.nytimes.com/2015/10/06/business/energy-environment/companies-struggle-to-make-carbon-capture-viable.html?_r=0

RELATED COV

An oil plant in Fort Saskatchewan, Alberta. The project, which is being led by Shell and received about $1 billion in grants from the Canadian government, aims to cut emissions from the facility by up to 35 percent.
Philip Chin/Shell

Strengths
Strong policy drivers to reduce emission
Overcame many of the initial challenges:
400 kT captured in Year 1; 800 kT in Year 2
Cleanest coal-fired power plant in Canada

Weaknesses
Plagued by problems, cost overruns
Negative earnings (EBIT)
Doubled price electricity
Only 50% stored
Subsidizing oil extraction

Other (cancelled) projects: Vattenfall

Vattenfall's Germany failed experiments

Schwarze Pumpe steam generator pulverized coal, 30 MW achieved, ~100% CO_2 capture

Jänschwalde, Germany (scaled up) cancelled due to public opposition and lack of the German Government to delineate the CCS legal framework

Vattenfall Ditches Carbon Capture and Storage Research

By Katherine Tweed
Posted 9 May 2014 | 17:00 GMT

Illustration of the proposed carbon capture demonstration plant at Jänschwalde, in eastern Germany.

CCS research was cut as Vattenfall decreases its R&D budget by 20%. They announced that they will focus on other energy sources as the challenging market conditions limited have spending.

Carbon Capture & Sequestration Technologies @ MIT

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As of September 30, 2016, the Carbon Capture and Sequestration Technologies program at MIT has closed. The website is being kept online as a reference but will not be updated.s

Vattenfall Janschwalde Fact Sheet: Carbon Dioxide Capture and Storage Project

Concerns about earthquake stimulation

PERSPECTIVE

Earthquake triggering and large-scale geologic storage of carbon dioxide

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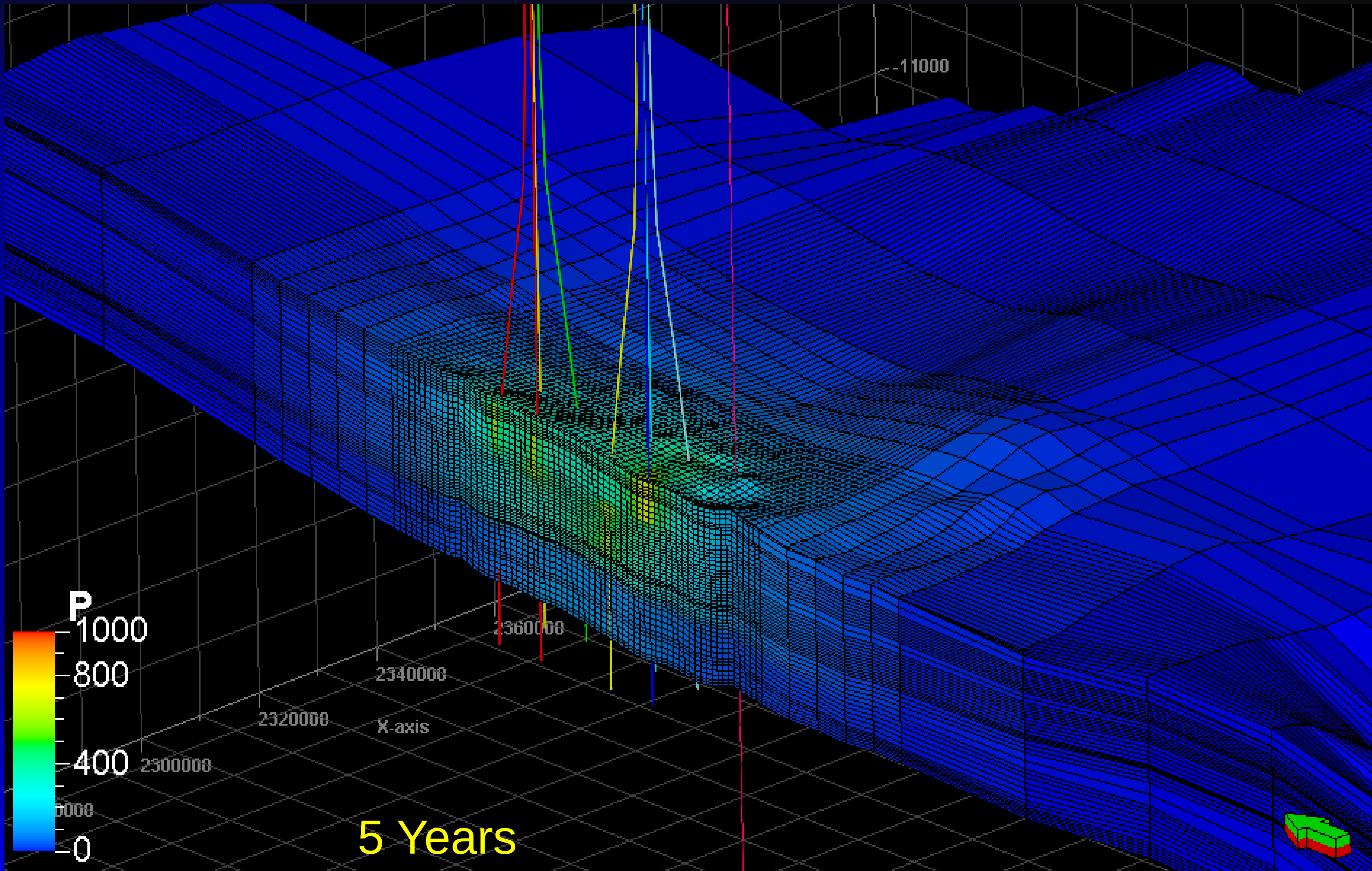
Edited by Pamela A. Matson, Stanford University, Stanford, CA, and approved May 4, 2012 (received for review March 27, 2012)

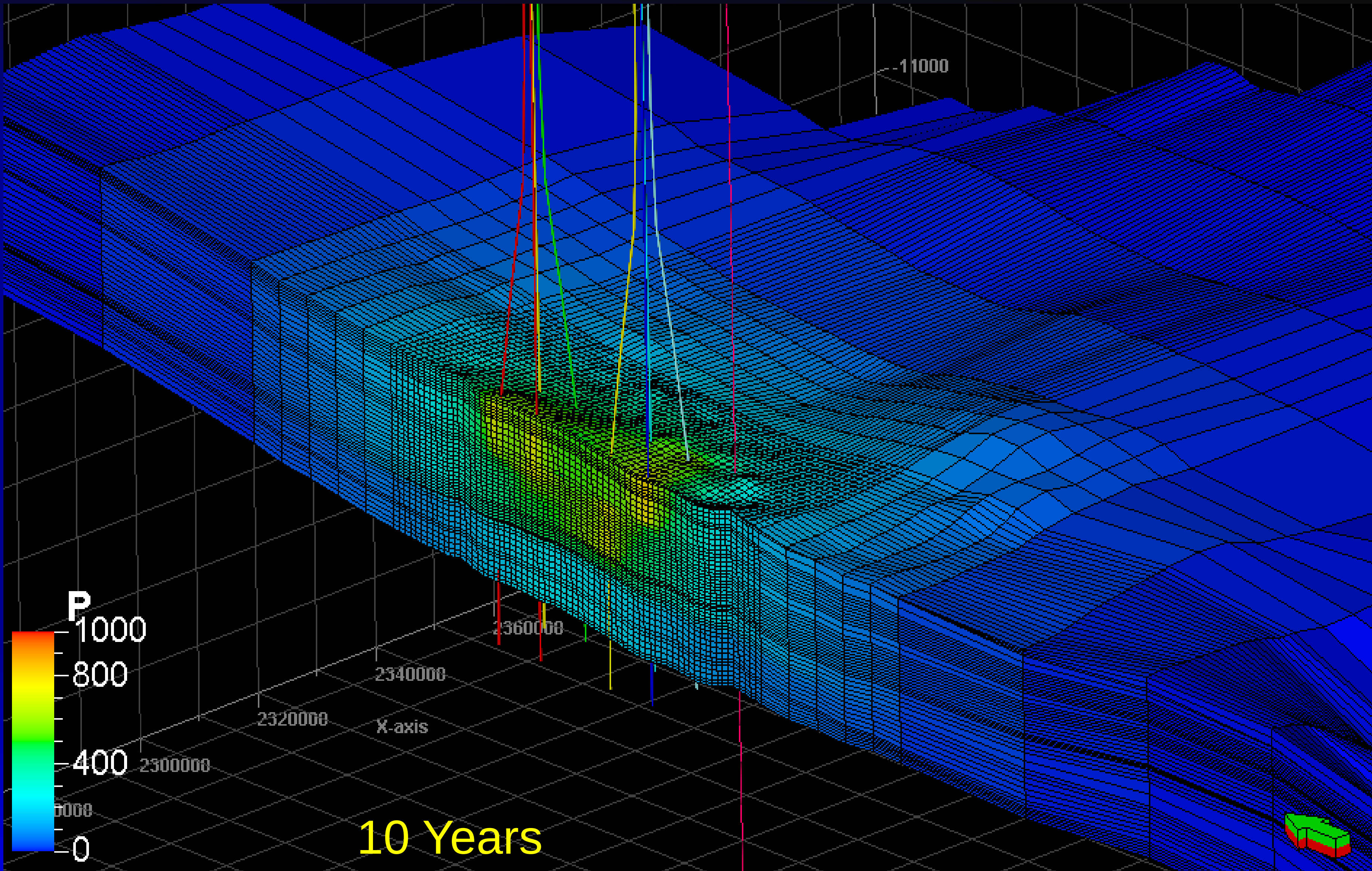
Despite its enormous cost, large-scale carbon capture and storage (CCS) is considered a viable strategy for significantly reducing CO_2 emissions associated with coal-based electrical power generation and other industrial sources of CO_2 [Intergovernmental Panel on Climate Change (2005) IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, eds Metz B, et al. (Cambridge Univ Press, Cambridge, UK); Szulczewski ML, et al. (2012) *Proc Natl Acad Sci USA* 109:5185–5189]. We argue here that there is a high probability that earthquakes will be triggered by injection of large volumes of CO_2 into the brittle rocks commonly found in continental interiors. Because even small- to moderate-sized earthquakes threaten the seal integrity of CO_2 repositories, in this context, large-scale CCS is a risky, and likely unsuccessful, strategy for significantly reducing greenhouse gas emissions.

"We argue here that there is a high probability that earthquakes will be triggered by injection of large volumes of CO_2 into the brittle rocks commonly found in continental interiors."

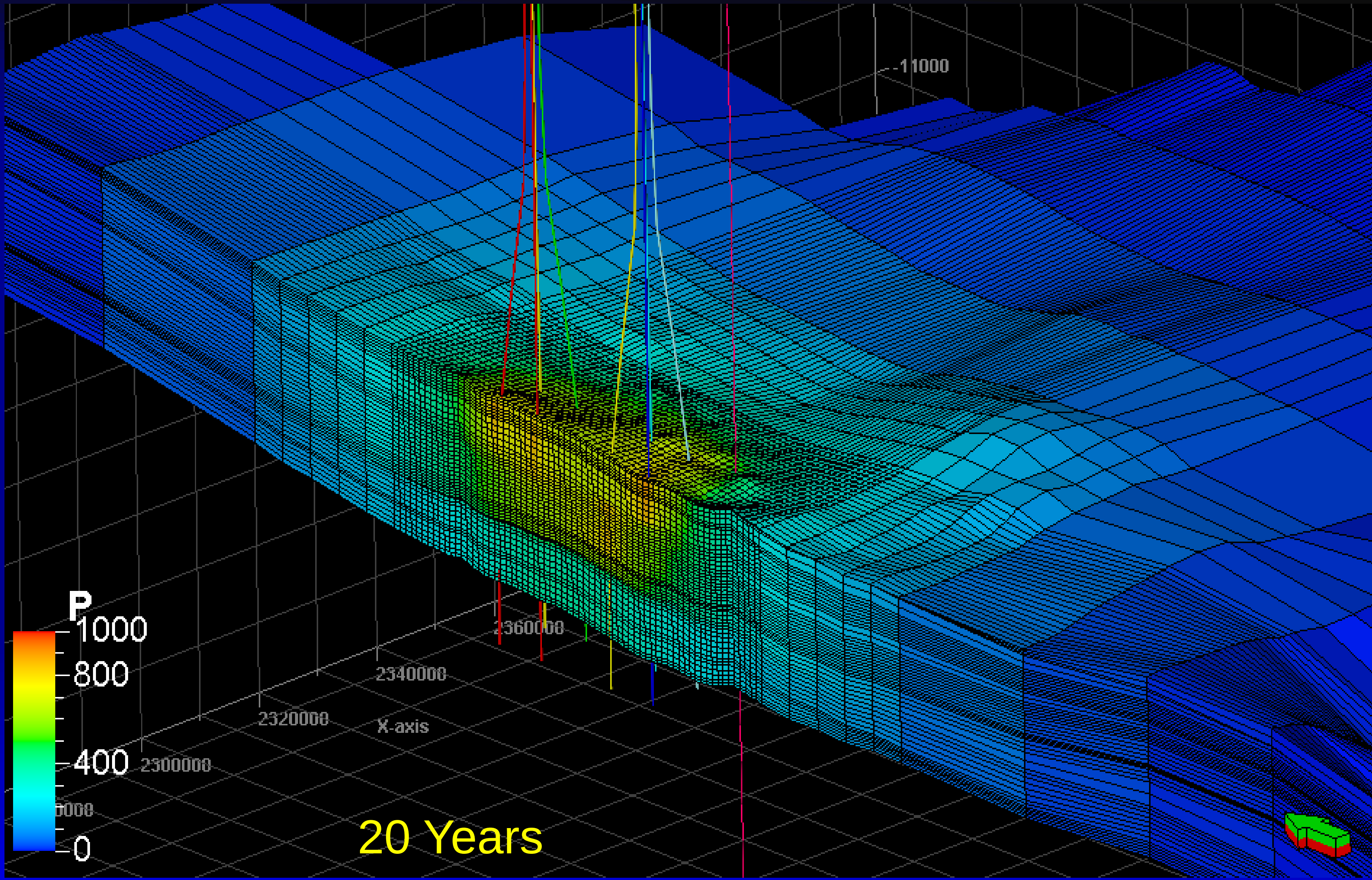
Not always true. Geology matters.



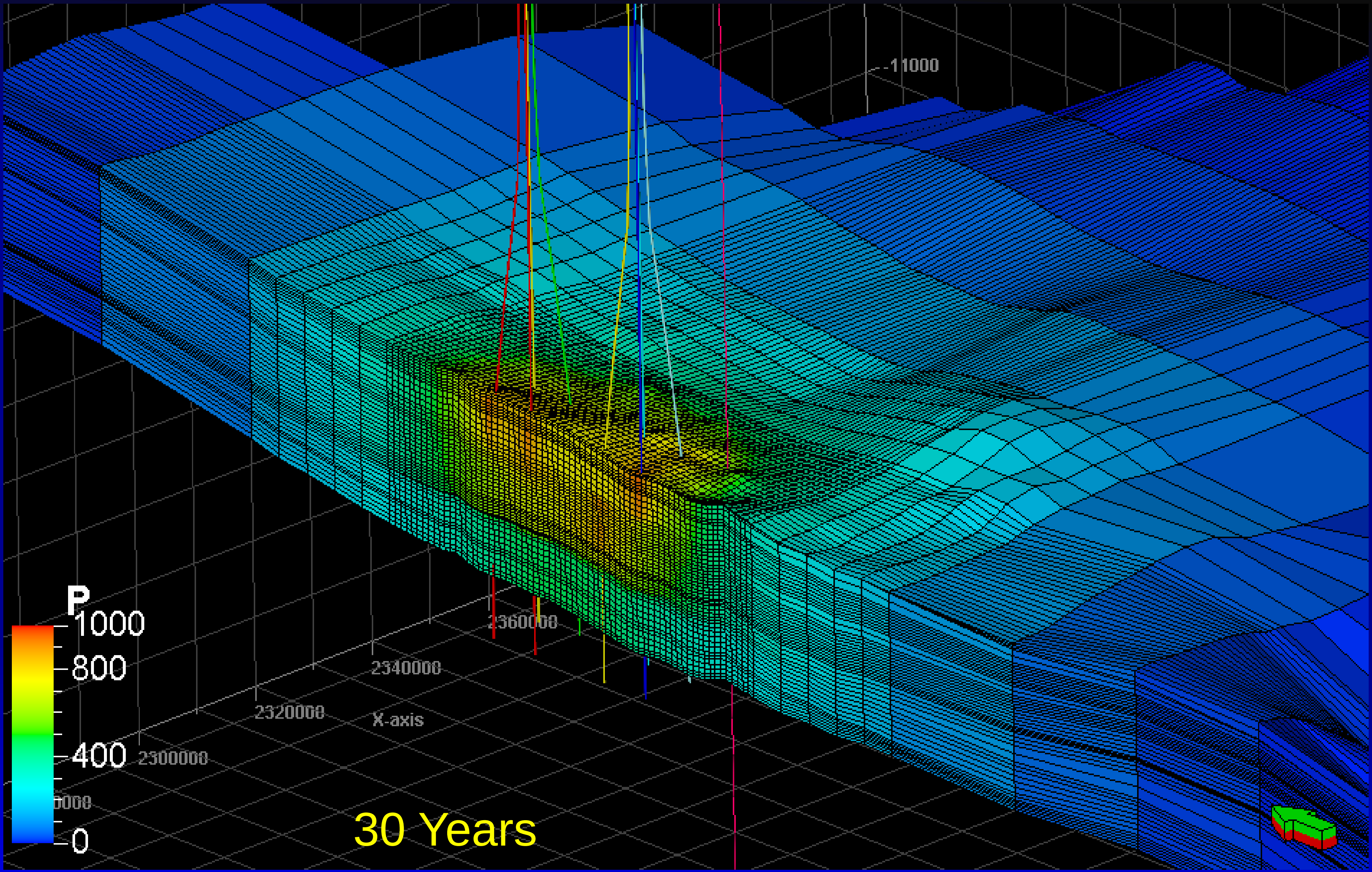
Models of injection into Logan Canyon Sands show pressures below failure
Courtesy of D. Schrag and Schlumberger Carbon Services



Courtesy of D. Schrag



Courtesy of D. Schrag



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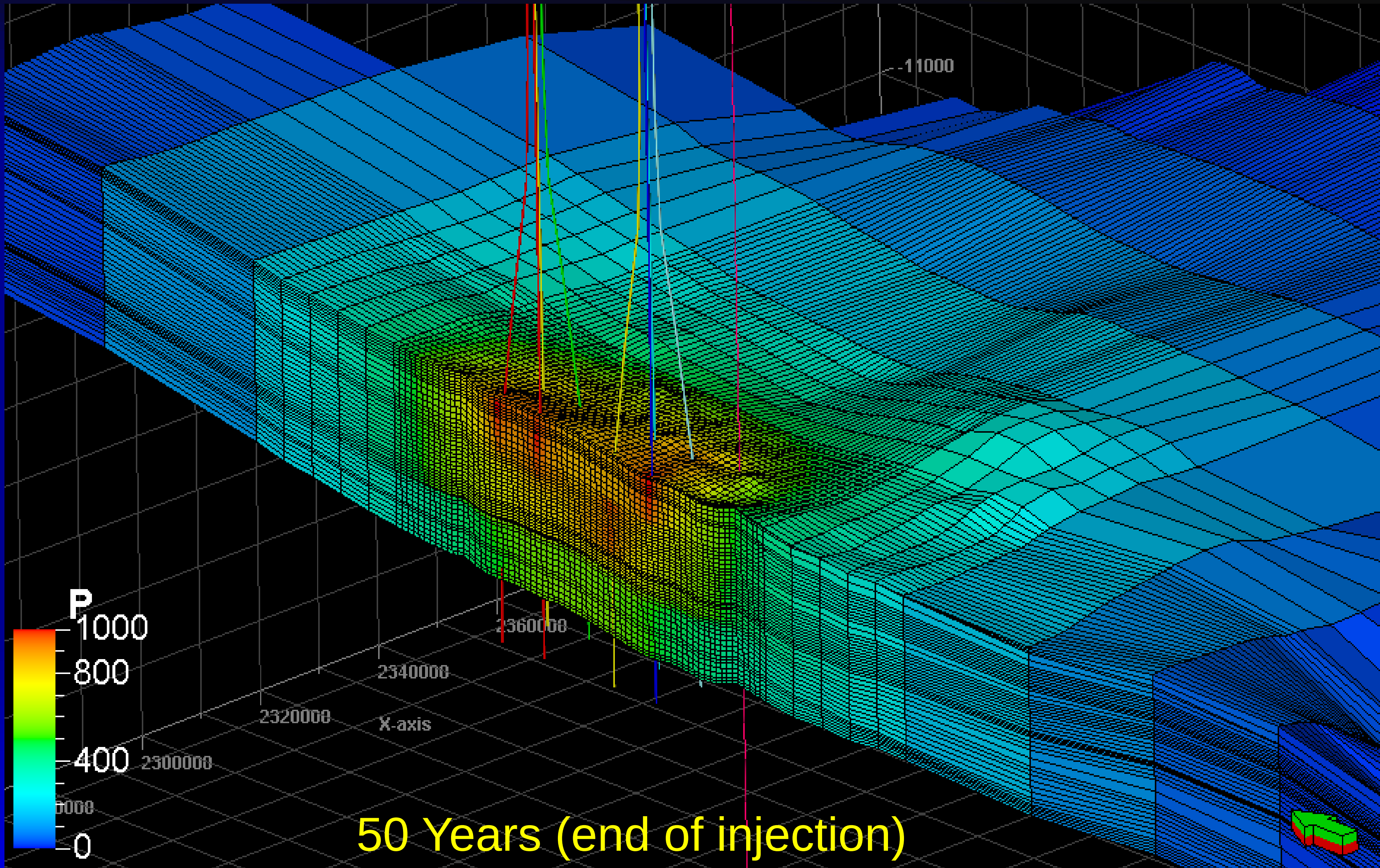
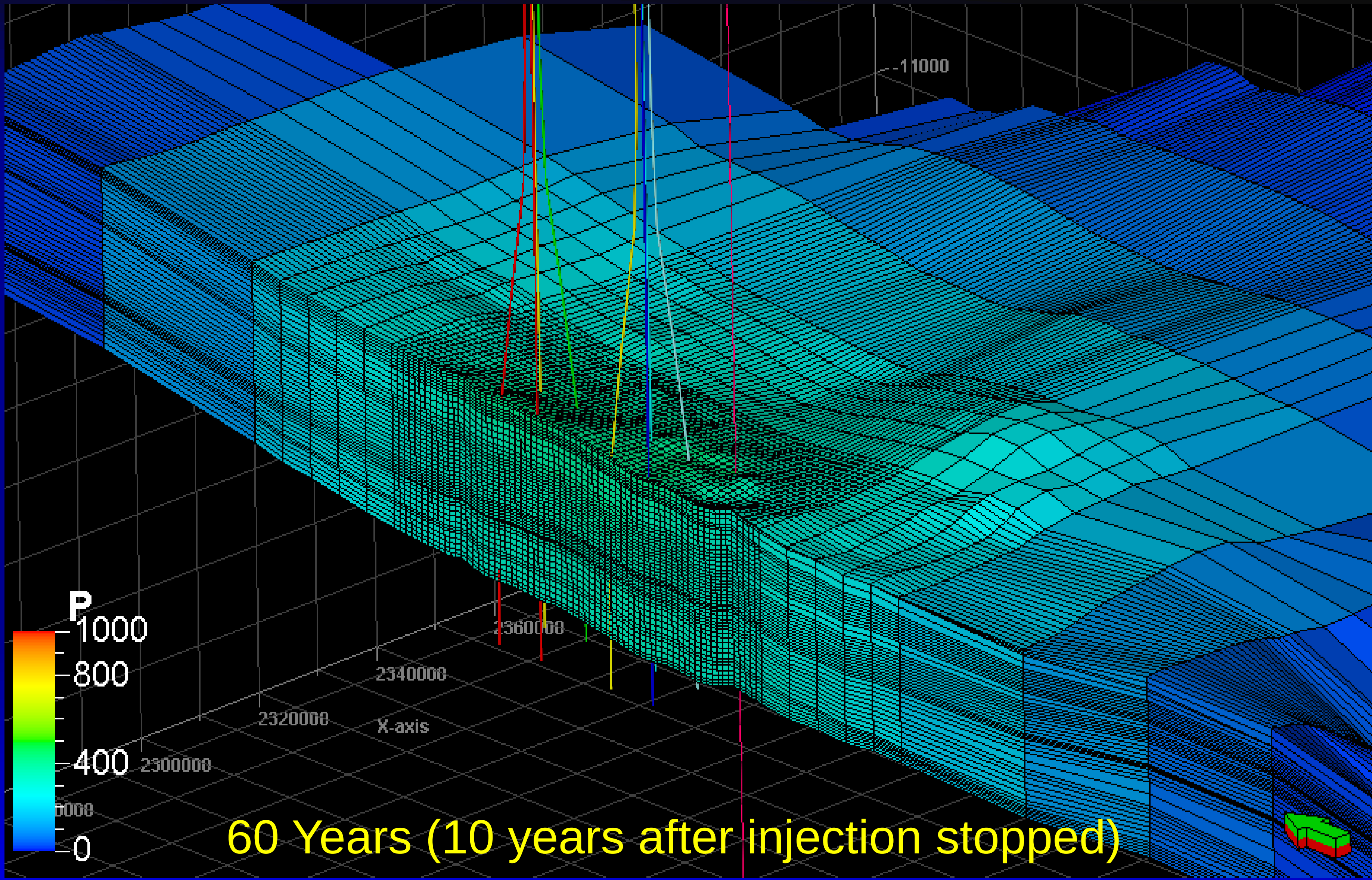


50 Years (end of injection)

Courtesy of D. Schrag



Courtesy of D. Schrag

Conclusions

Geology is ready!

Onshore suitable for storage at Beesley’s Point, NJ and Indian River, DE not feasible due to NUMBY and Green opposition

The Logan Canyon Sands are a world class target for storage offshore; Could have multiple injection sites on east coast

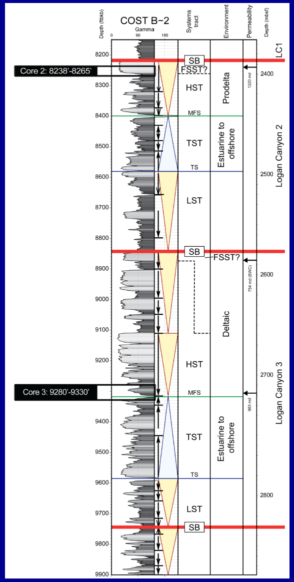
Political opposition to geological storage offshore; PurGen plan could be done with natural gas; Greens might not oppose

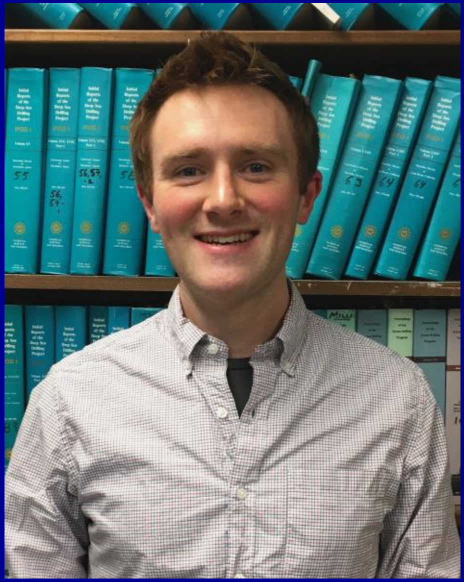
Economics not there without a price for carbon

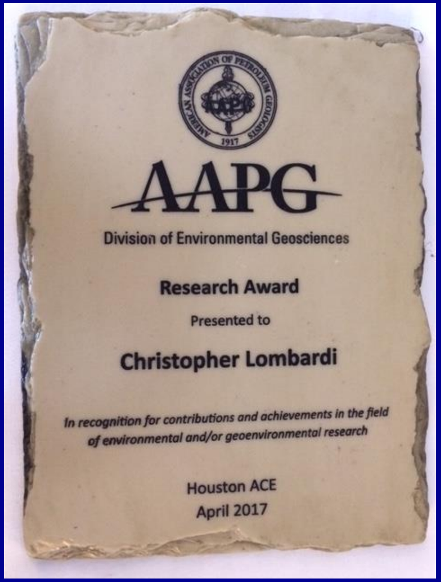
All current projects are EOR or “wet” gas recovery

In Memoriam
Christopher J. Lombardi

Chris passed unexpectedly on Nov. 29, 2016 and will be posthumously awarded a Ph.D. in Geological Sciences from Rutgers University May 2017.







Chris had been working with the New Jersey contingent of the Midwest Regional Carbon Sequestration Partnership (MRCSP) for the past 4 years as a graduate student at Rutgers University. He made great strides in the correlation of chronostratigraphy of Mid-Atlantic offshore formations that are being evaluated for carbon storage opportunities. Specifically, his work on the Great Stone Dome and adjacent areas shows that sands targeted for carbon storage are bracketed by sequence boundaries, provided increased confidence in their continuity and seals.

Coastal and offshore storage options

Requirements

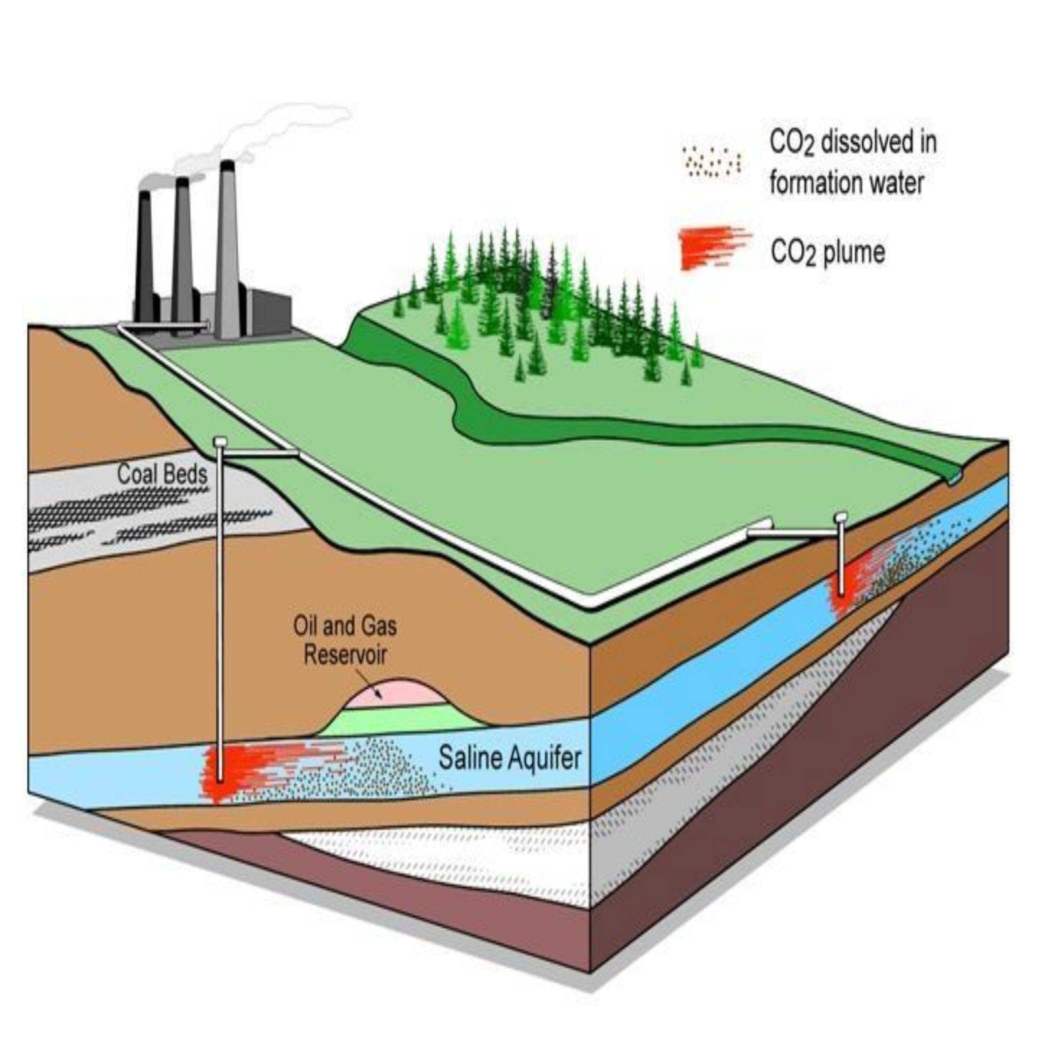
Large stationary point source

Reservoir: saline aquifers (not in potable water)

Cap rock: confining bed mudstones

Burial > 800 m deep

Geology matters



Earthquake issues

Earthquakes: injection of fracking fluids into underground disposal wells causes faults to slip. This is what is responsible for Oklahoma's massive earthquake spike. Yet, same injection in TX does not. Geology matters.

Earthquakes Caused by Human Activity

The maps below show where there has been seismic activity, caused mostly by oil and gas operations. Northern Oklahoma and southern Kansas have been especially hard hit, with an exponential growth in the number of human-caused earthquakes.

So

The New York Times

U.S.

U.S. Maps Pinpoint Earthquakes Linked to Quest for Oil and Gas

By RICHARD PÉREZ-PEÑA APRIL 23, 2015

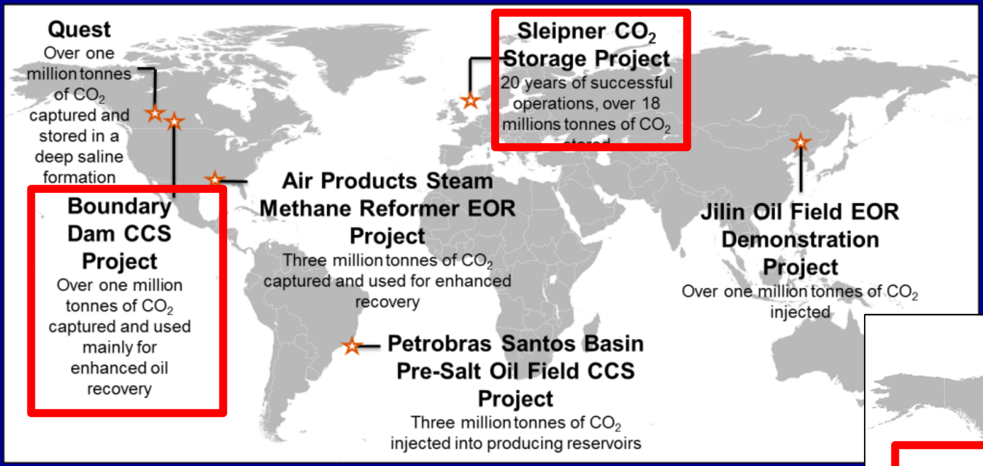
U.S.

New Concern Over Quakes in Oklahoma Near a Hub of U.S. Oil

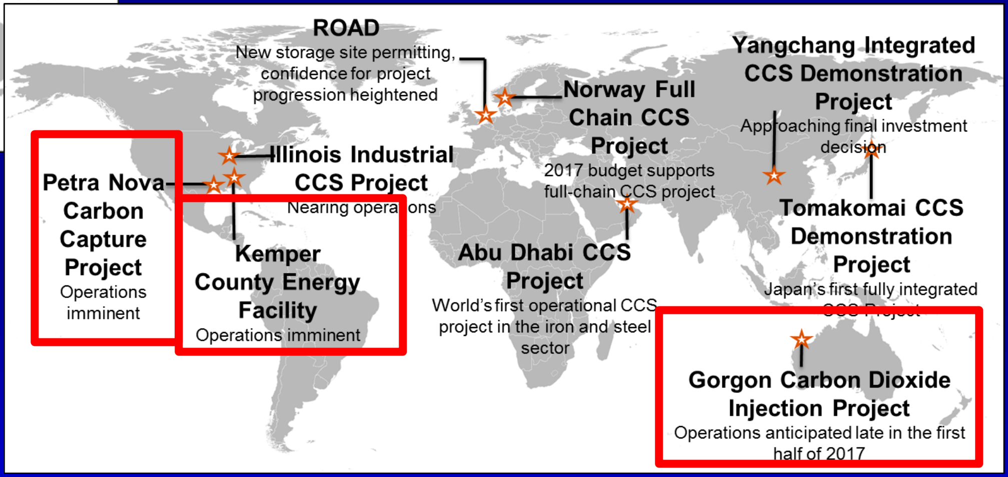
By MICHAEL WINES OCT. 14, 2015

Current Geologic CO_2 Injection Projects

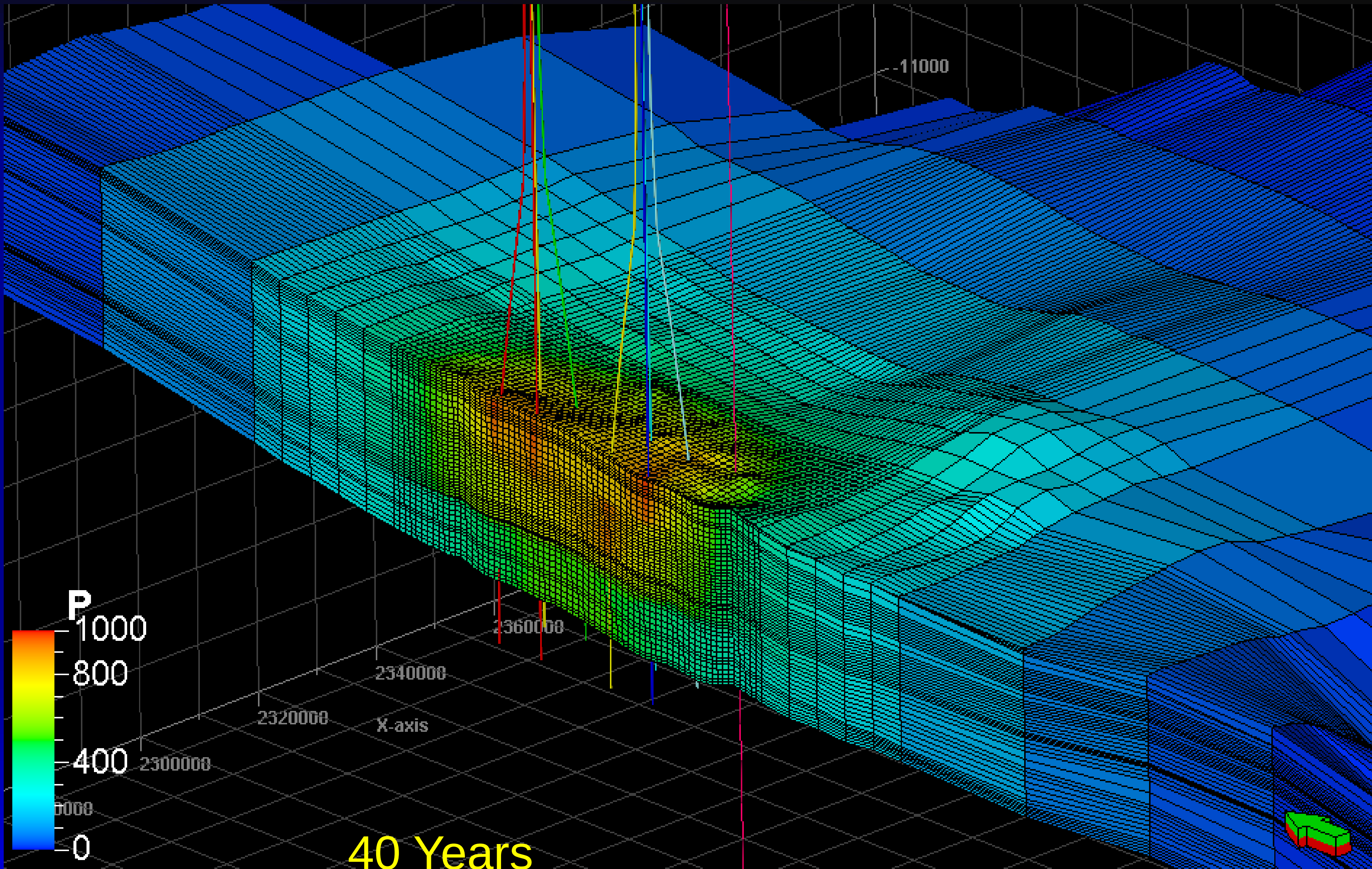
- Commercial-scale & demonstration projects are taking place around the world – USA, Canada, Norway, Spain, Algeria, Australia, China, and Japan
- Most are tied to O&G, disposal of “wet” gas CO_2 or EOR



Operational CCS Projects



Source of images: Global CCS Institute



Courtesy of D. Schrag