SAND2011-7779 C

Exceptional service in the national interest

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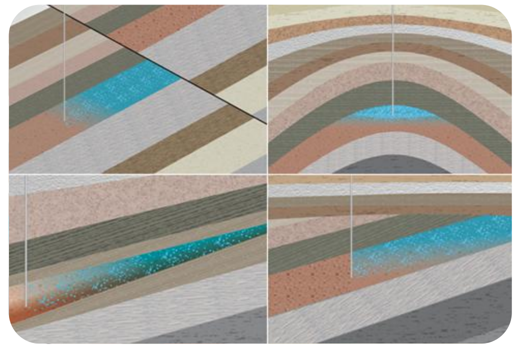

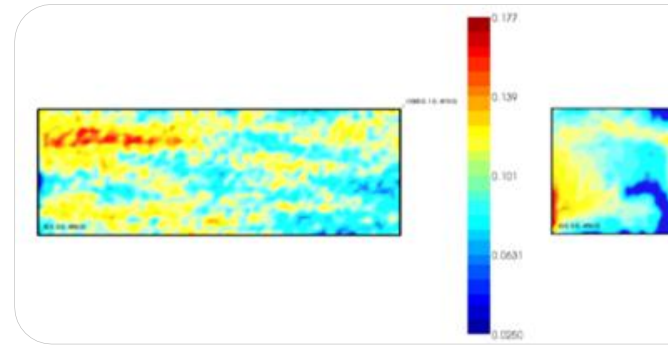

A Systems Approach for CO_2 Sequestration & Saline Water Utilization

Geoff Klise

Earth Systems Analysis Department

October 18, 2011

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Today's Talk

- Brief Sandia Labs overview
- Why is Sandia involved in CO_2 sequestration?
  - Climate change – national security implications
  - Addresses the Water-Energy nexus
  - Systems modeling expertise
- Evolution of CO_2 and saline water systems model
  - What is carbon capture and sequestration (CCS)?
  - What is a 'Systems Approach'?
  - Importance of this work
  - Early Results

Sandia's History

Sandia National Laboratories

AMERICAN TELEPHONE & TELEGRAPH CO.
BELL SYSTEM
AND ASSOCIATED COMPANIES

THE WHITE HOUSE
WASHINGTON

May 13, 1949

Dear Mr. Wilson:

I am informed that the Atomic Energy Commission intends to ask that the Bell Telephone Laboratories accept under contract ... at Albuquerque, New Mexico.

... atomic ... national defense, ... technical direction.

I hope that after you have heard more in detail from the Atomic Energy Commission, your organization will find it possible to undertake this task. In my opinion you have here an opportunity to render an **exceptional service in the national interest.**

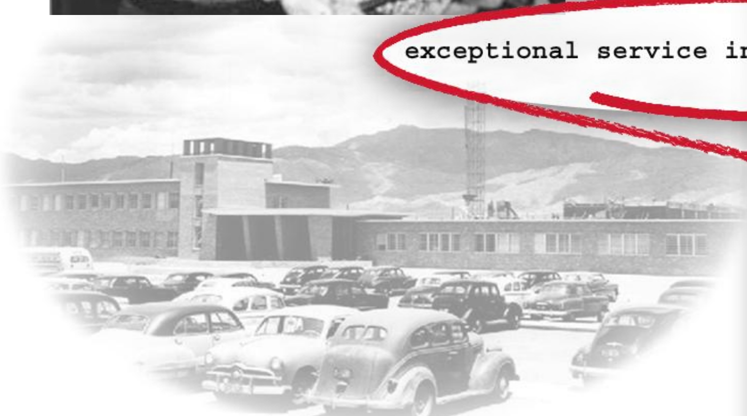
I am writing a similar note direct to Dr. O. E. Buckley.

Very sincerely yours,

Harry Truman

Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.

exceptional service in the national interest.



Sandia's Sites

Albuquerque, New Mexico

Livermore, California

Tonopah, Nevada

Waste Isolation Pilot Plant, Carlsbad, New Mexico

Pantex, Texas

Why is Sandia in this business?

Sandia National Laboratories

National Security is intimately linked with Energy, Climate, & Infrastructure Security Challenges.

Prosperity

"Without energy, there is no economy."

National Security

"Without energy and environment, there is no security."

John Holdren

Director of the White House Office of Science and Technology Policy

Environmental Stewardship

"Without climate, there is no environment."

Geologic CO_2 Sequestration - Why?

- Engineering response to reducing GHG emissions
  - Allows for gradual phasing out of high CO_2 emitting technologies
  - It will take time for low and no-carbon generating sources of electricity to come on-line
  - Electrical generating sources account for 60 percent of all CO_2 emissions
  - Theoretically sequesters CO_2 for long time-horizons (100 to 1000s of years)

Geologic CO_2 Sequestration - How?

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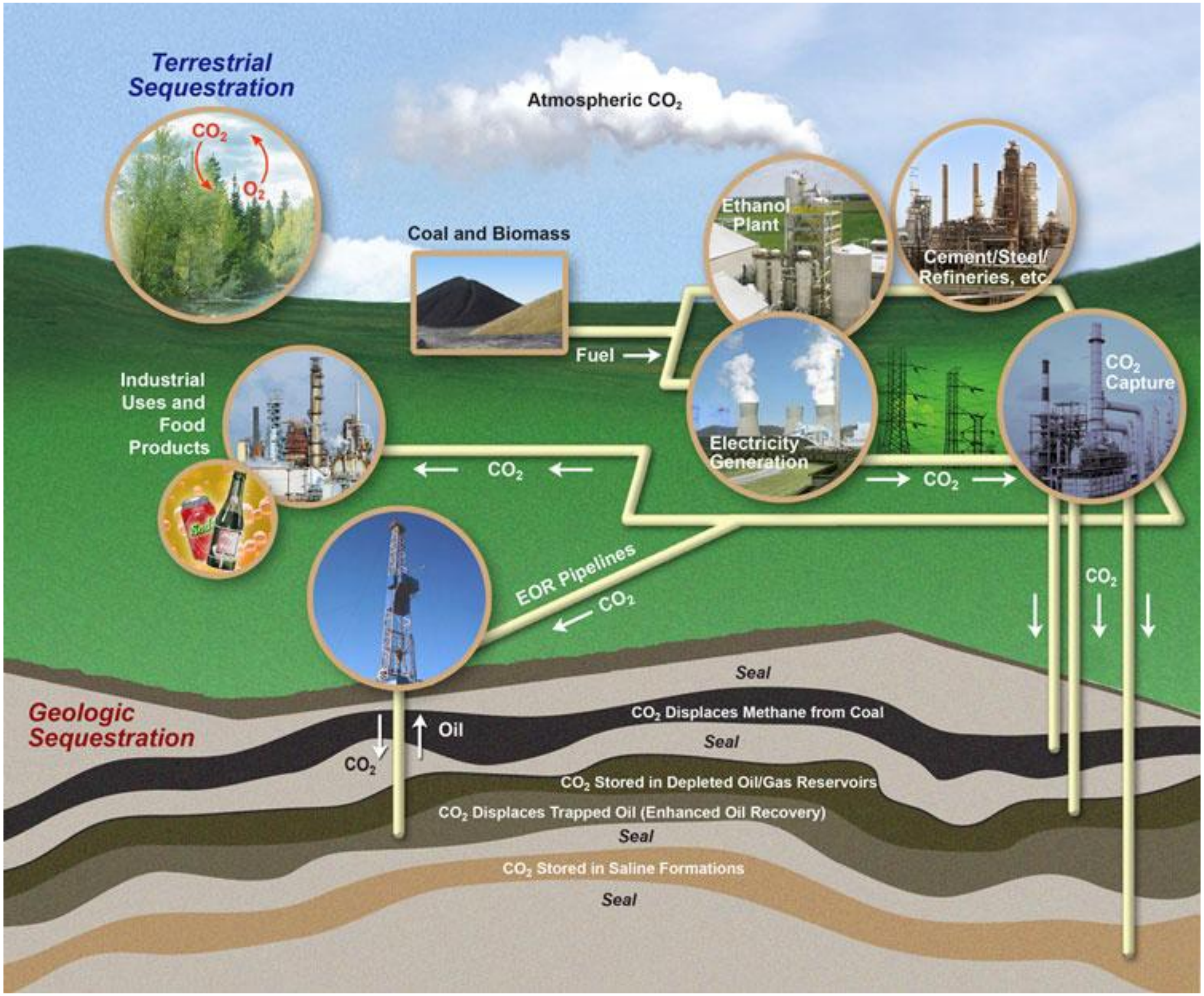


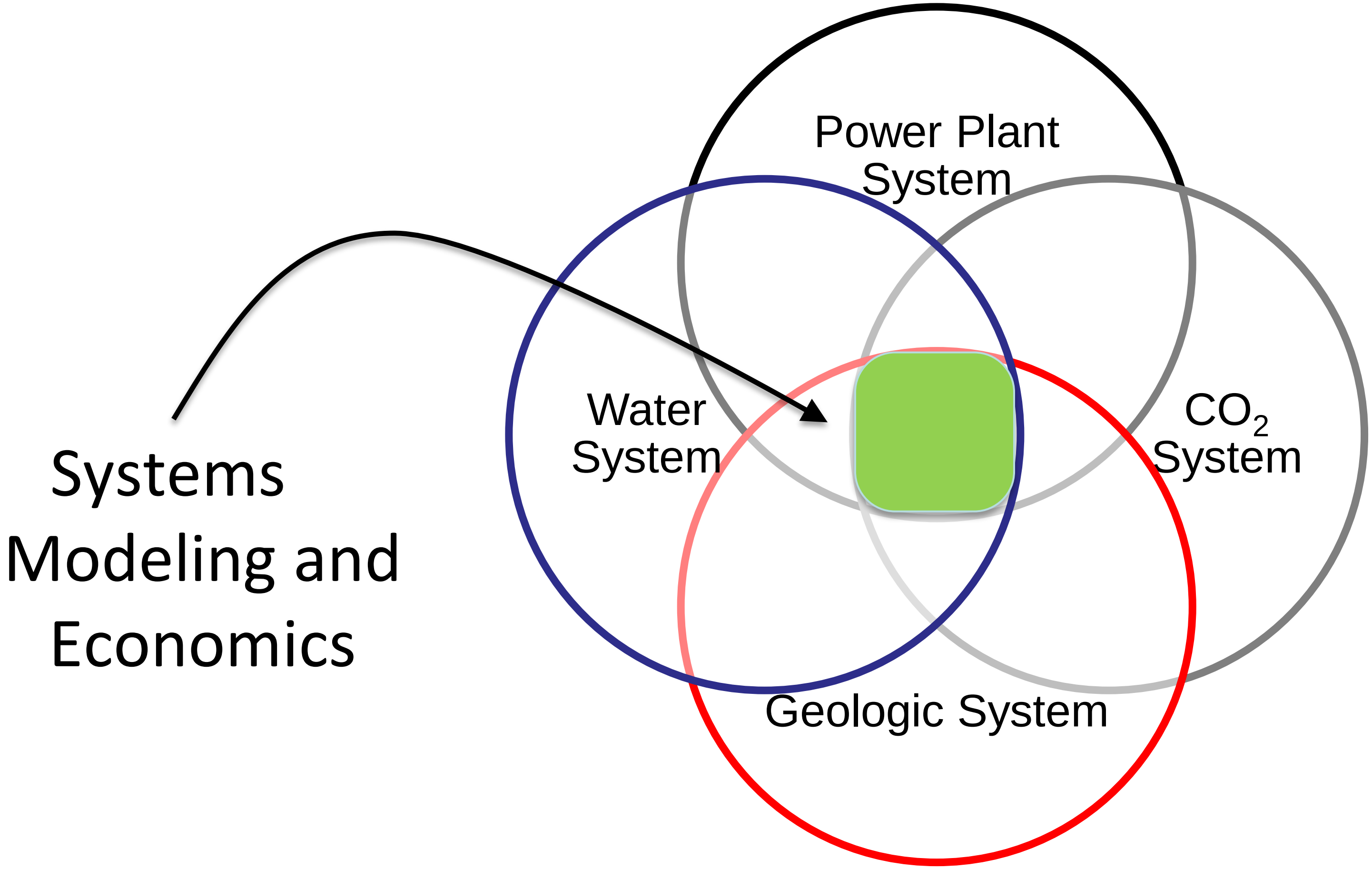
Credit: NETL

- Essentially, injecting supercritical CO_2 (>100 bar and > 300 K) at depths > 2500 ft into saline sink, coal seam or oil and gas reservoir
- Currently employed using naturally occurring CO_2 for Enhanced Oil Recovery (EOR)

Challenges

- Keeping CO_2 in the ground
  - Verification and Validation
- Cost
- No real carbon market / no tax
- Increased water demand for new parasitic energy production
- Restricted to injection zone, and water use zone
  - TDS of water greater than 20,000 ppm
  - Depth > 2500 ft

What is a Systems Approach?



What is the feasibility of storing CO2 in a saline sink, while extracting that same water for power plant cooling, or other uses?

Overall goals

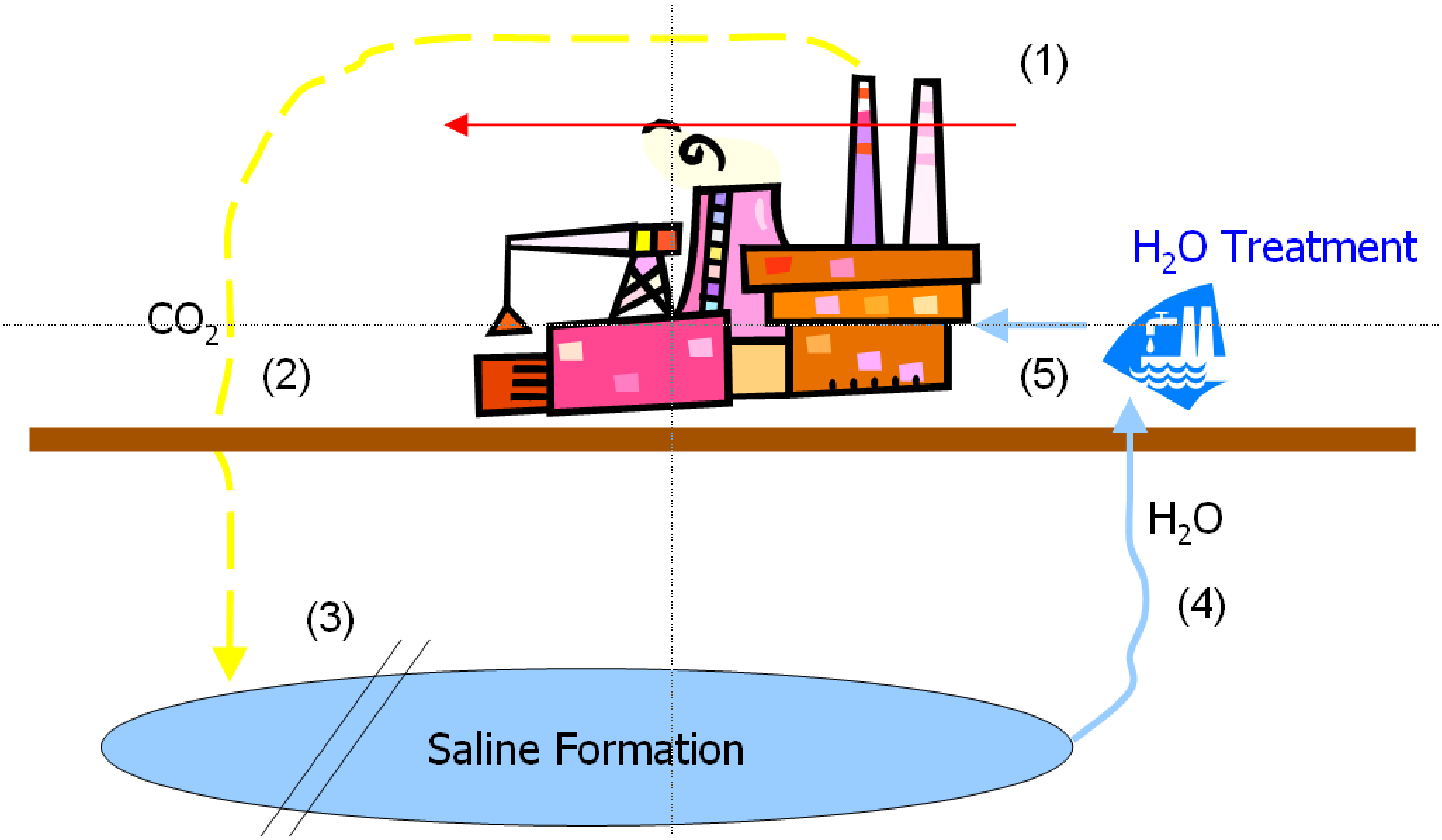
- Determine Levelized Cost of Energy (LCOE) for different CO_2 storage and water extraction options

  Price where the electricity generated will break even, as a function of the lifetime system cost

- Develop cost curves for different scenarios for national-scale comparison

  How much low-cost storage exists in the U.S.? Where are these sinks located?

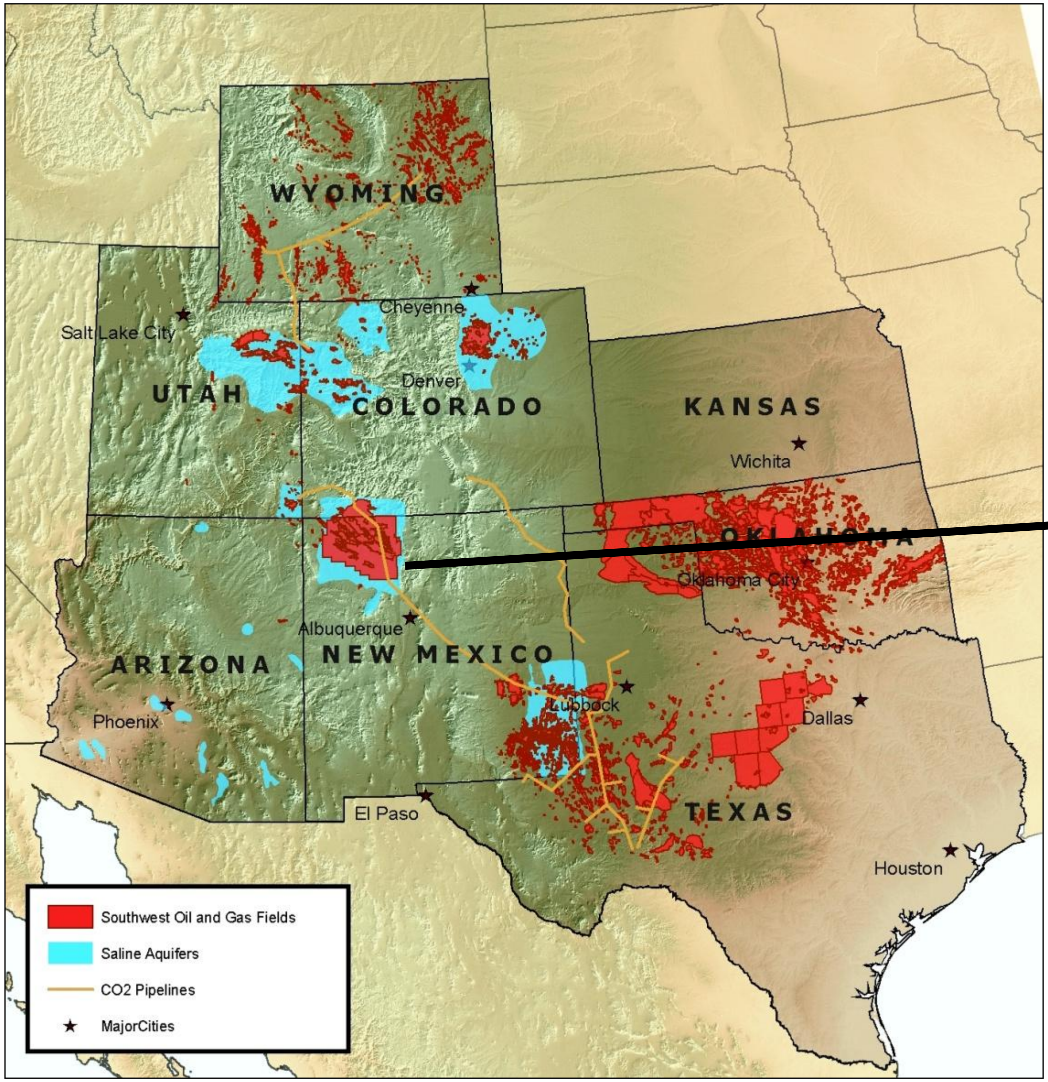
Conceptual Framework



WECS model

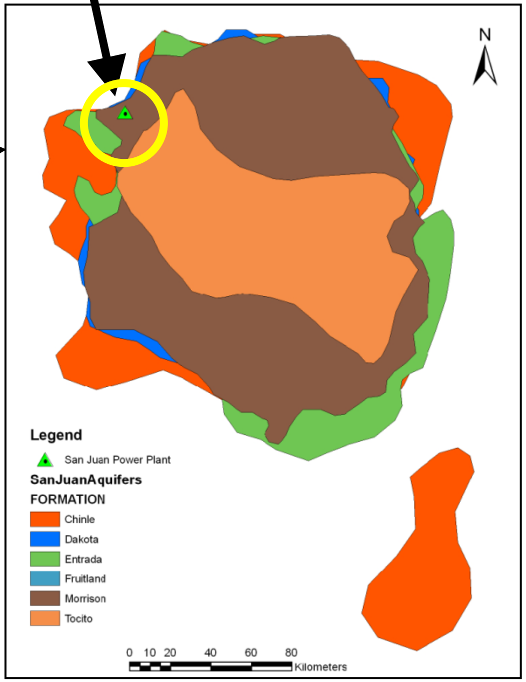
- Funded by the National Energy Technology Laboratory (NETL)
- Started with San Juan Basin - NW New Mexico
  - 1 power plant – 1 saline basin with multiple sinks
  - Plant size 1.8 GW, water demand 20 MGD
- Geochemistry Analysis using REACT
  - Sink water chemistries most suitable for reverse osmosis
  - Water chemistry from long-term reaction with CO_2
- Feasibility study for CO_2 injection, water extraction, treatment and use at power plant

WECS model



San Juan Power Plant

Morrison Formation



WECS model - Dashboard

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Power Plant | **CCS Assumptions** | **CO2 Sink** | **Displaced Water**

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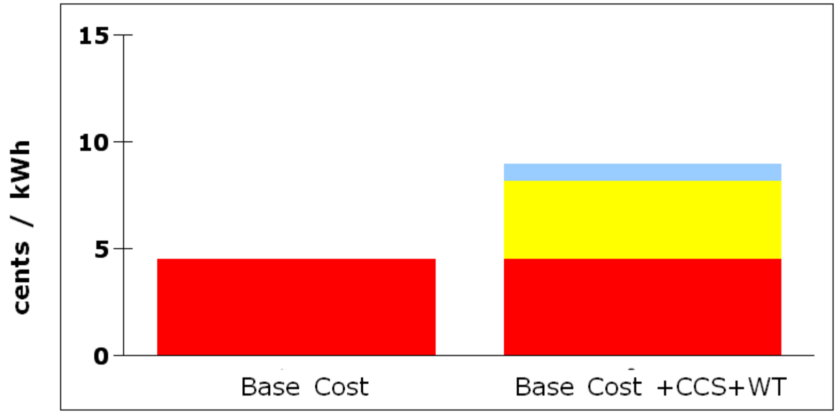
Saline Aquifers for Combined Thermoelectric Power Plant Water Needs and Carbon Sequestration at a Regional-Scale



Base Cost	(red)
Carbon Capture and Sequestration (CCS)	(yellow)
Water Treatment (WT)	(blue)

Input Variable	
Power Plant Emissions (CO2)	14,512,417 ton/yr
% CO2 Sequestered	50 %
Formation Depth	4,725 ft
Formation Size	5,000 mmt
Power Plant Water Demand	6.90 cubic ft/s
	6,421,612,530 gallon/yr
	17.84 MGD
High-Level Results	
CO2 Sink Longevity	760 yr
Displaced Water	625,809,605 gallon/yr
	1.74 MGD
% of Annual Plant Demand Met	9.75 %
Years Worth of H2O in Formation	74 yr
Electricity Cost	4.50 cents/kWh
Water Treatment Costs	$7.37 per thousand gallons
Electricity Cost, CO2 Seq & H2O Treament	8.95 cents/kWh

CO2 per year
ton/yr
20,000,000
10,000,000
0
14,512,417 ton/yr

% CO2 Captured
90%
70%
50%
30%
0%
50 %

Geological Formation (ft deep)
Morrison (4750)

CO2 Density to H2O
Handbook of Phys Const
1.20 cubic cm/gram

% H2O Recovery
%
100
0
30 %

San Juan MGD
MGD
15
0
17.84 MGD

Base Cost of Electricity
cents/kWh
20
0
4.50 cents/kWh

WECS model - Results

- Modeled 700 years of potential CO_2 storage in all sinks within San Juan basin

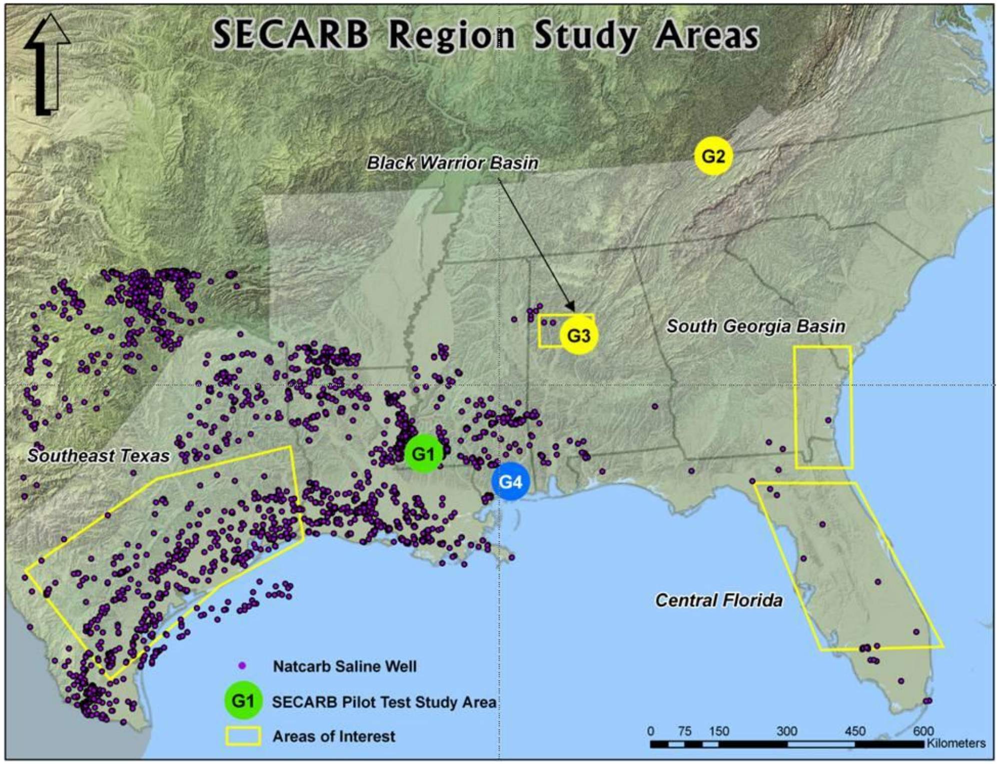
- Up to 200 years worth of saline water for meeting existing cooling needs, if power plant is still operating
  - Pumping, reverse osmosis treatment = $5.00/1000 gallon

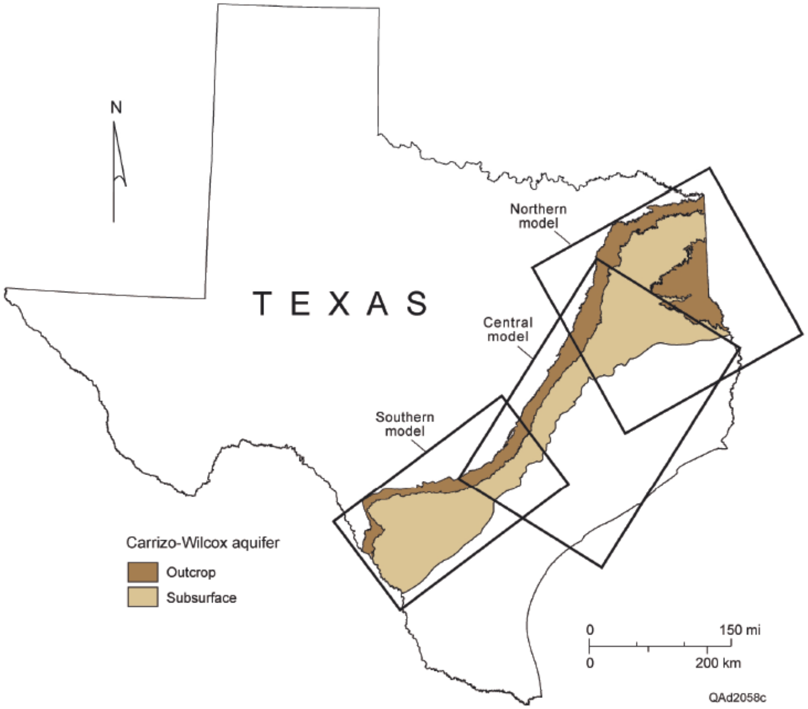
**Conceptual framework established for regional analysis

- Next steps:
  - More detailed CO_2 storage and transport processes
  - Address costs in a more integrated way

WECS II Model

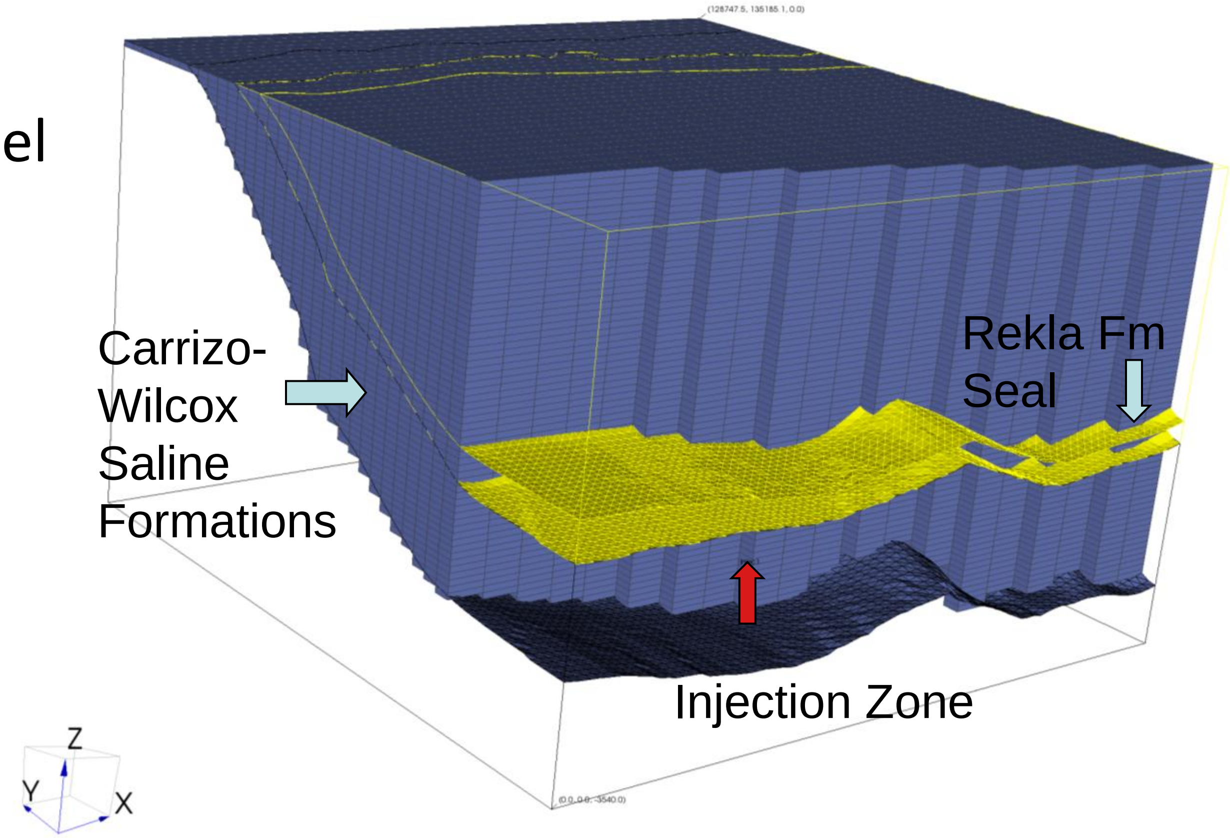
- Focused on southeast U.S.
- Carrizo-Wilson saline sink – geomodeling
- Water treatment costs at power plants



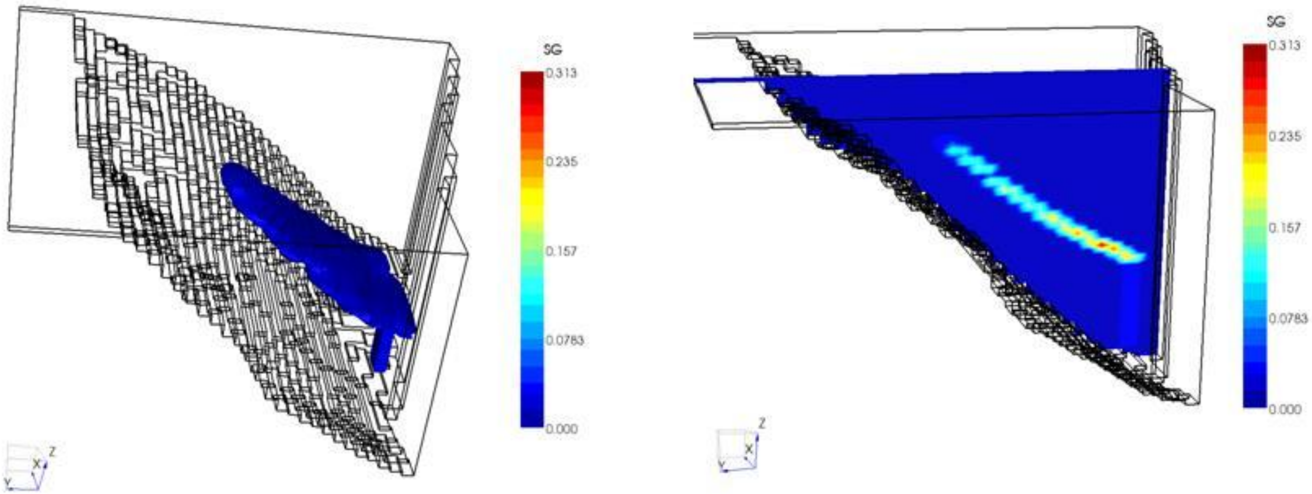


WECS II model - Geomodeling

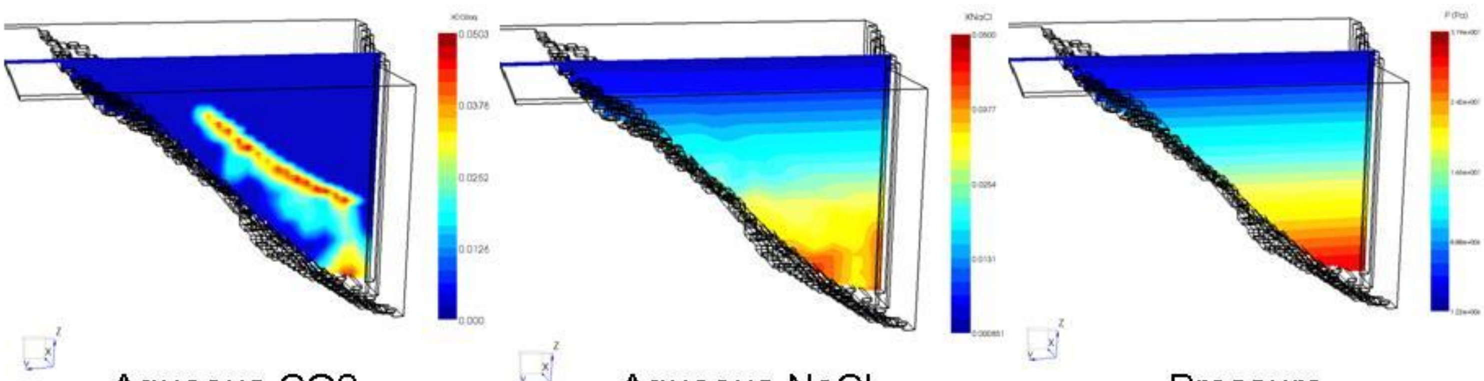
- Dipping saline sink – no structural closure
  - Potential migration pathway for CO_2
- TOUGH2
  - Numerical Model
  - Determine migration rates and paths over 1000 and 5000 years



WECS II model - Geomodeling



3D and "slice" view of CO2 plume after 5000 years



Aqueous CO2 Aqueous NaCl Pressure

WECS II model - Results

- Uncertainty in vertical conductivity drove whether CO_2 gas/liquid migrates under or through caprock
  - Some leakage or no leakage at all
  - Forced to model using homogeneous permeability
  - Next efforts will focus on heterogeneous permeability
- Desalination costs for reverse osmosis
  - From $5.50 to $9.00/1000 gallon depending on dispoal method. Included evaporation and brine injection

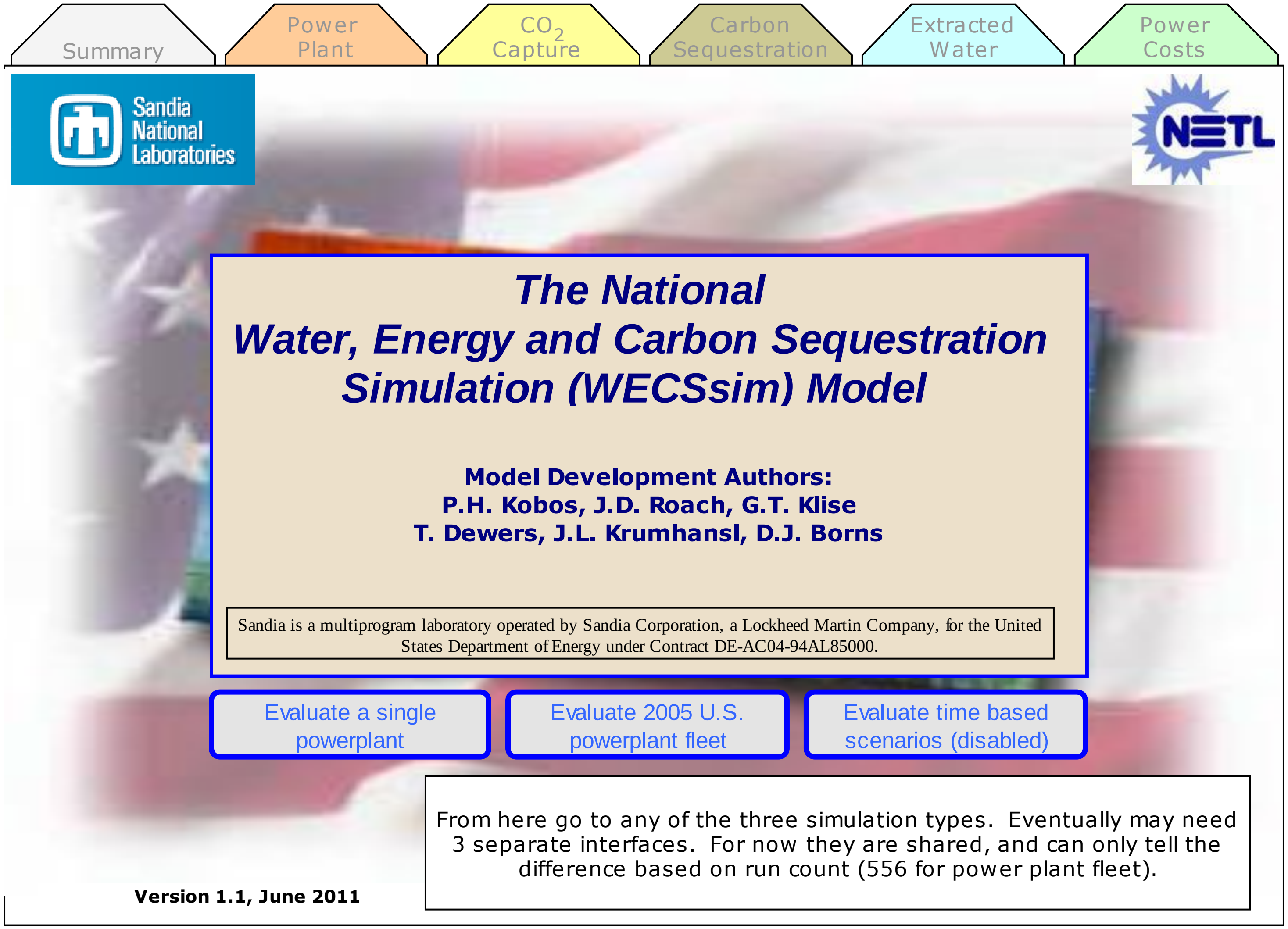
Kobos et al. (2011) Combining power plant water needs and carbon dioxide storage using saline formations: Implications for carbon dioxide and water management policies. *Int J Greenhouse Gas Control* 5:899-910

WECSsim - National Effort

- Utilize NatCarb data for saline sinks
  - 325 saline sinks identified for this model
- National modeling platform
- Develop cost curves for cost of storing CO_2 and cost of avoided emissions
- Emphasize the saline water link as competing demands for water in the future will make the cost of freshwater highly variable

WECSsim - Dashboard

WECSsim: a dynamic analysis tool



From here go to any of the three simulation types. Eventually may need 3 separate interfaces. For now they are shared, and can only tell the difference based on run count (556 for power plant fleet).

WECSsim - Dashboard

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WECSsim: a dynamic analysis tool

Summary | **Power Plant** | CO_2 Capture | Carbon Sequestration | Extracted Water | Power Costs

Module Input

- *Summary*
- *Plant location*
- *Plant type & size*
- ***H_2O use & LCOE***

Cooling Technology

- ○ Once through
- ◉ Cooling tower(s)
- ○ Cooling pond(s)
- ○ Dry cooling

Base Water Use	Withdrawal	Consumption
◉ Use default:	670 gal/MWh	520 gal/MWh
○ Use custom: (click # to change)	25,361 gal/MWh	17 gal/MWh

Defaults based on Tables D-1 and D-4 of NETL 400/2008/1339 and Figure 4-2 and B-1 of NETL 402/08018

Base Levelized Cost of Electricity (LCOE)

	Total		Fuel Costs		Cooling		All Other	$ Year:
◉ Default:	6.7 cents/kWh	=	2.1 cents/kWh	+	0.3 cents/kWh	+	4.4 cents/kWh	2010
○ Custom: (changeable)	6.4 cents/kWh	=	2 cents/kWh	+	0.2 cents/kWh	+	4.2 cents/kWh	2007

Defaults based on Exhibits ES-2, 3-29, 3-62, 3-95, 4-12, 4-33, 5-12 in NETL 2007/1281 and Figure 13 of Tawney, Khan, Zachary, Journal of Engineering for Gas Turbines and Power, April 2005, V 127

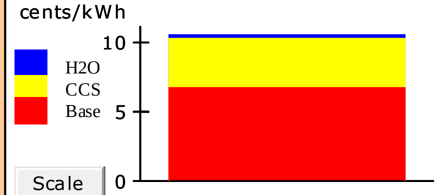
Output

Key Information from Power Plant Module

Plant type	Pulverized coal subcritical
Base electricity generation	14.4 TWh/yr
Base CO2 generation	12.3 Mmt/yr
Cooling type	Cooling tower
Base water withdrawals	26.8 MGD
Base water consumption	20.8 MGD

Power Plant Location

Change to LCOE

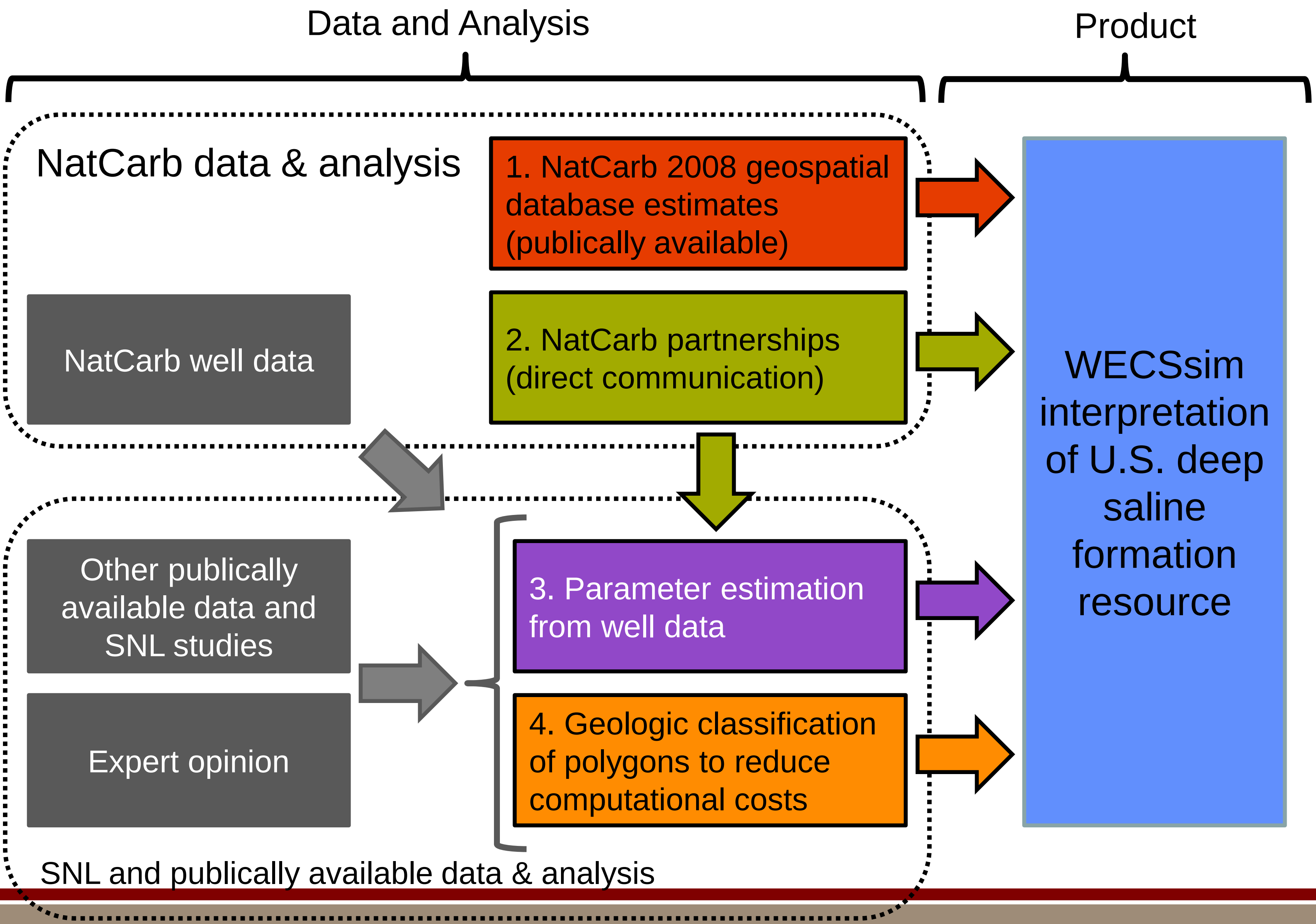


Background and Documentation

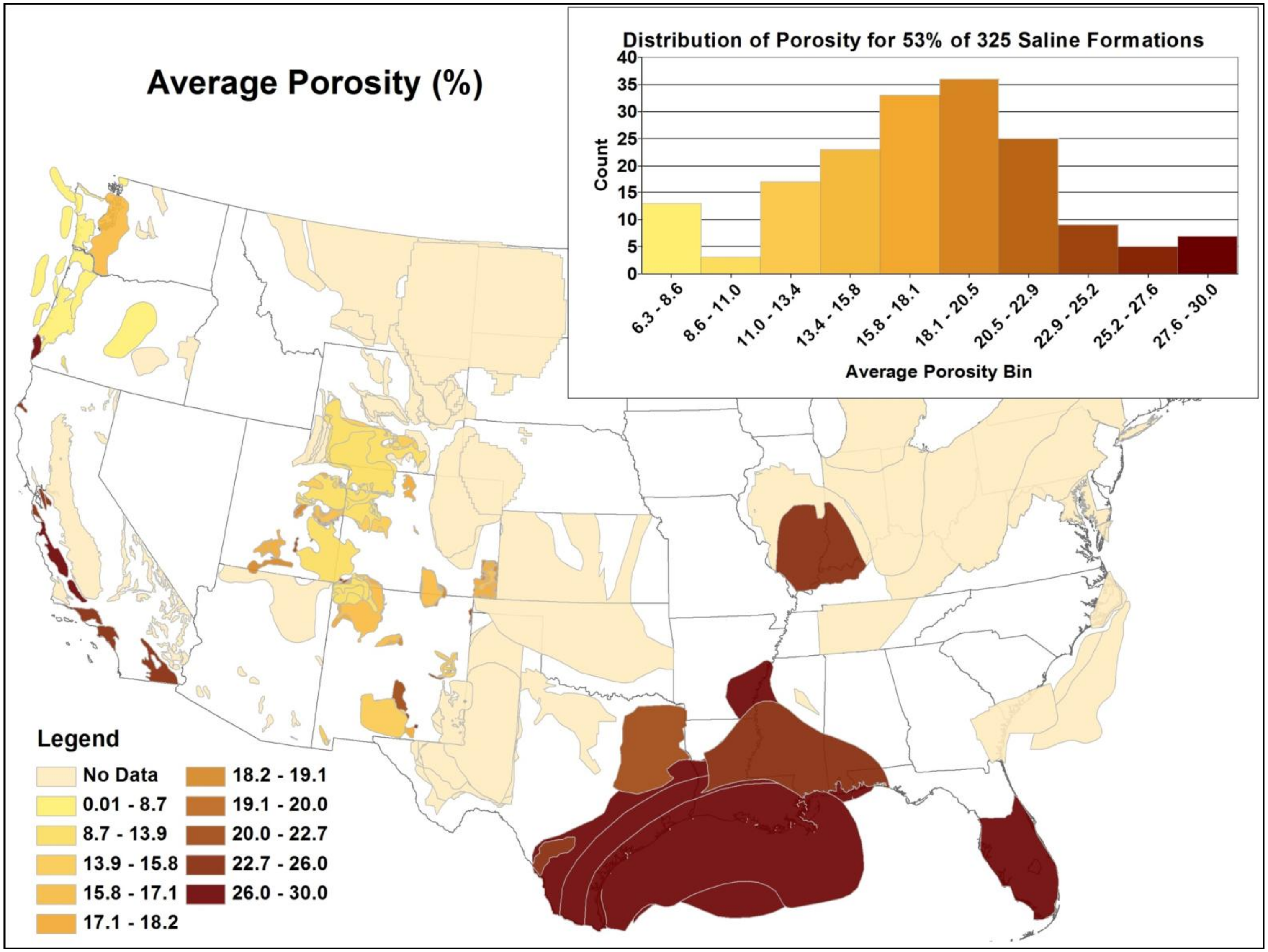
WECSsim - Challenges

- Data issues
  - 325 saline formations
- National modeling platform
- Geomodeling done on a few sinks, but not all
  - Sink water chemistries most suitable for reverse osmosis
  - Water chemistry from long-term reaction with CO_2
- Feasibility study for CO_2 injection, water extraction, treatment and use at power plant

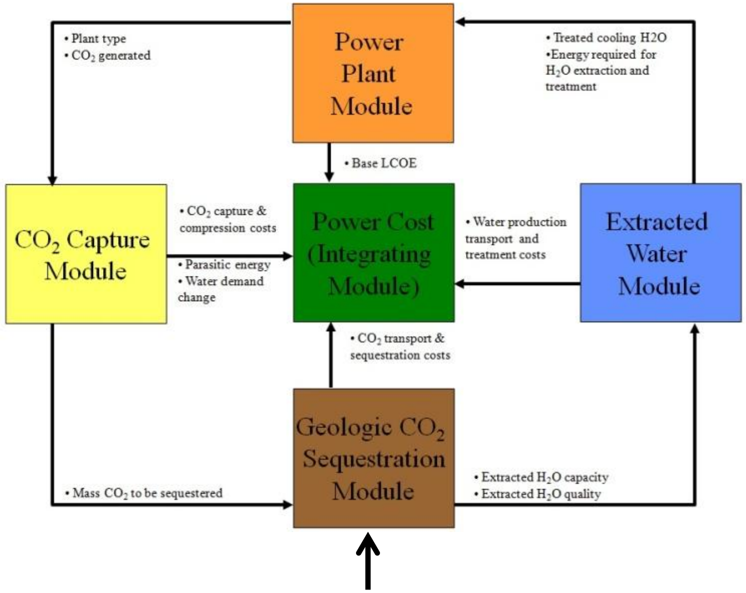
Assessing U.S. deep saline formations



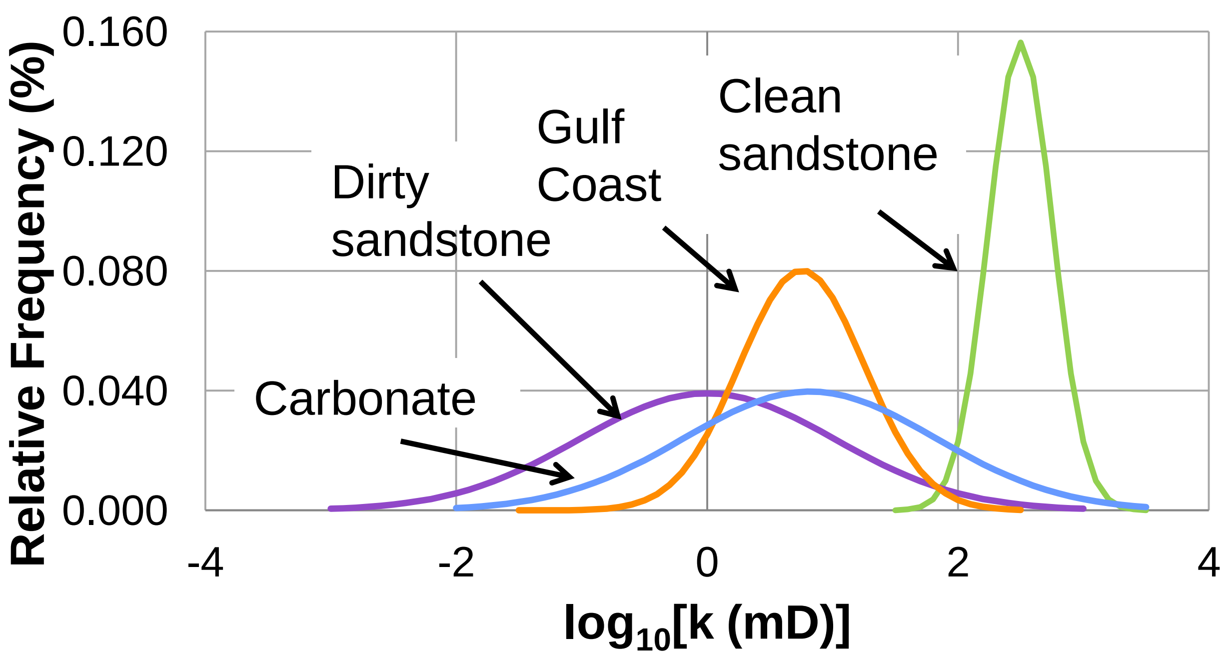
WECSsim - Challenges



Rock Type Classification



Injectivity equation: permeability sampled from 4 Rock Types



Uncertainty and the Well Injectivity Index

$$I \equiv \frac{q}{\Delta P}$$

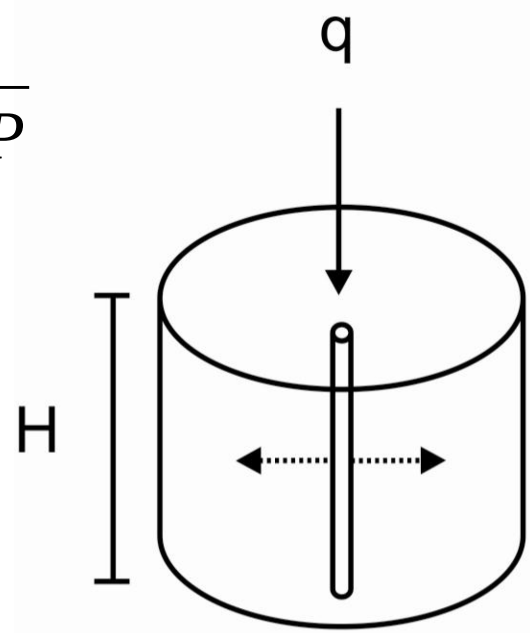
I well injectivity index; measure of the "ease" of injecting CO_2 into the well

q volumetric injection rate

ΔP the pressure gradient

$$I = \frac{4\pi k k_r H}{\mu\left(\ln\left(\frac{4A}{1.781 C_A r_w^2}\right) + 2s\right)}$$

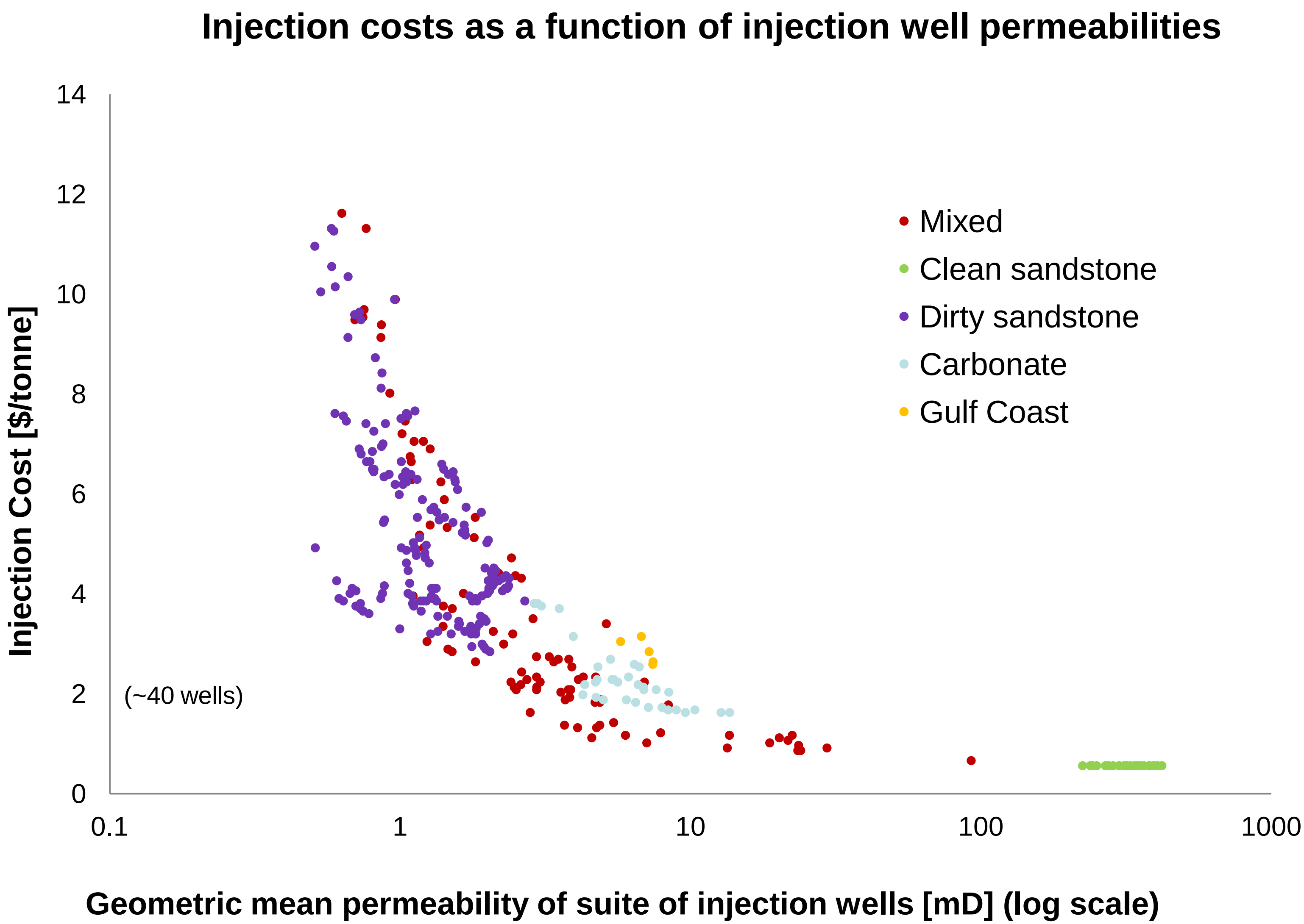
(Bryant and Lake, 2005)



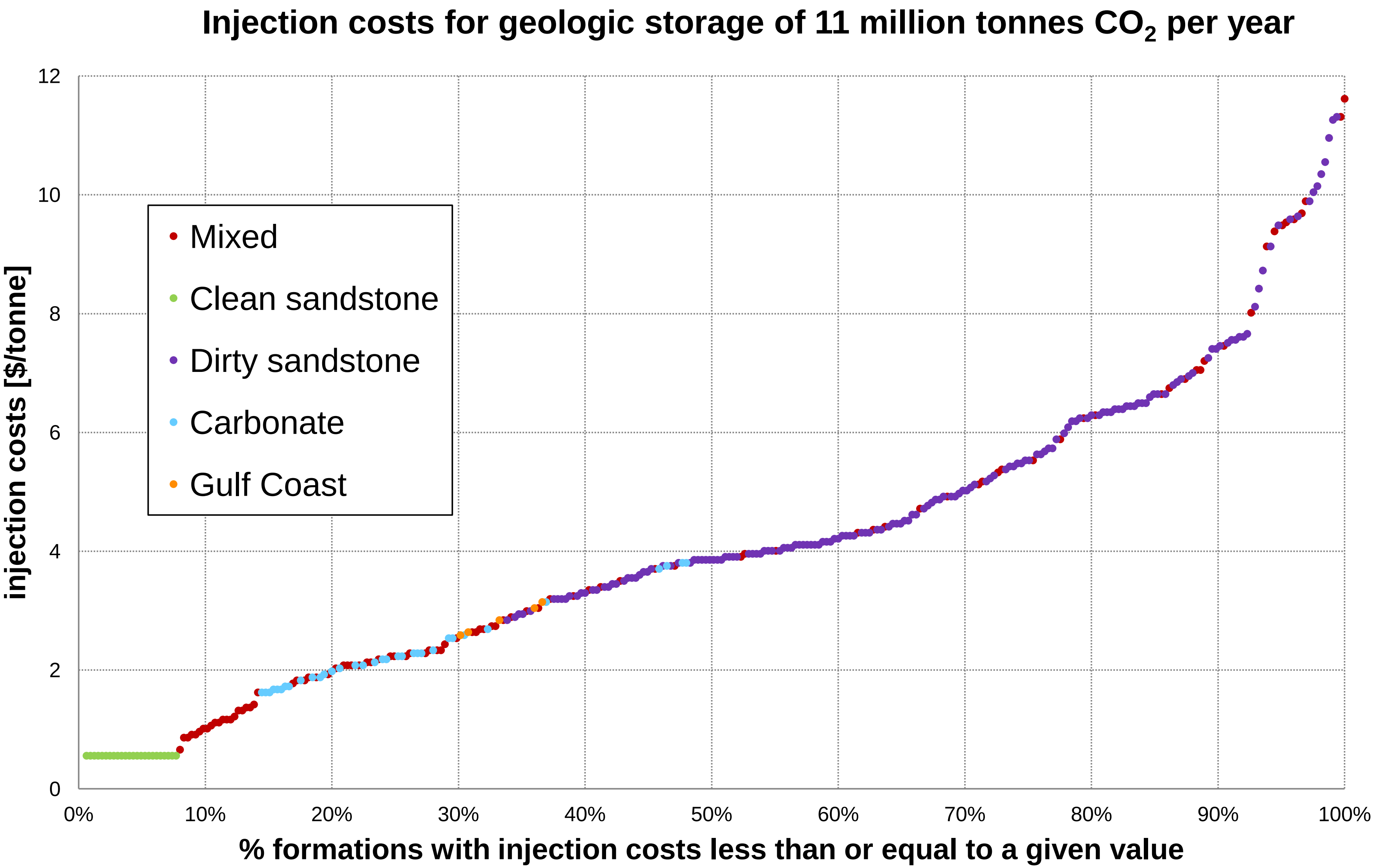
Reservoir volume

Radial flow from the well

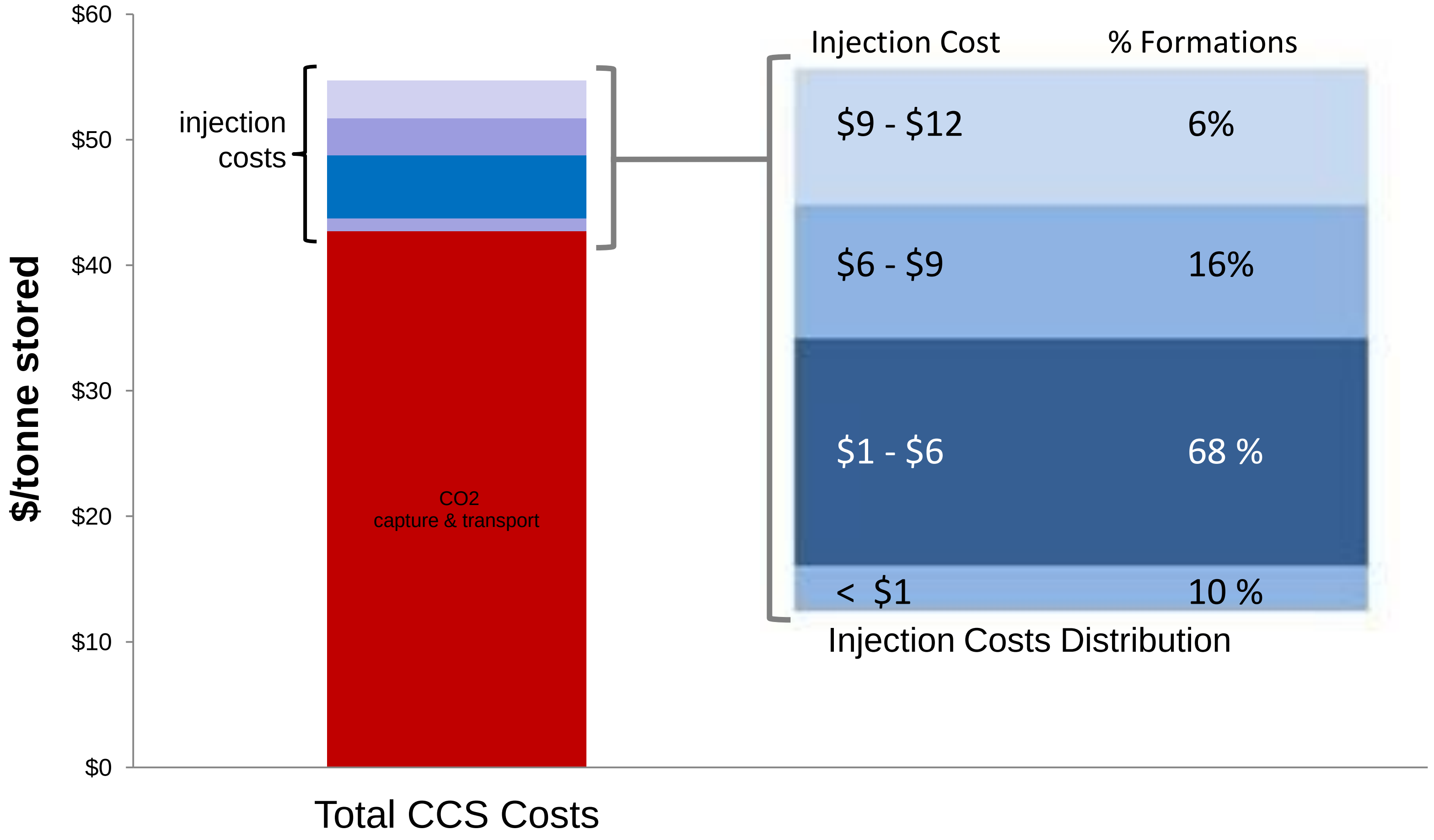
WECSsim Results: *Permeability and Costs*



WECSsim Results:
Injection Costs and Formation Types

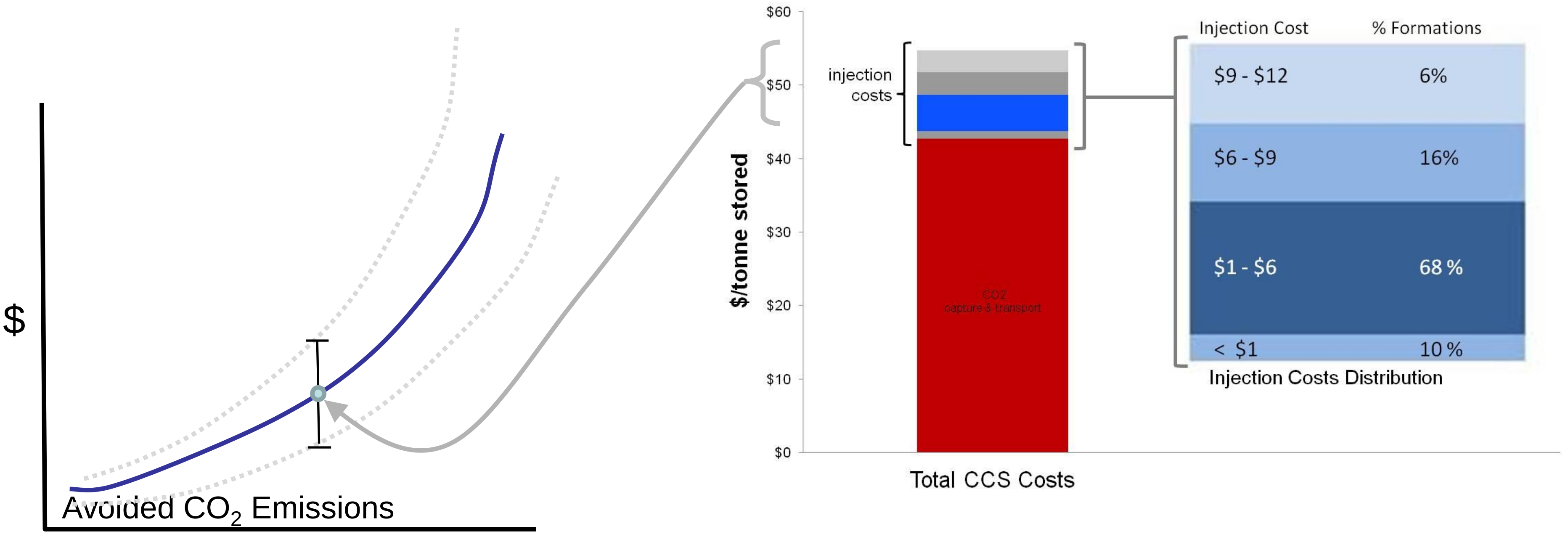


WECSsim Results:
Injection Costs Relative to Total Costs



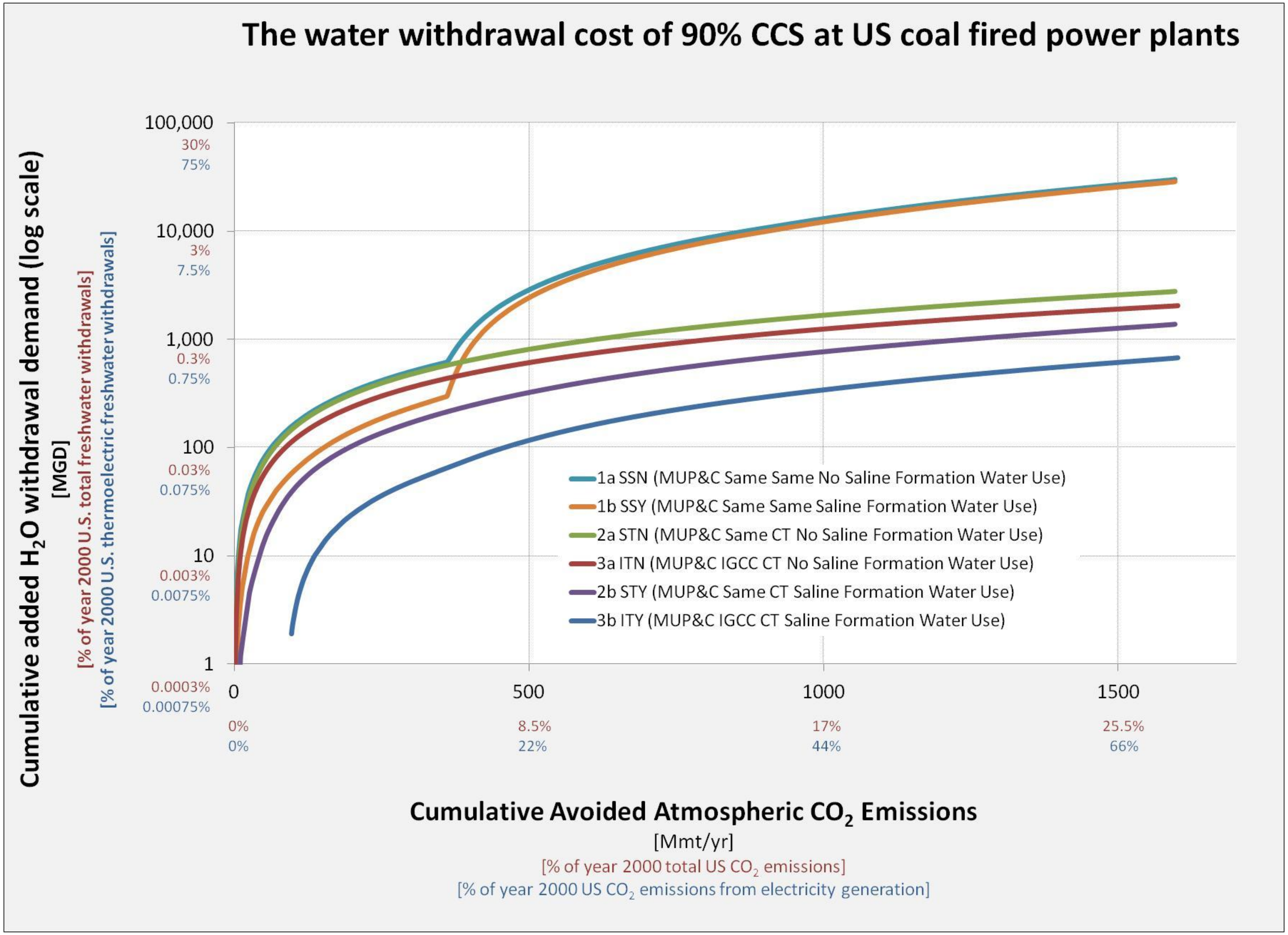
WECSsim Results:

Similar Full Economic Analysis Underway



Note: Illustrative Example at this time

WECSsim – Results



Conclusions

- Low CO_2 injection rates results in higher costs
  - Low injectivity requires more injection wells and therefore higher costs
  - Accurate Site Permeability Characterization is key
- Importance of High Quality Saline Reservoirs
  - High permeability reservoirs with low injection costs (< $1/tonne) represent < ~10% of the 325 formations
  - Scale-up challenge: What is your willingness to pay?
- Using a national-level systems approach
  - The mix of reservoirs of different quality is a major factor that will control ‘supply’ of CO_2 storage

On going and Future Work

- CO_2 injectivity-brine extractivity and heterogeneity
  - i.e., “How do injection rates improve with brine extraction?”
- Spatial distribution of CO_2 sources to sinks
  - i.e., “Are the high quality sinks accessible to large sources?”
- National Level Supply Assessment
  - i.e., “How much low-cost CO_2 storage exists in the U.S.?”
- Develop integrated geospatial output with WECSsim model

Thank you

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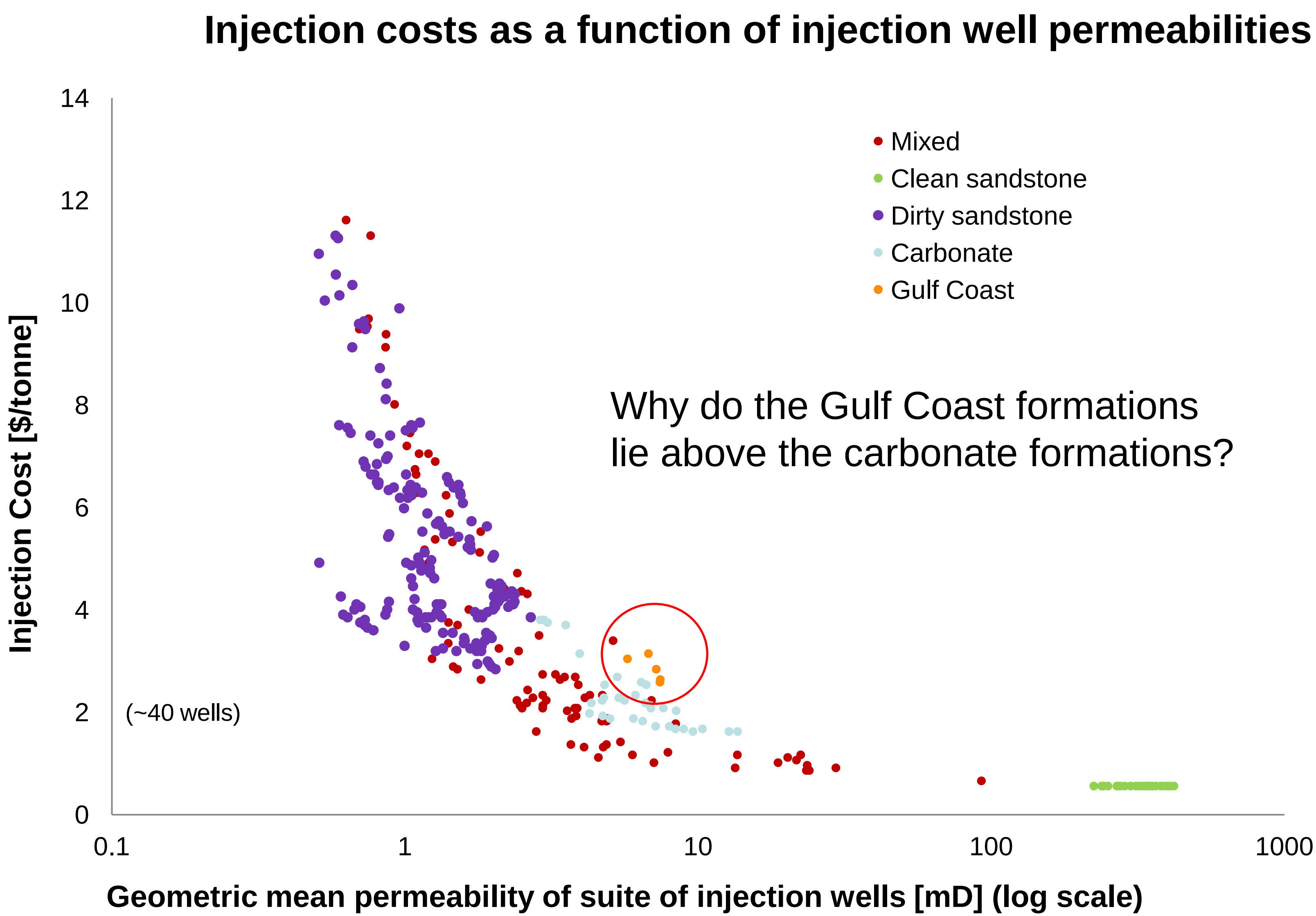
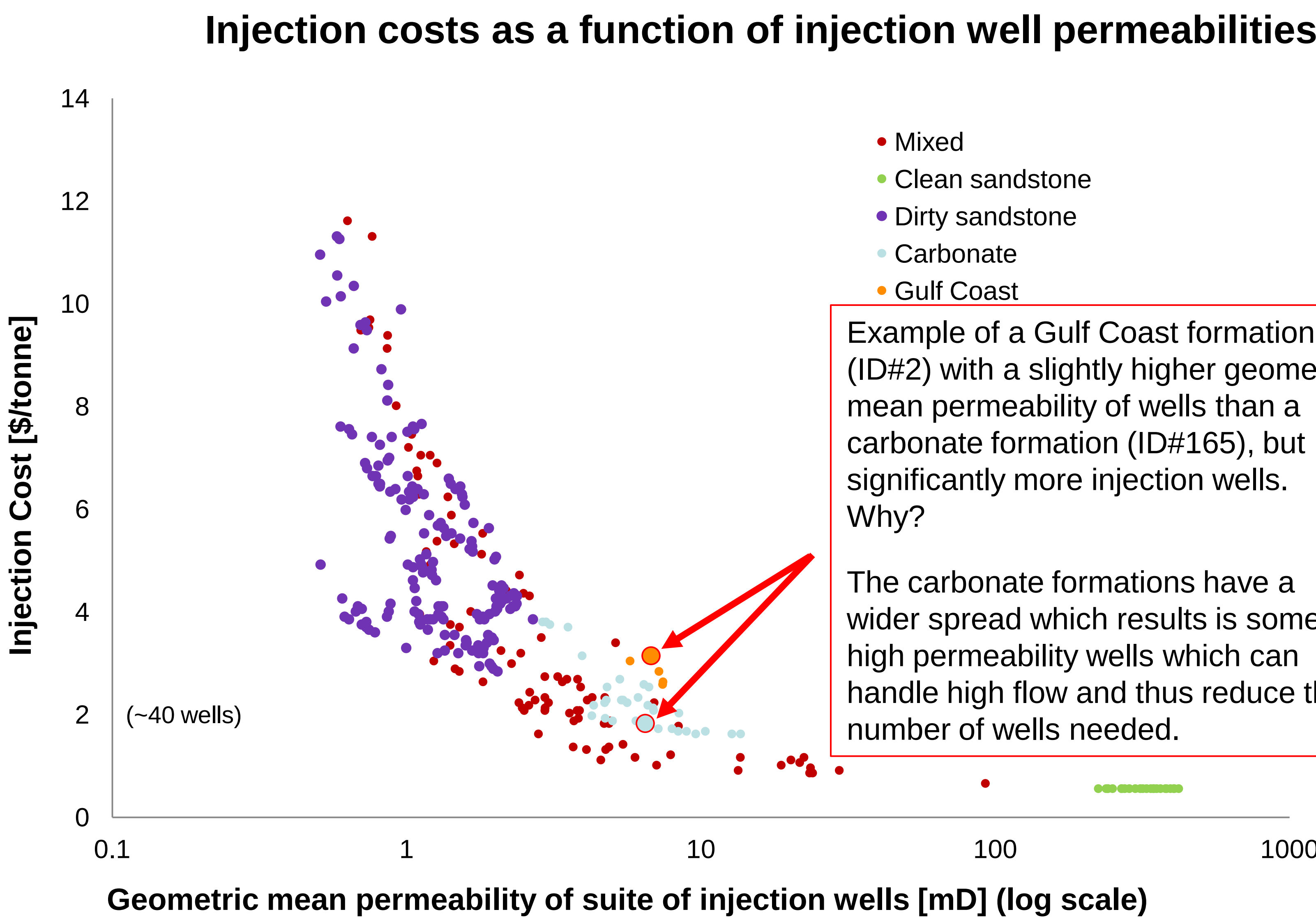
Gulf coast outliers



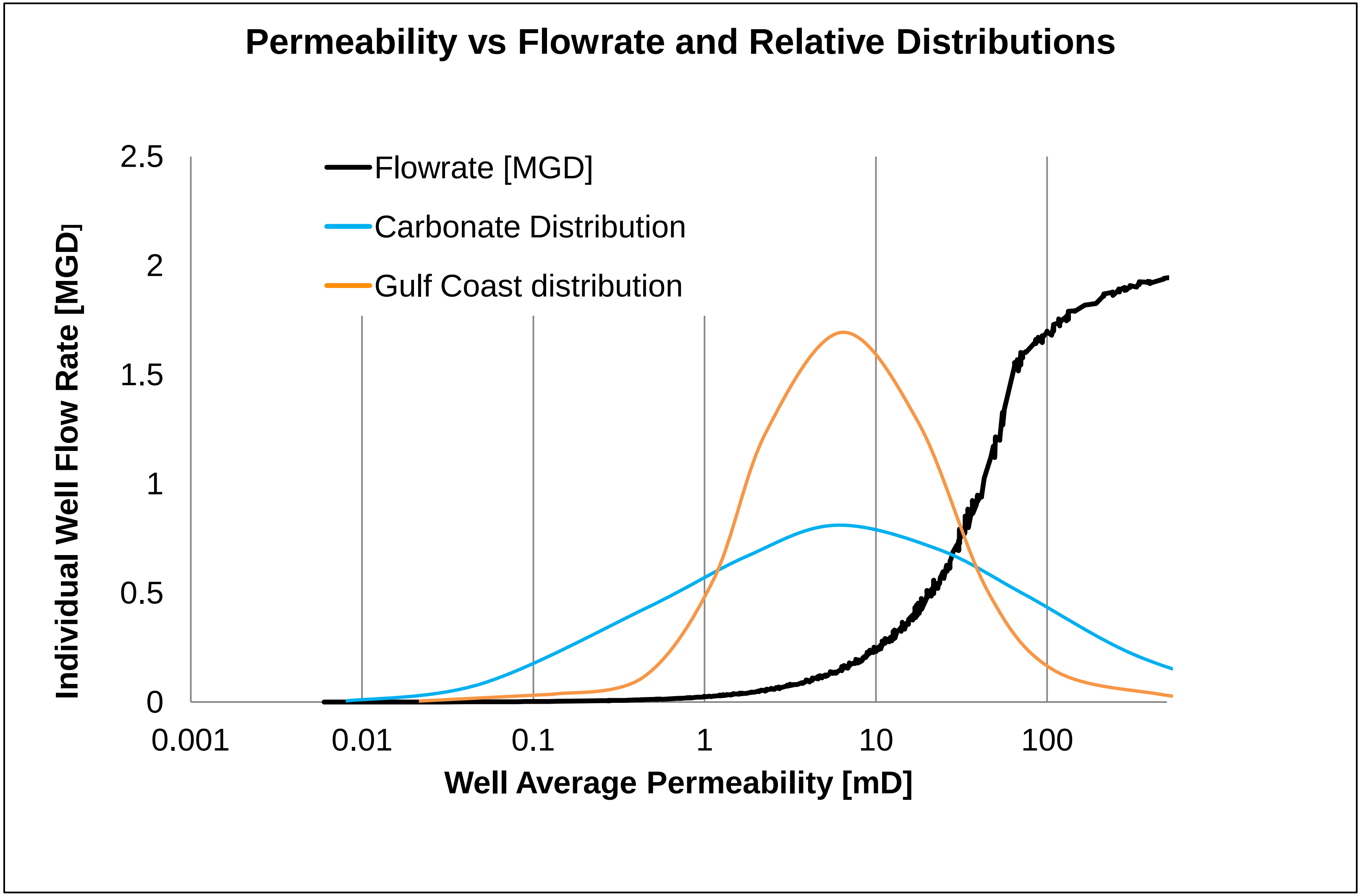
Gulf coast outliers



Example of a Gulf Coast formation (ID#2) with a slightly higher geometric mean permeability of wells than a carbonate formation (ID#165), but significantly more injection wells. Why?

The carbonate formations have a wider spread which results is some high permeability wells which can handle high flow and thus reduce the number of wells needed.

Gulf coast outliers



Gulf coast outliers

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