SAND2011-1718C

Economics, Modeling and CO_2 Management:

Developing Policy Insight with Data Uncertainty

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and

Jason E. Heath, Thomas Dewers, Jesse D. Roach, Geoffrey T. Klise, and many others.

Society for Industrial and Applied Mathematics (SIAM)

Conference on Mathematical & Computational Issues in the Geosciences

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Mathematical Modeling Approaches for Energy Policy Planning

- **Top-down**
  - Energy sector, economy-wide, Computable General Equilibrium (CGE)
  - Useful for simulating taxes and externalities for economic costs
  - e.g., Input-Output Analysis, Jorgenson-Wilcoxen Model (CGE)

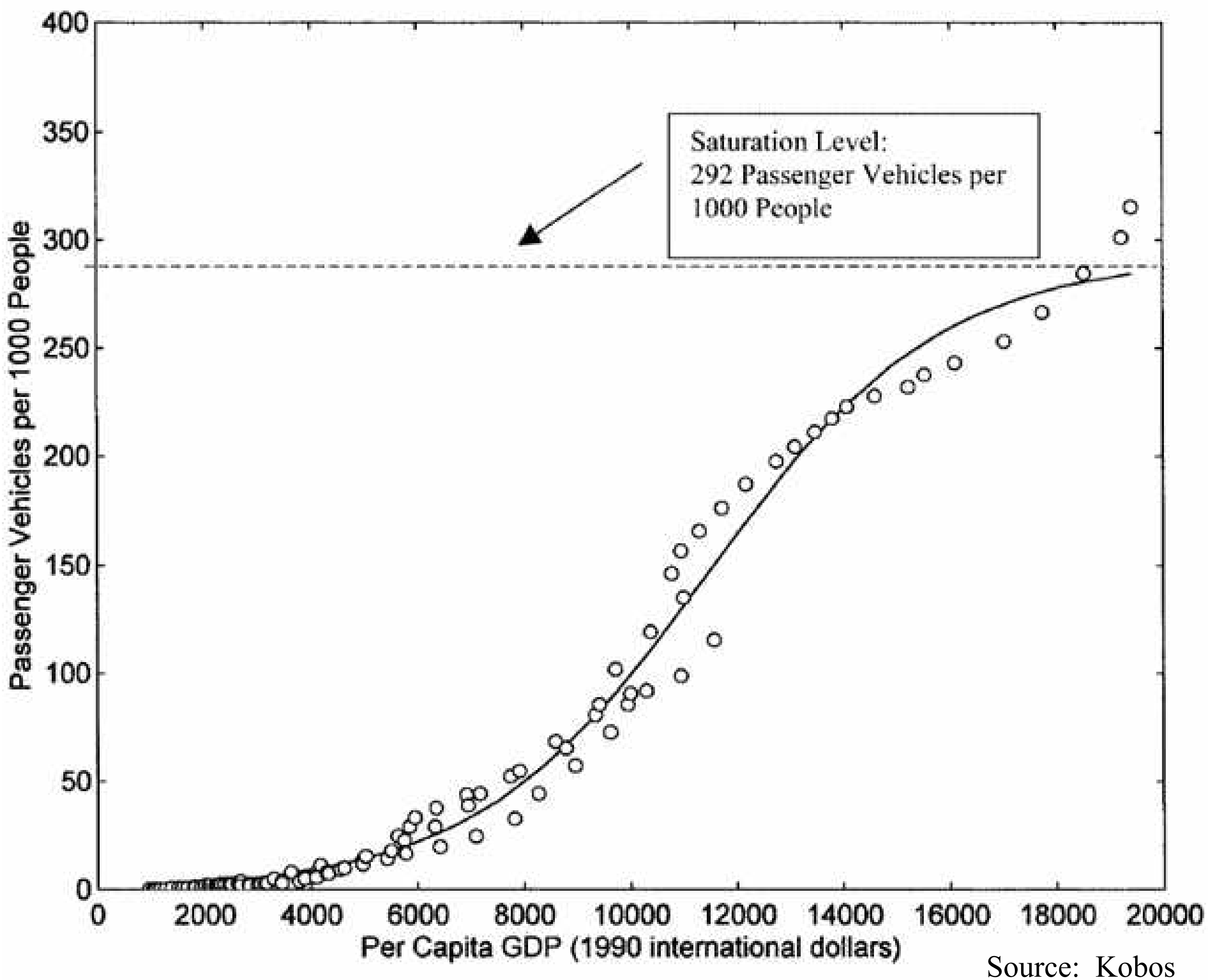
- **Bottom-up**
  - Simulation / optimization, technology descriptive
  - Useful for selecting fuel and technology choices
  - e.g., Least-Cost optimization models, MARKAL, MESSAGE, NEMS

- **Hybrid / Integrated Assessment Models**
  - Builds on the strengths of both Top-down and Bottom-up methods
  - Economic tools, technology, builds the systems view from several sets of detailed components
  - Useful to develop technology rich analysis modules combined with economic/policy insight

Sources: IEA, 1998; IIASA, 2005

Bottom-Up Product Adoption Forecasting:
Employing the Bootstrap Method

Estimating Market Saturation of Passenger Vehicle Ownership



Source: Kobos

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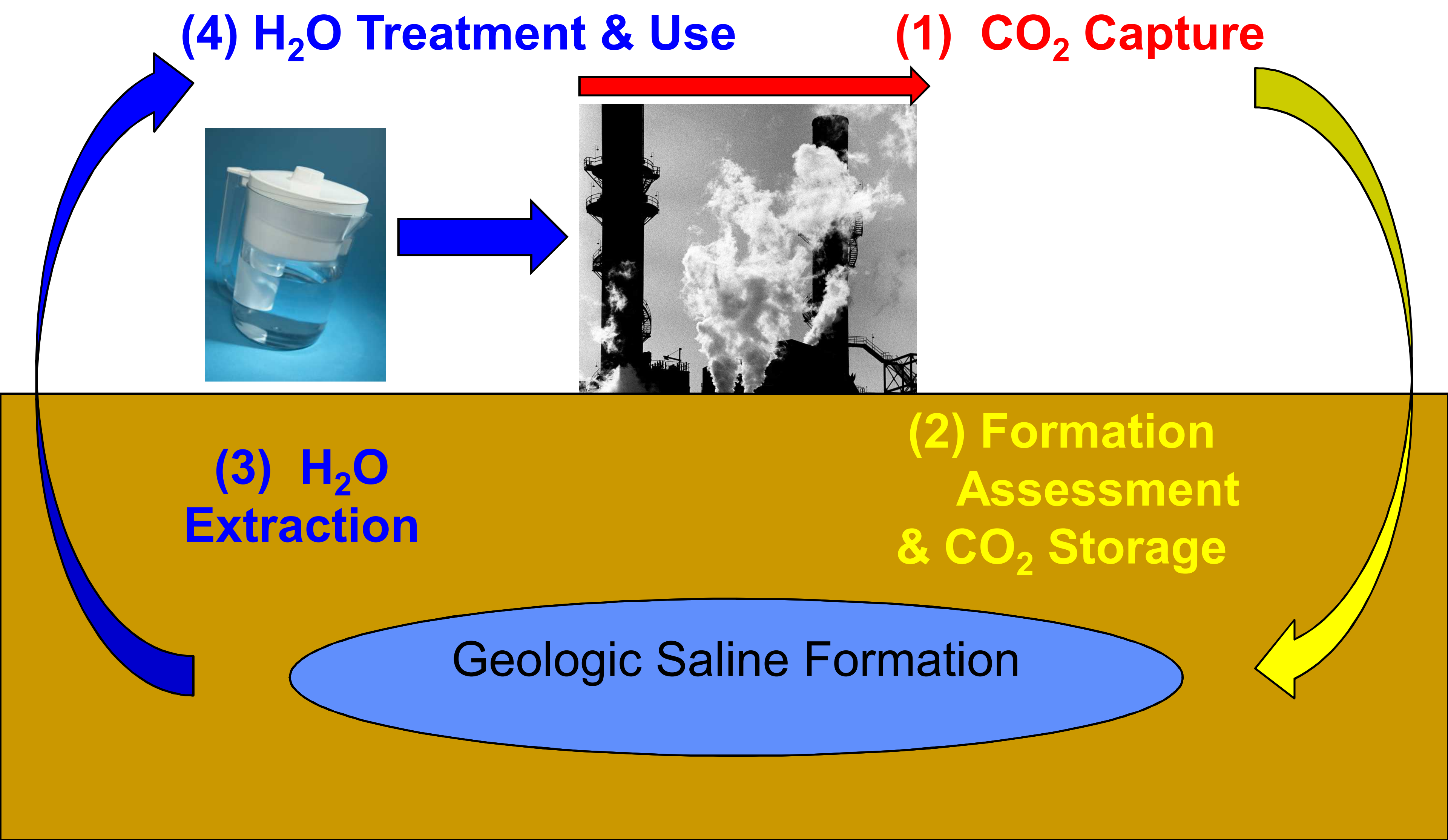
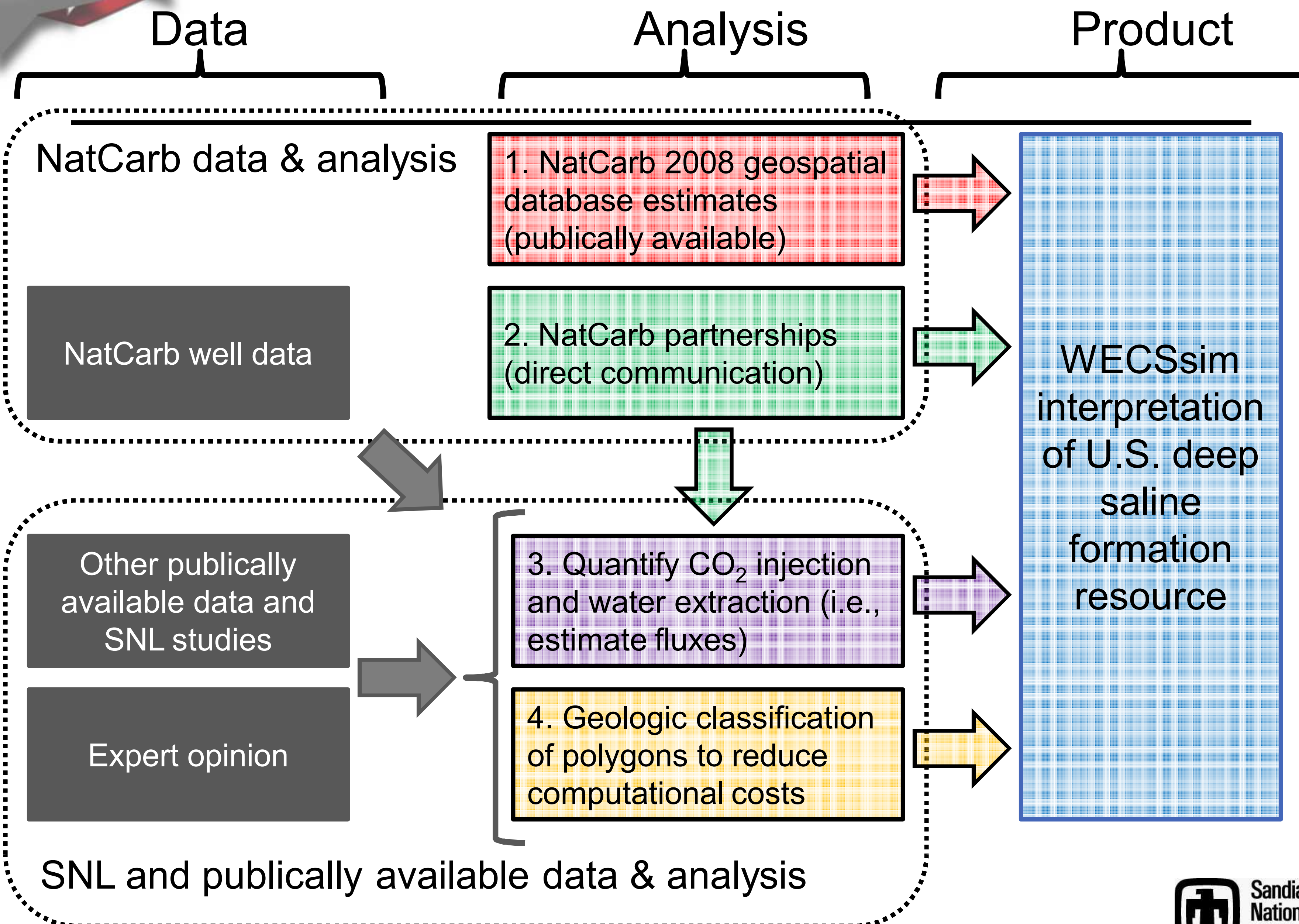
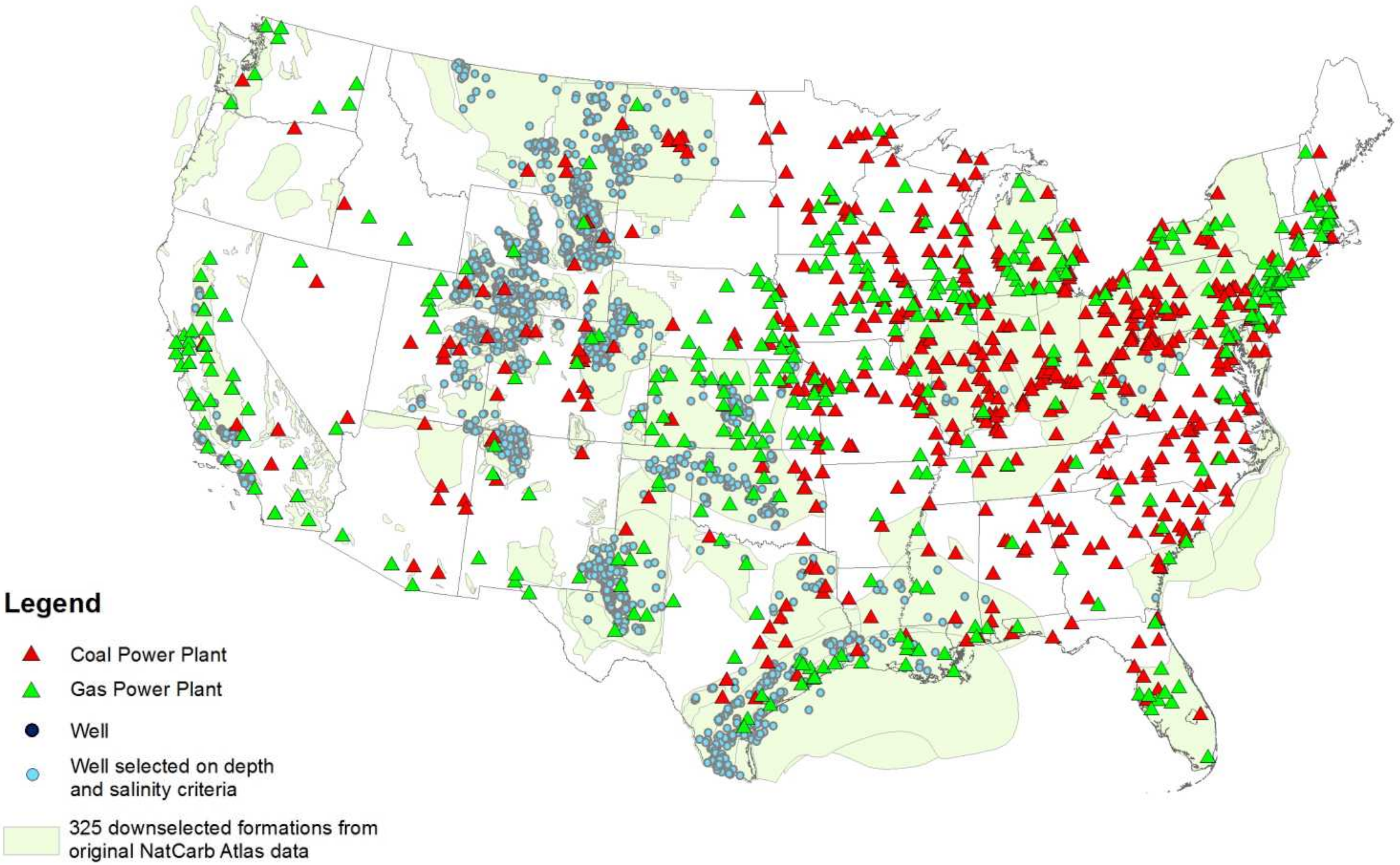
Building a Framework for
Water, Energy and CO_2 Storage (WECS):
Addressing Uncertainly in the Data



Assessing U.S. deep saline formations



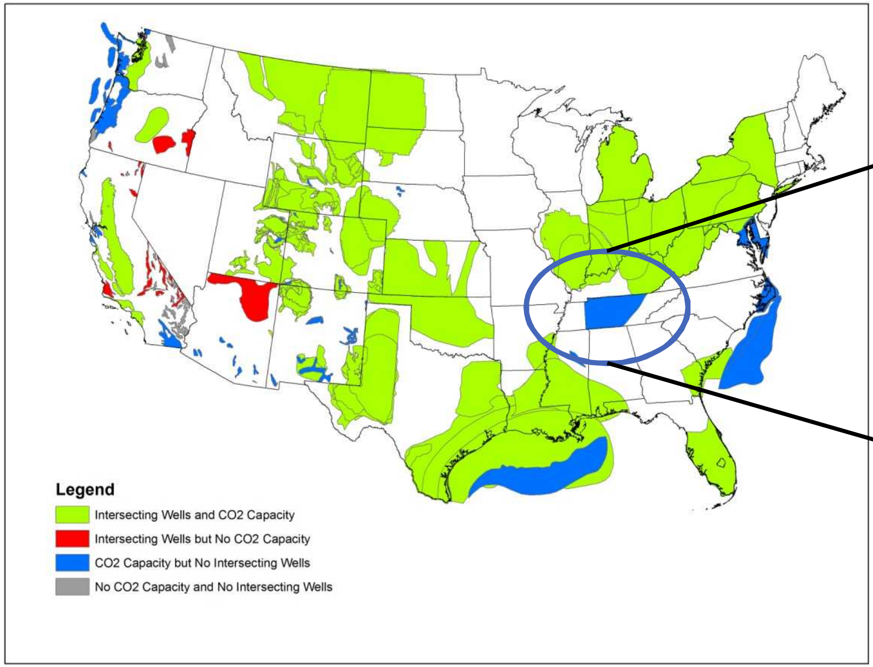
Geological CO_2 Storage Database is Incomplete: *Makes Source/Sink Matching Difficult*

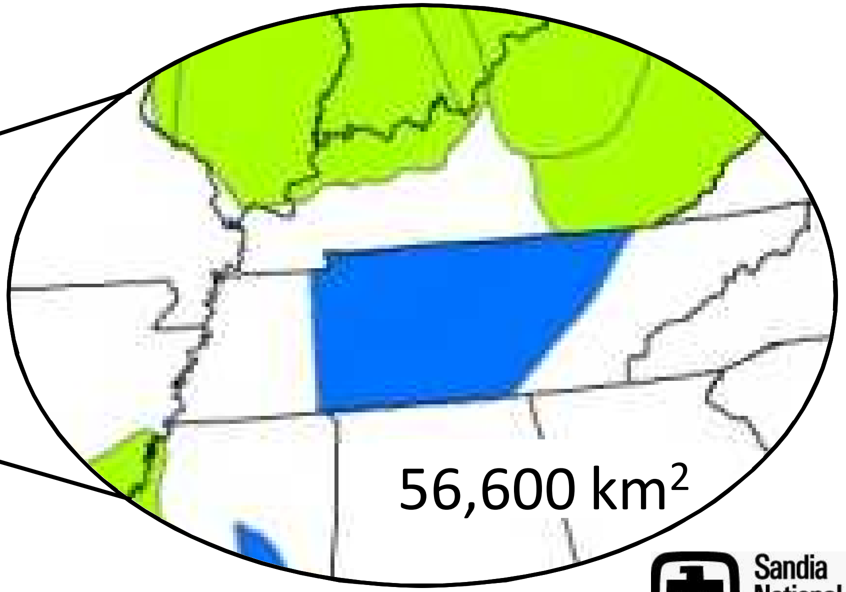


Mt. Simon Sandstone: Polygon in Tennessee w/sparse data

→One of the 47 polygons lacking desired information in NatCarb:

- Depth, thickness, porosity, permeability, pressure, temperature, and salinity information
- Any potentially intersecting wells (in the well databases we evaluated).





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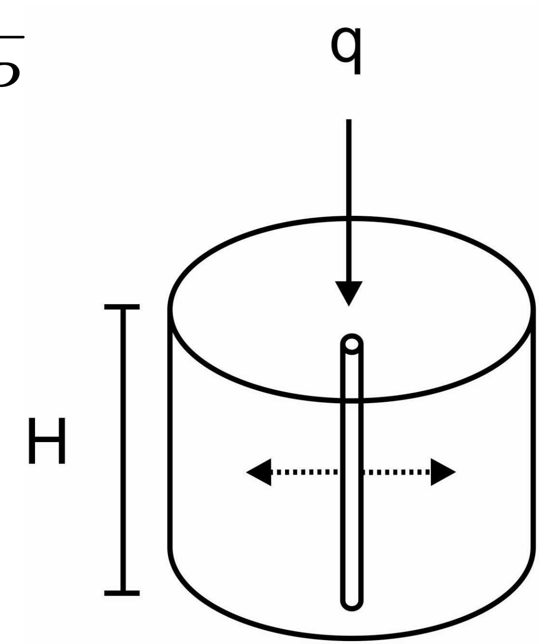
Uncertainty and the Well Injectivity Index

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

q volumetric flow rate

ΔP the pressure gradient

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



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

Reservoir Volume

Radial flow from the well

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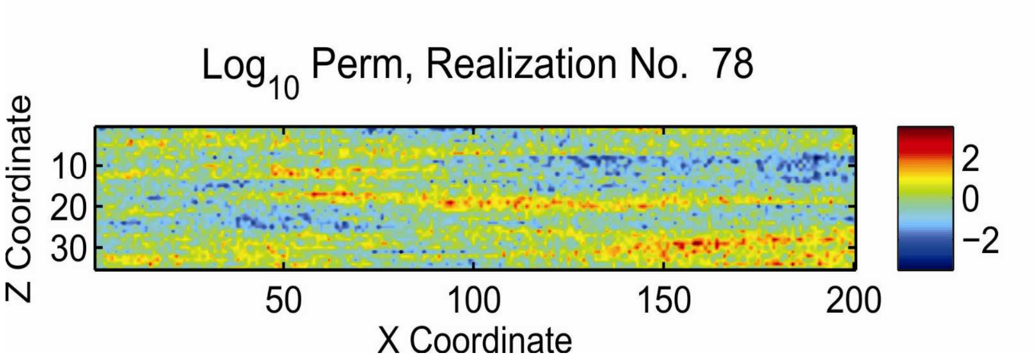
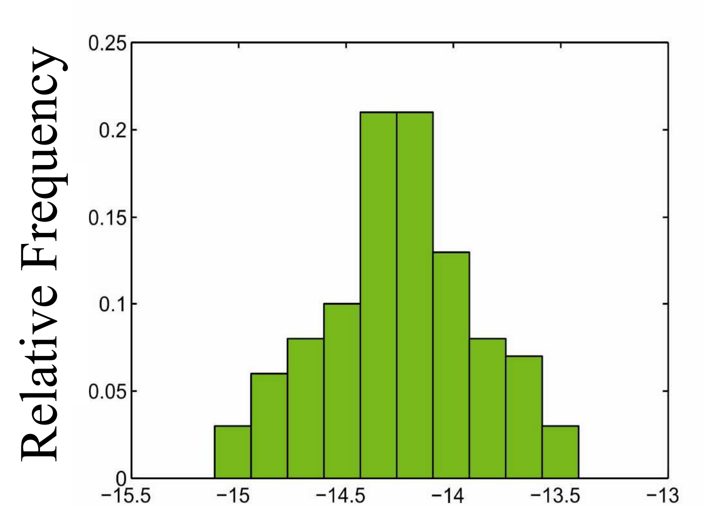
Generating pdfs of Well Injectivity Index

Use geostatistics to generate multiple realizations of relevant parameter fields

Average key parameters of each realization, giving pdfs for the parameters





Log_{10}(averaged permeability)

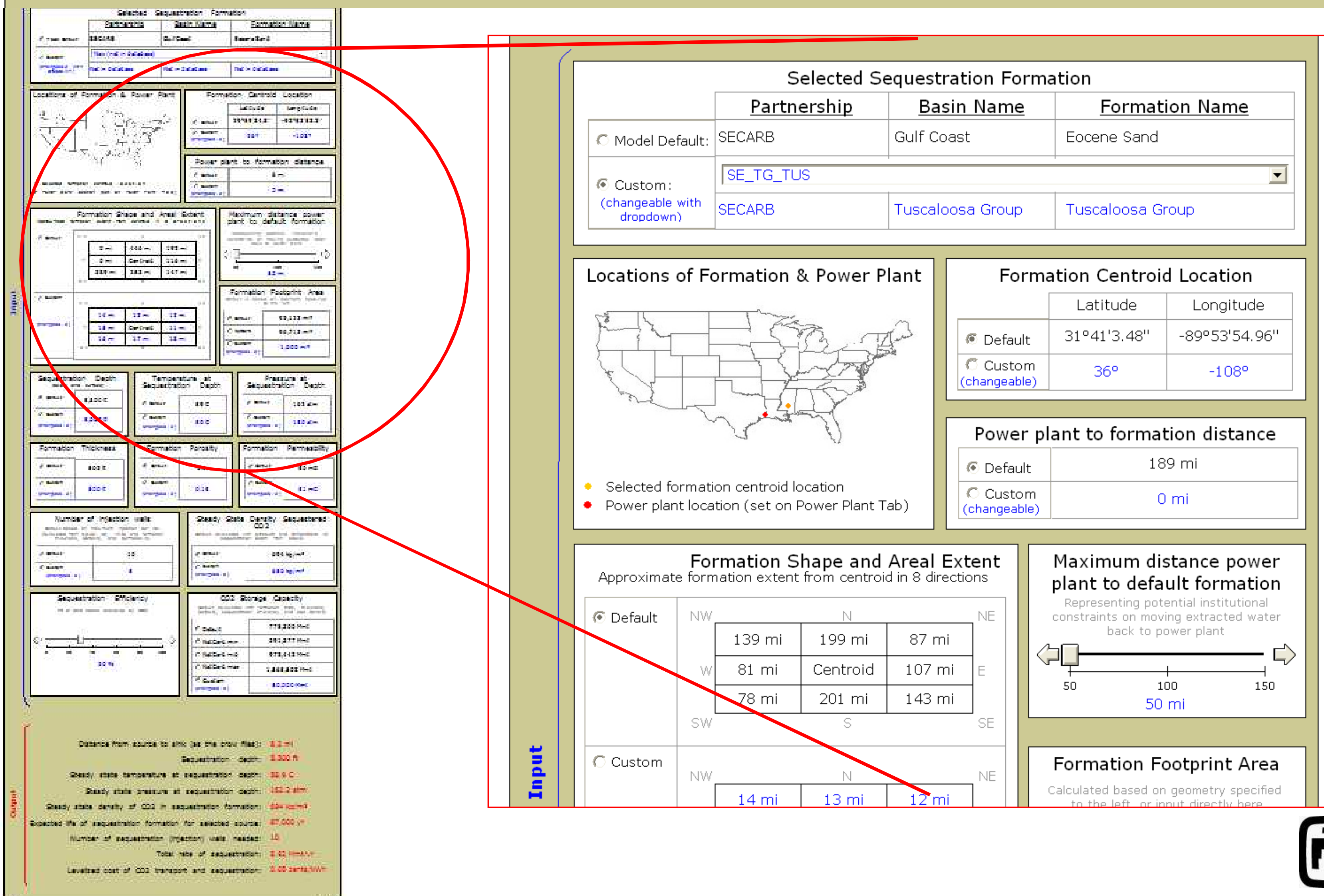
Feed the averaged parameters into equation to get a pdf of ***I***

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

Power plant generated carbon sequestration in saline formations

a dynamic analysis tool

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



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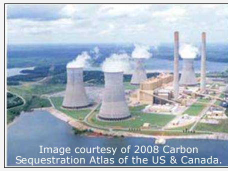
Summary | Power Plant | Carbon Capture | Carbon Sequestration | Extracted Water | Power Costs

General Summary

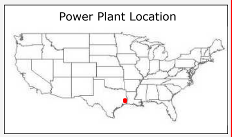
Power Plant Specifications	1,848 MW	PC Subcritical
% CO_2 Captured	90 %	
LCOE Increase	51 %	
Cost of Avoided CO_2 Emissions	$65 per tonne	
H_2O Demand Increase	12.5 MGD	58 %
Distance to Sequestration Formation	6 mi	
Formation Life For This CO_2 Only	73,000 yr	
% H_2O Demand Increase Served	60 %	



Power Plant Summary

(Power Plant tab for details or to change values.)

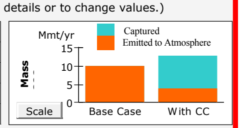
Power Plant Type	Pulverized coal subcritical	
Latitude and Longitude	30°	-94°
Base Electricity Production	11.5 TWh/yr	
Base CO_2 Production	9.9 Mmt/yr	
Base H_2O Withdrawals	21.4 MGD	
Base H_2O Consumption	6 billion gal/yr	



Carbon Capture (CC) Summary

(Carbon Capture tab for details or to change values.)

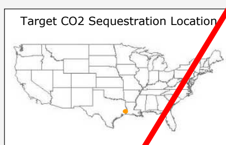
% Base CO_2 Captured	90 %
Parasitic Energy Loss	30 %
Make-Up-Power (MUP) CO_2 Production	2.8 Mmt/yr
% MUP CO_2 Captured	0 %
MUP and CC H_2O Withdrawals	12.5 MGD



Carbon Sequestration (CS) Summary

(Carbon Sequestration tab for details or to change.)

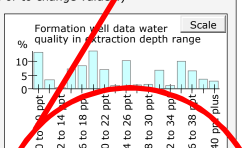
CO_2 To Be Sequestered	8.9 Mmt/yr	
Target Sink Centroid Lat-Long	29°59'35"	-93°53'58"
Power Plant to Sink (centroid) Distance	6 mi	
Target Sink Partnership	SECARB	
Target Sink Basin Name	Gulf Coast	
Target Sink Formation Name	Eocene Sand	
Sink Life for this CO_2 only	73,000 yr	



Extracted Water Summary

(Extracted Water tab for details or to change values.)

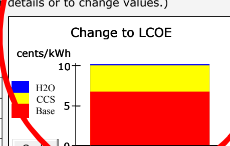
Rate of Water Extraction	10.1 MGD
Treated Water Stream	7.6 MGD
% CCS Related Water Demand Served	60 %
Extracted Water Target Quality	10 ppt to 30 ppt
Number of Extraction Wells	21
Extraction Well Depth Range	2500' to 5000'
Brine Disposal Method	Reinjection



Power Costs Summary (2010 $)

(Power Costs tab for details or to change values.)

Base Electricity Levelized Cost of Energy (LCOE)	6.7 cents/kWh
CO_2 Capture & Compression Additions to LCOE	3.2 cents/kWh
CO_2 Transport & Sequestration Additions to LCOE	0 cents/kWh
H_2O Extraction & Treatment Additions to LCOE	0.2 cents/kWh
Total New LCOE	10.1 cents/kWh
LCOE % Increase Due to CCS	51 %
Cost of Avoided CO_2 Emissions to Atmosphere	$65 per tonne



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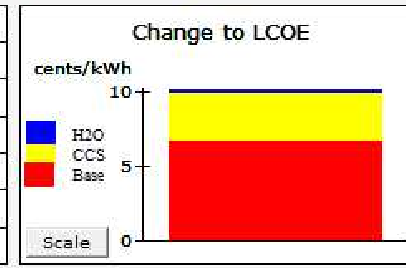
CO_2 Transport & Sequestration Additions to LCOE	0 cents/kWh
H_2O Extraction & Treatment Additions to LCOE	0.1 cents/kWh
Total New LCOE	10.1 cents/kWh
LCOE % Increase Due to CCS	51 %
Cost of Avoided CO_2 Emissions to Atmosphere	$64 per tonne



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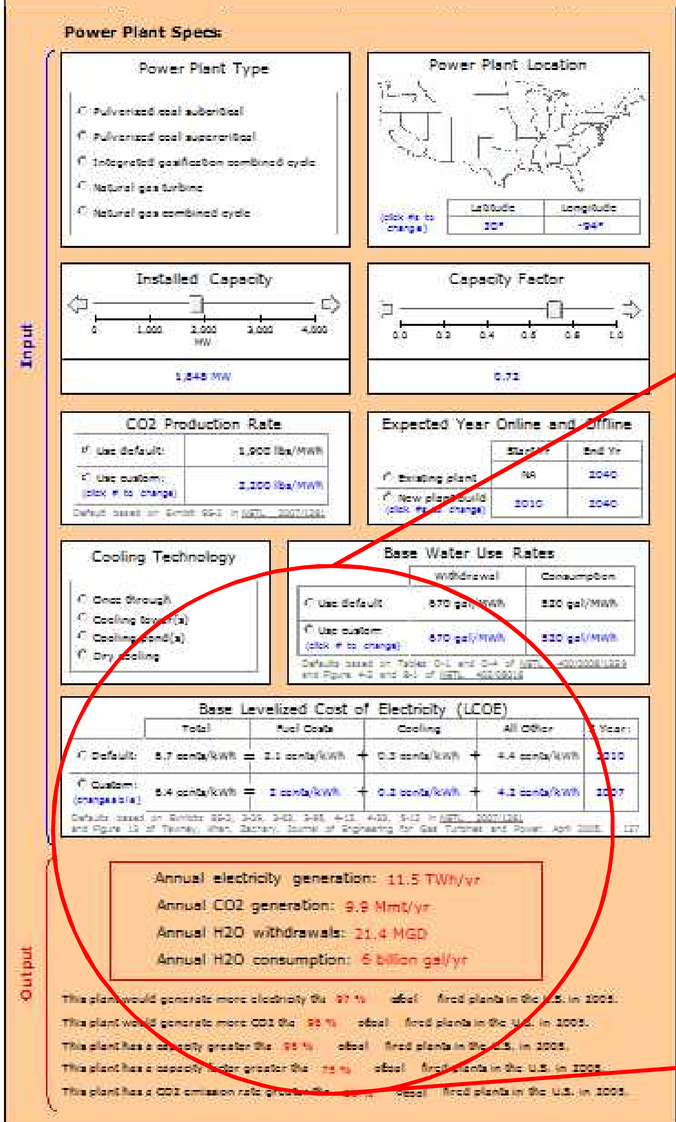
Summary | **Power Plant** | Carbon Capture | Carbon Sequestration | Extracted Water | Power Costs



Cooling Technology

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

Base Water Use Rates

	Withdrawal	Consumption
Use default	670 gal/MWh	520 gal/MWh
Use custom (click # to change)	670 gal/MWh	520 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

Annual electricity generation: 11.5 TWh/yr
Annual CO2 generation: 9.9 Mmt/yr
Annual H2O withdrawals: 21.4 MGD
Annual H2O consumption: 6 billion gal/yr

This plant would generate more electricity tha 97 % ofoal fired plants in the U.S. in 2005.
This plant would generate more CO2 tha 96 % ofoal fired plants in the U.S. in 2005.
This plant has a capacity greater tha 96 % ofoal fired plants in the U.S. in 2005.
This plant has a capacity factor greater tha 75 % ofoal fired plants in the U.S. in 2005.
This plant has a CO2 emission rate greater tha 26 % ofoal fired plants in the U.S. in 2005.

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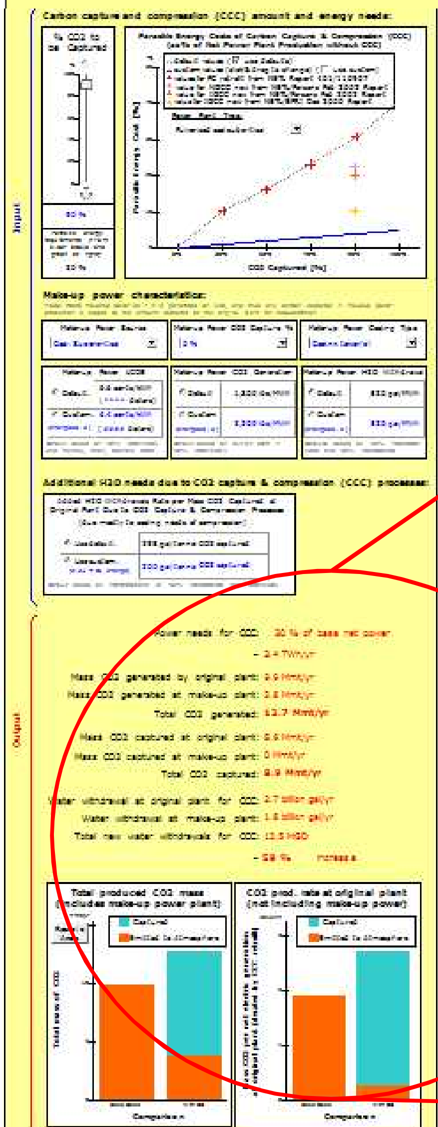


Output

Power needs for CCC: 30 % of base net power

= 3.4 TWh/yr

Mass CO_2 generated by original plant: 9.9 Mmt/yr

Mass CO_2 generated at make-up plant: 2.8 Mmt/yr

Total CO_2 generated: **12.7 Mmt/yr**

Mass CO_2 captured at original plant: 8.9 Mmt/yr

Mass CO_2 captured at make-up plant: 0 Mmt/yr

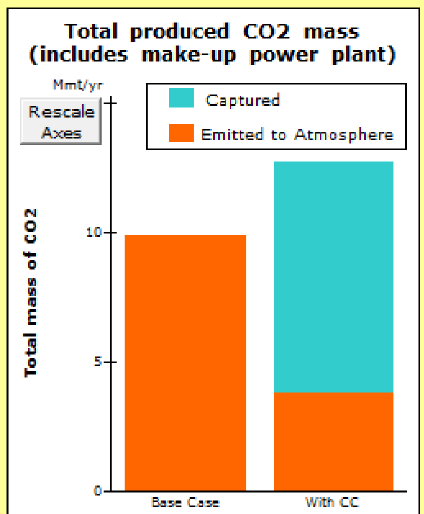
Total CO_2 captured: **8.9 Mmt/yr**

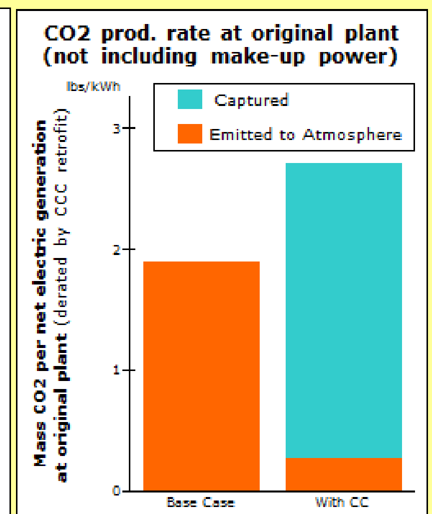
Water withdrawal at original plant for CCC: 2.7 billion gal/yr

Water withdrawal at make-up plant: 1.8 billion gal/yr

Total new water withdrawals for CCC: 12.5 MGD

= **58 %** increase





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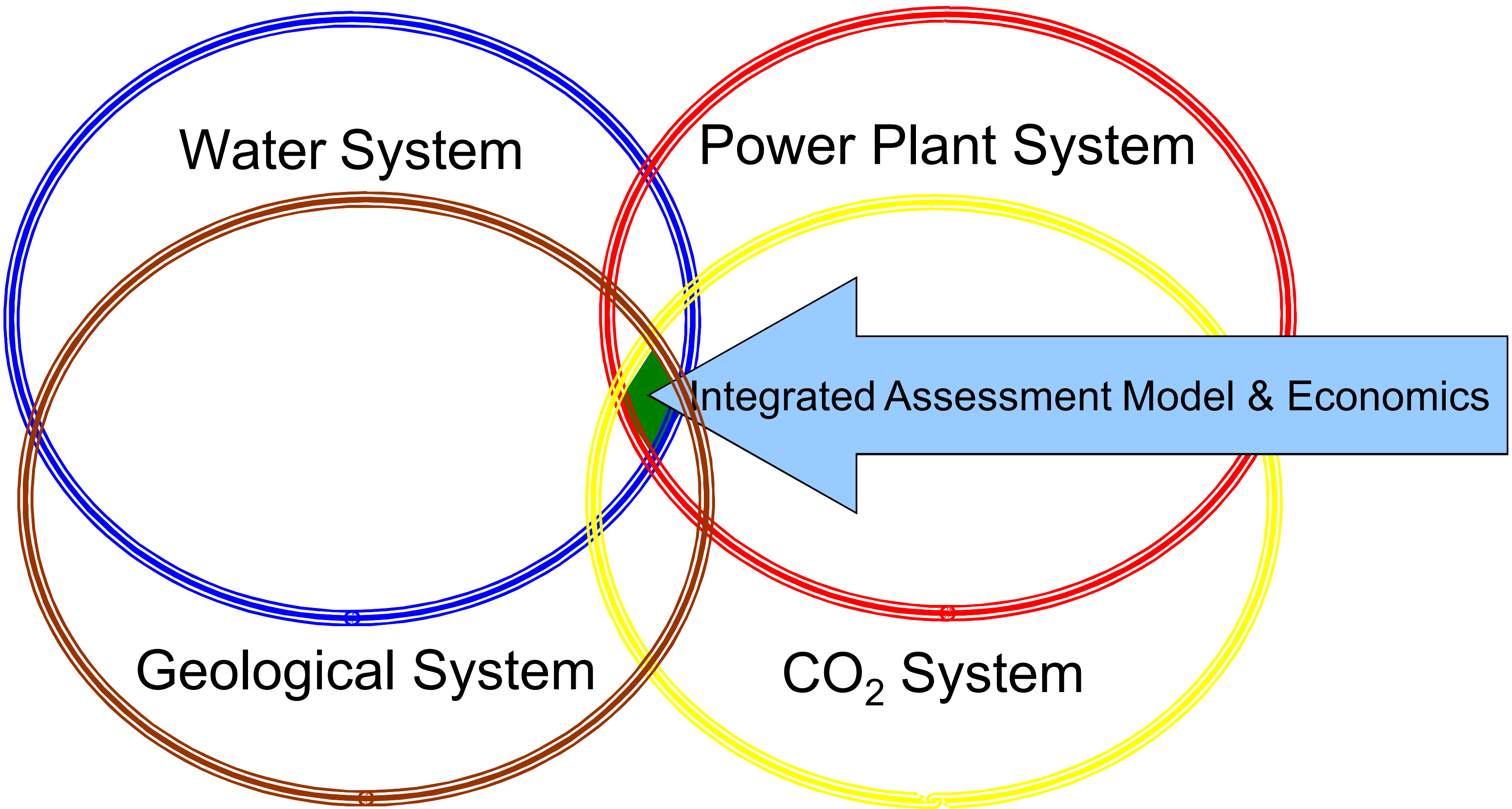
Improving Confidence in the Integrated Assessment Model by Addressing Uncertainty



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