Tenth Annual Conference on Carbon Capture & Sequestration

SAND2011-2756C

Ancillary Benefits of CCS Systems

Expanding the Potential for Saline Formations: Modeling Carbon Dioxide Storage, Water Extraction and Treatment for Power Plant Cooling

Peter H. Kobos, Jesse D. Roach, Geoff T. Klise, Jim L. Krumhansl, Jason E. Heath, Thomas A. Dewers, David J. Borns, Andrea McNemar, and Malynda A. Cappelle

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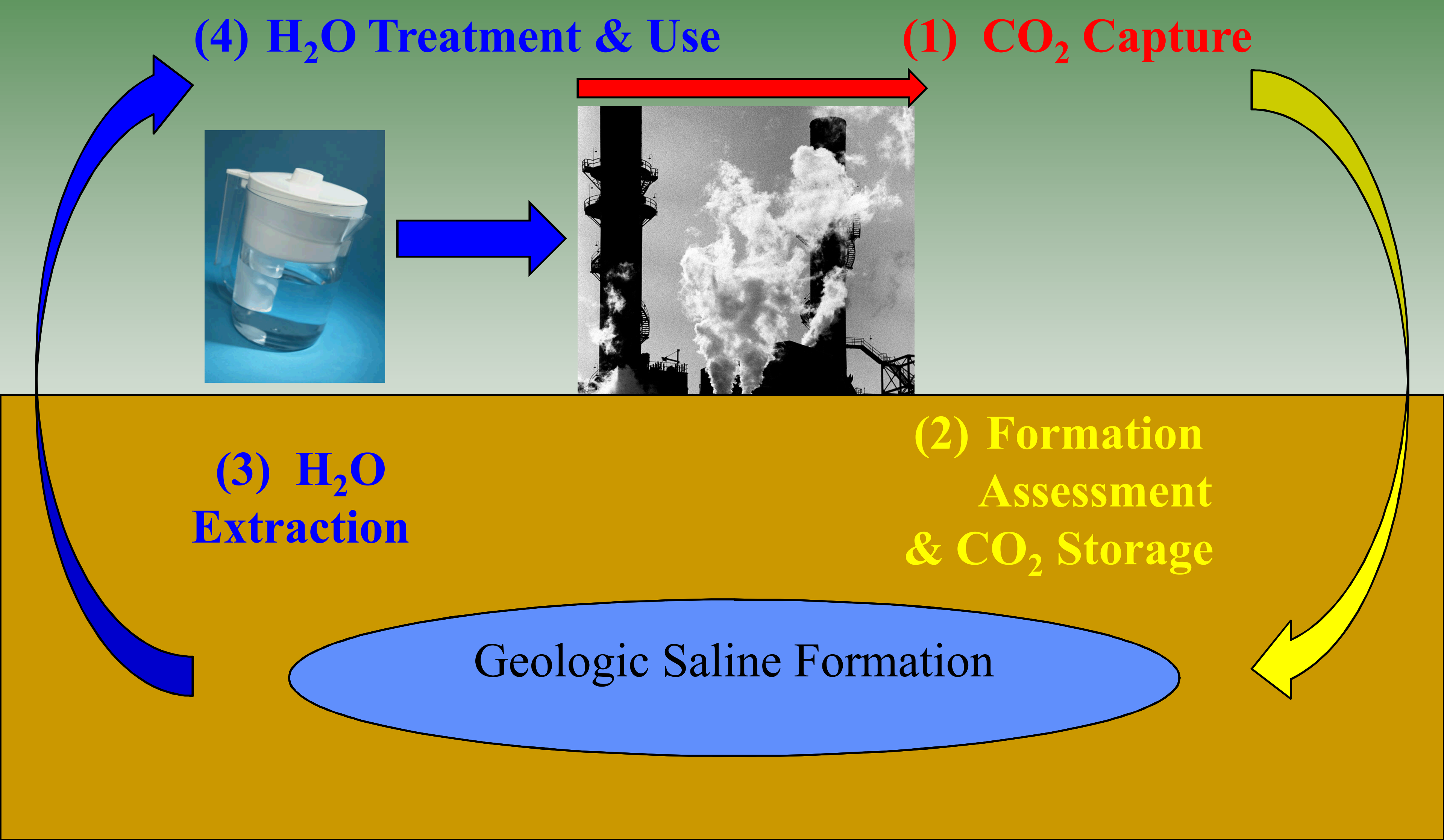
Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. Working Results.

The Water, Energy and CO_2 Storage (WECS) Model:

Addressing Uncertainly in the Data



Project Timeline & Goals

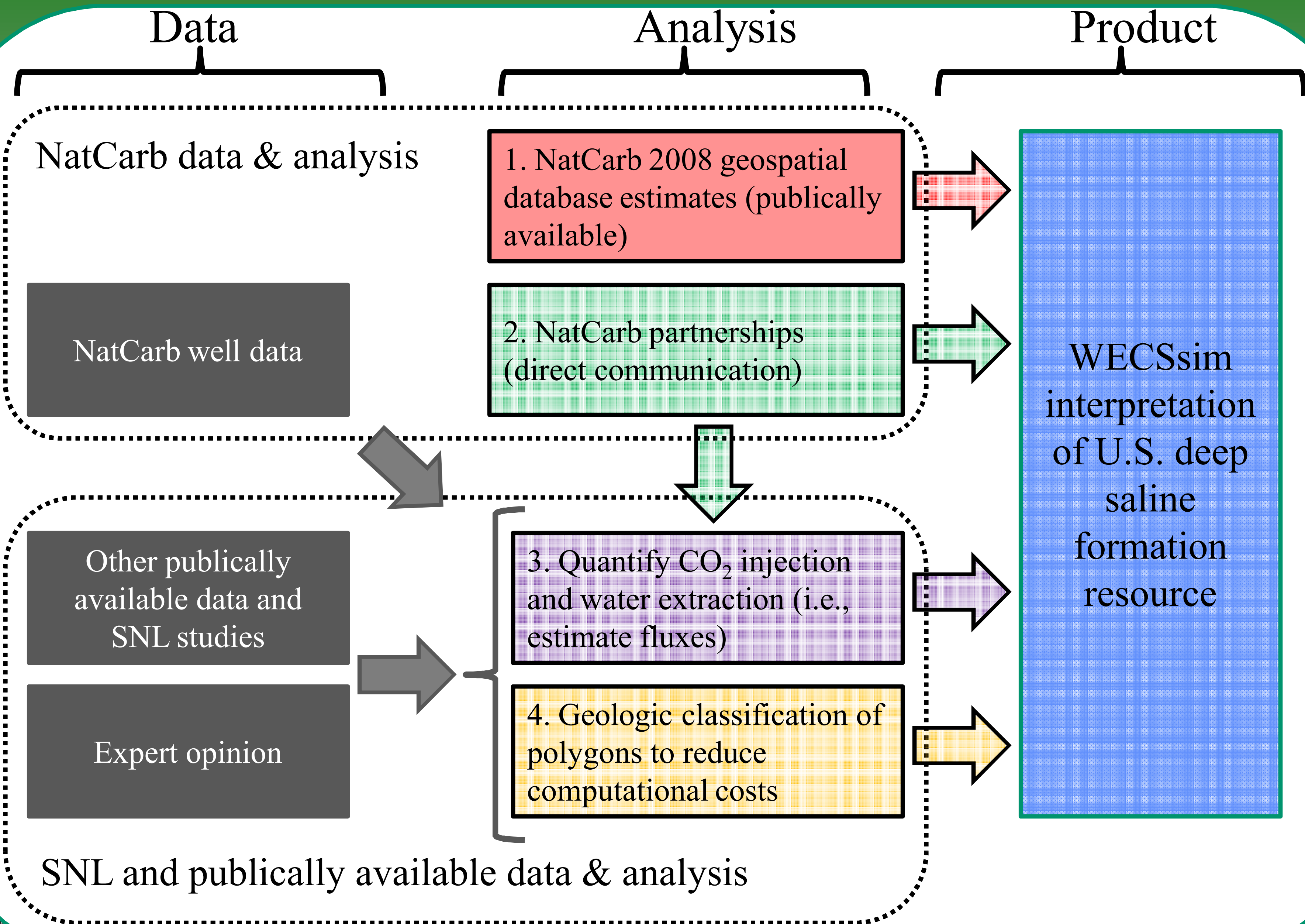
Timeline

2008
2009
2010
2011
2012

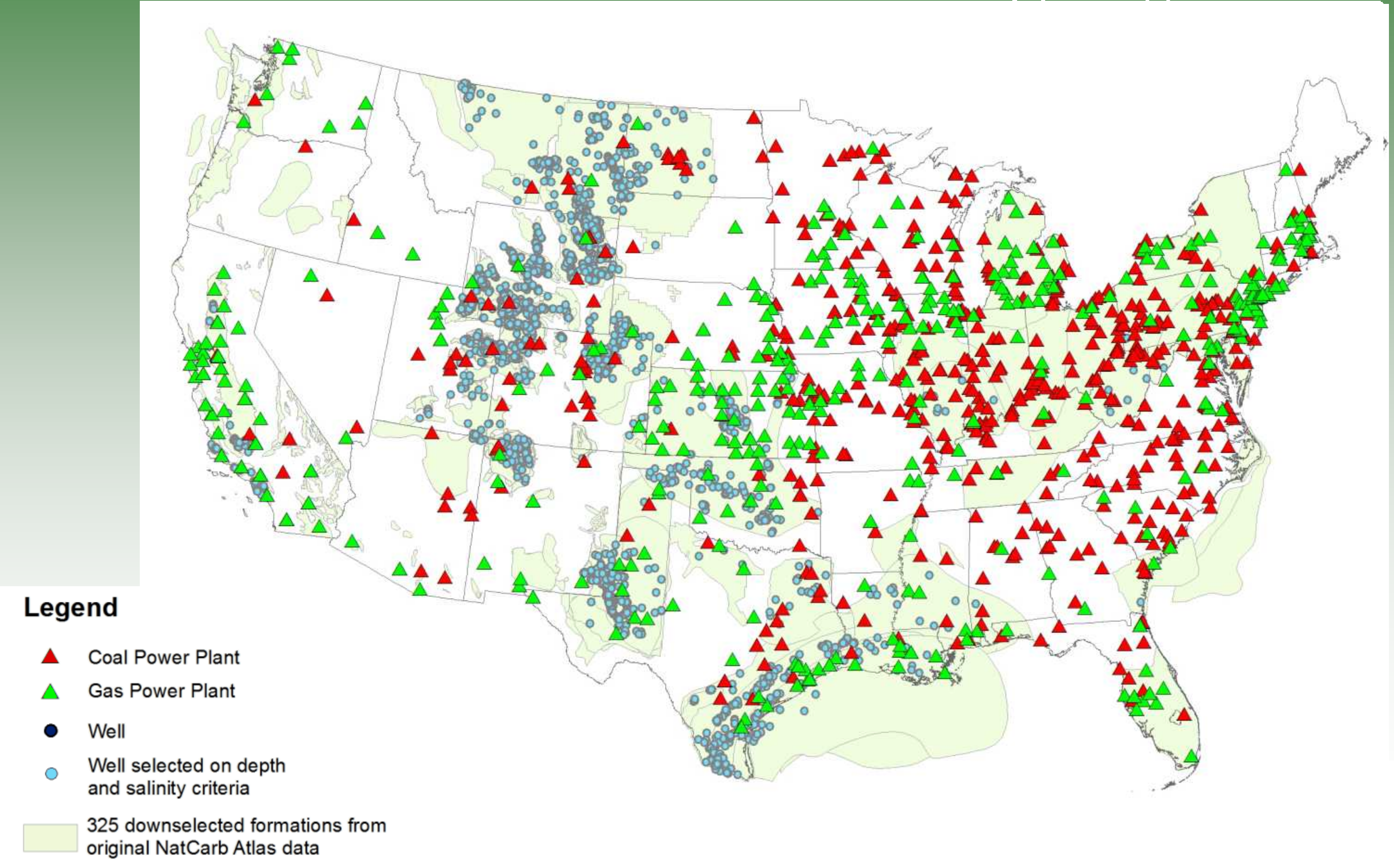
- Completed Phase I:
  - Developed a Test Case Model (WECS)
- Completed Phase II:
  - Additional Geosystems Analysis
    - Detailed TOUGH 2 modeling
- Completed Phase III:
  - Developed a single power plant to any saline formation sink in the U.S. systems calculator
- **Phase IV & V:**
    - Expanding the role of uncertainty within the model

	Single Source (power plant)	Multiple Sources
Single Sink (saline formation)	WECS	
Multiple Sinks	WECSsim →	

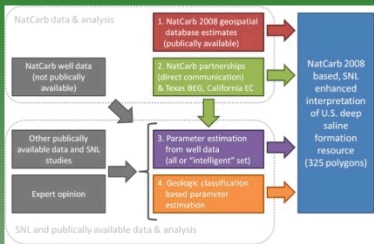
Assessing U.S. deep saline formations



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



Limited Saline Formation Data



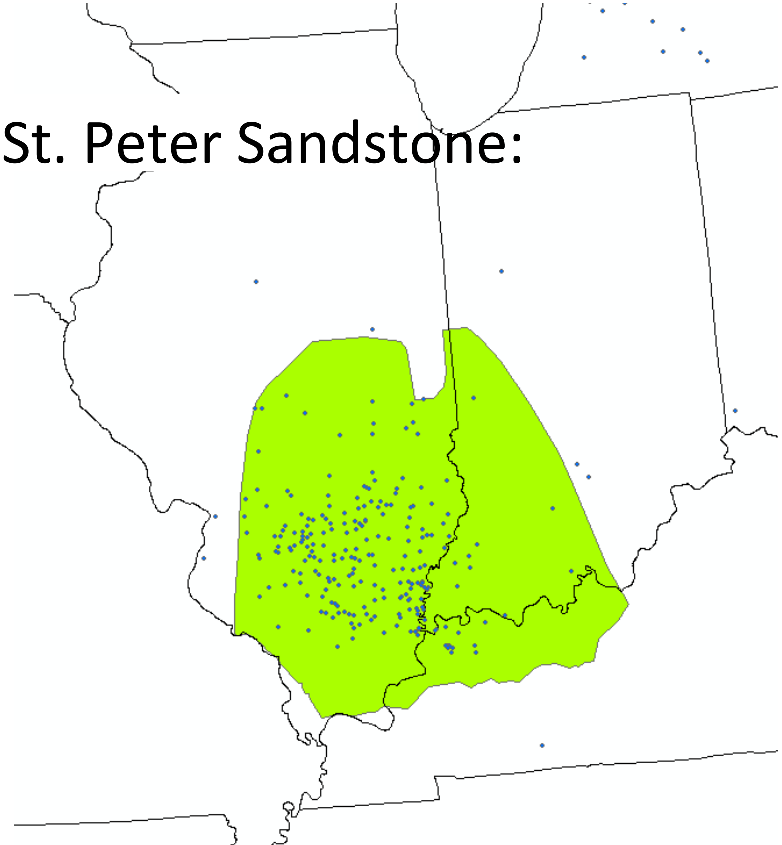
Data availability by source for 325 polygons derived from NatCarb 2008

Data Source	CO_2 storage capacity	Area	Depth	Thickness	Porosity	TDS	Temp	Pressure
NatCarb 2008	42%	100%	0%	0%	0%	0%	0%	0%
Partnerships	42%	100%	62%	64%	55%	18%	44%	45%
Well records	NA	NA	70%[1]	70%[1]	0%	70%[1]	100%[2]	NA
Geologic class	NA	NA	NA	NA	? %[3]	0%	NA	NA
No estimate	**16%** (52)	**0%** (0)	**14%**[4] (47)	**14%**[4] (47)	**0 - 45%** (0 - 147)	**14%**[4] (47)	**14%**[4] (47)	**14%**[4] (47)

Notes:
1. 30% of polygons (97 of 325) have no potentially intersecting wells associated with them from well databases used here.
2. Temperature calculated from depth and geothermal gradient. Geothermal gradient was developed spatially from publically available well records.
3. Current attempts to classify all 325 polygons according to geology may not result in reliable data estimates for all polygons.
4. 14% of polygons (47 of 325) have no depth, thickness, or salinity information and no potentially intersecting wells.

Example formations: The good

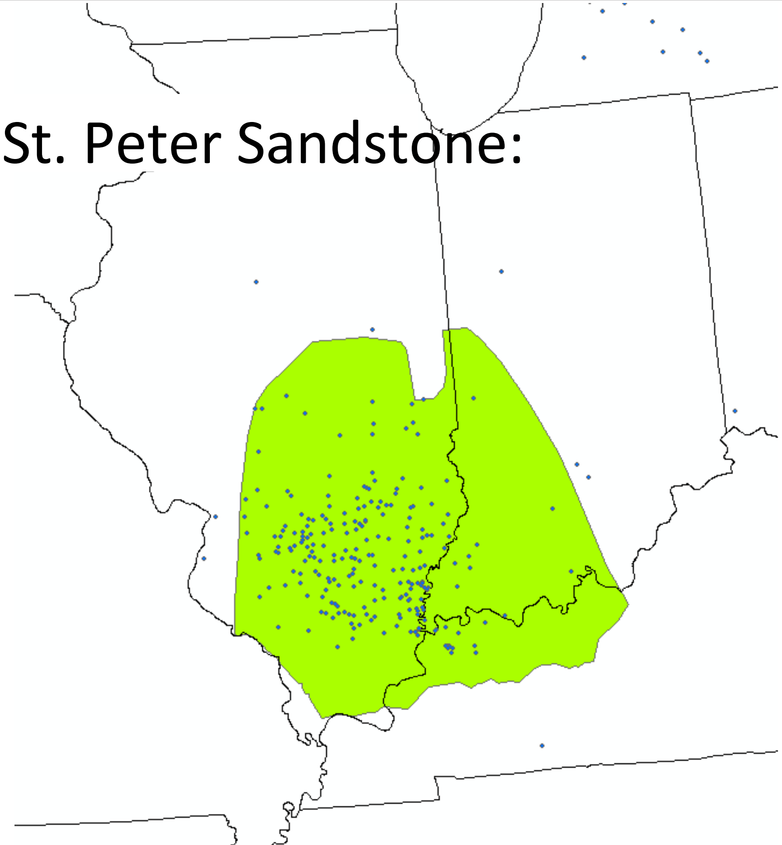
St. Peter Sandstone:



Includes NatCarb or MGSC derived estimates and ranges for capacity, depth, thickness, porosity, pressure, temperature, and salinity, as well as 892 potentially intersecting wells.

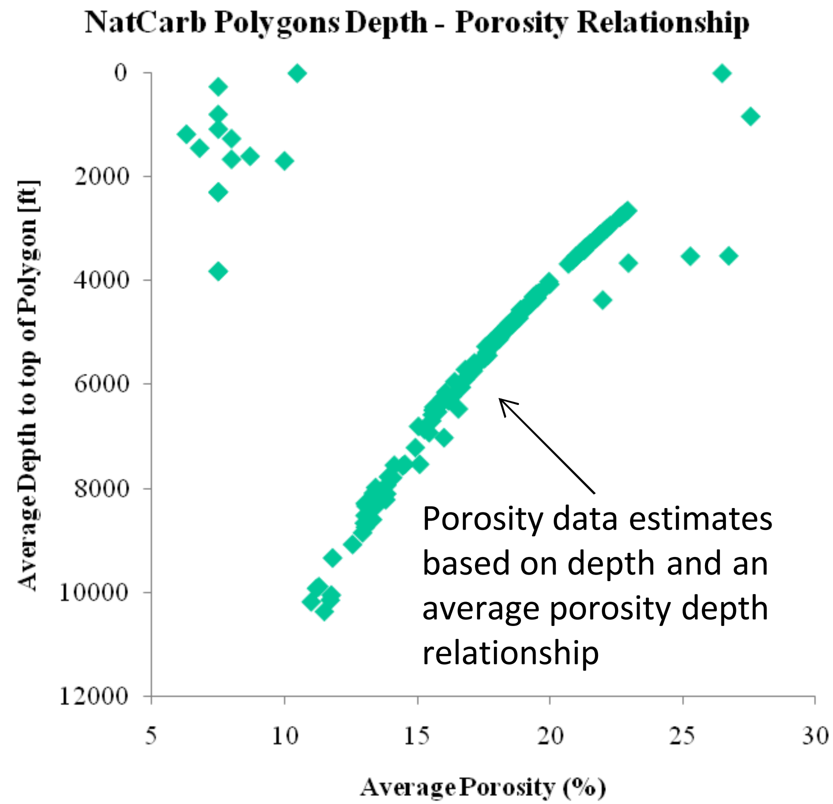
Example formations: The good, but…

St. Peter Sandstone:



Includes NatCarb or MGSC derived estimates and ranges for capacity, depth, thickness, porosity, pressure, temperature, and salinity, as well as 892 potentially intersecting wells.

But caution with reported data is advisable:



Of the156 polygons w/NatCarb or partnership depth and porosity info., but limited actual porosity data…

Porosity & Permeability

- From data analysis, recall that porosity data is limited
- Additionally, permeability/injectivity data is needed for economic analysis

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No estimate	**16%** (52)	**0%** (0)	**14%**[4] (47)	**14%**[4] (47)	**0 - 45%** (0 - 147)	**14%**[4] (47)		

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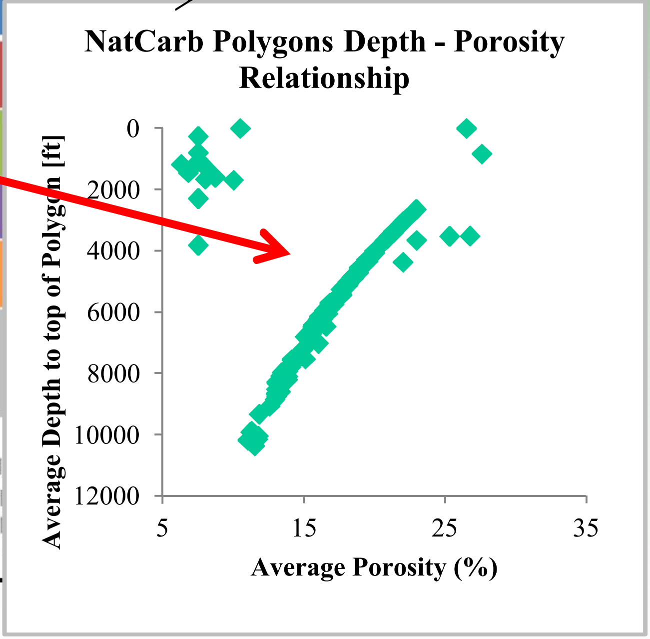


Uncertainty and the Well Injectivity Index

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

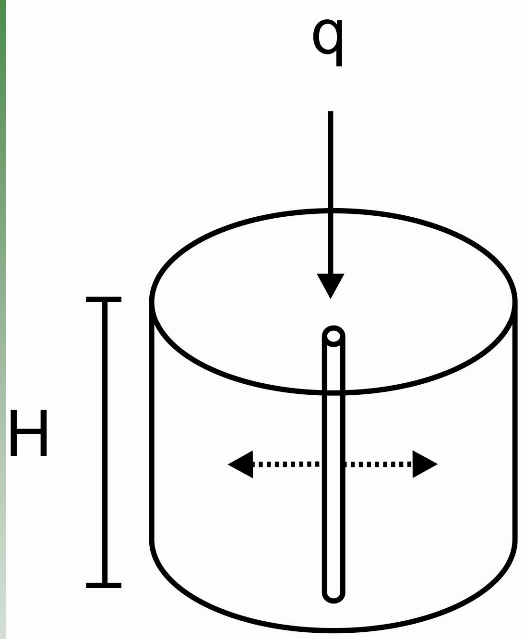
$$I \equiv \frac{q}{\Delta P}$$

q volumetric flow 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)



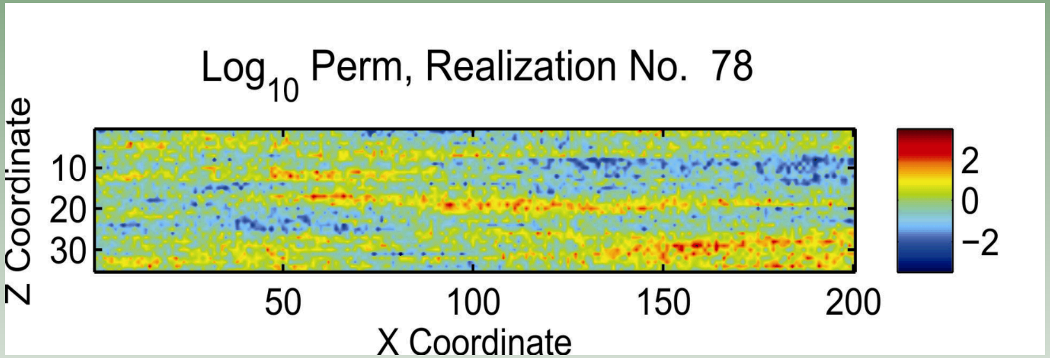
Reservoir volume

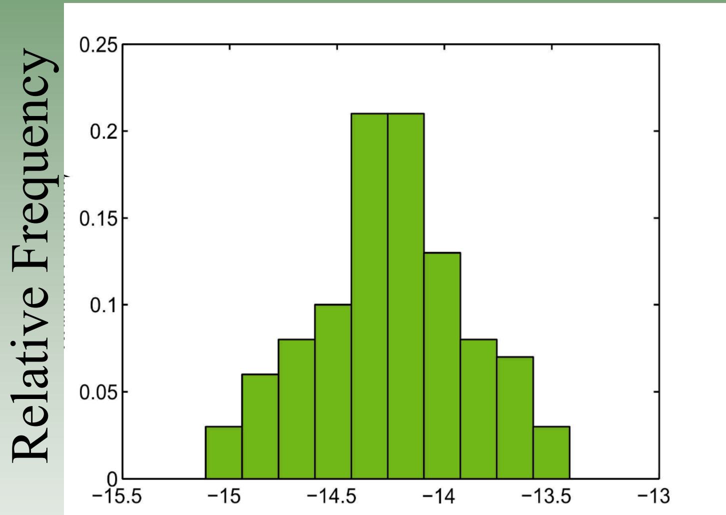
Radial flow from the well

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)

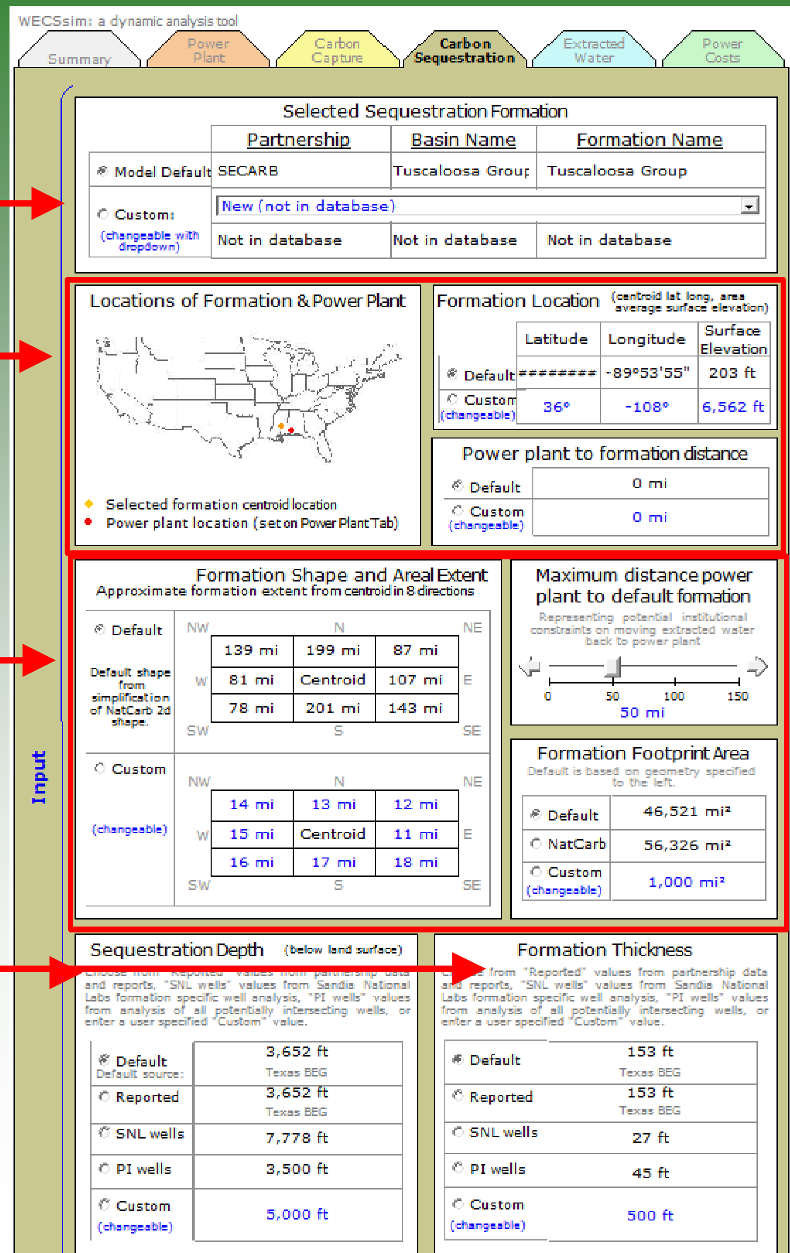
Feed the "properly" averaged parameters into equation to get a pdf of ***I***

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

CO_2 Storage Module Inputs - 1

User Specified Saline Formation Info.:

- Formation utilized
- Location related
- Shape and area
- Sequestration depth & formation thickness

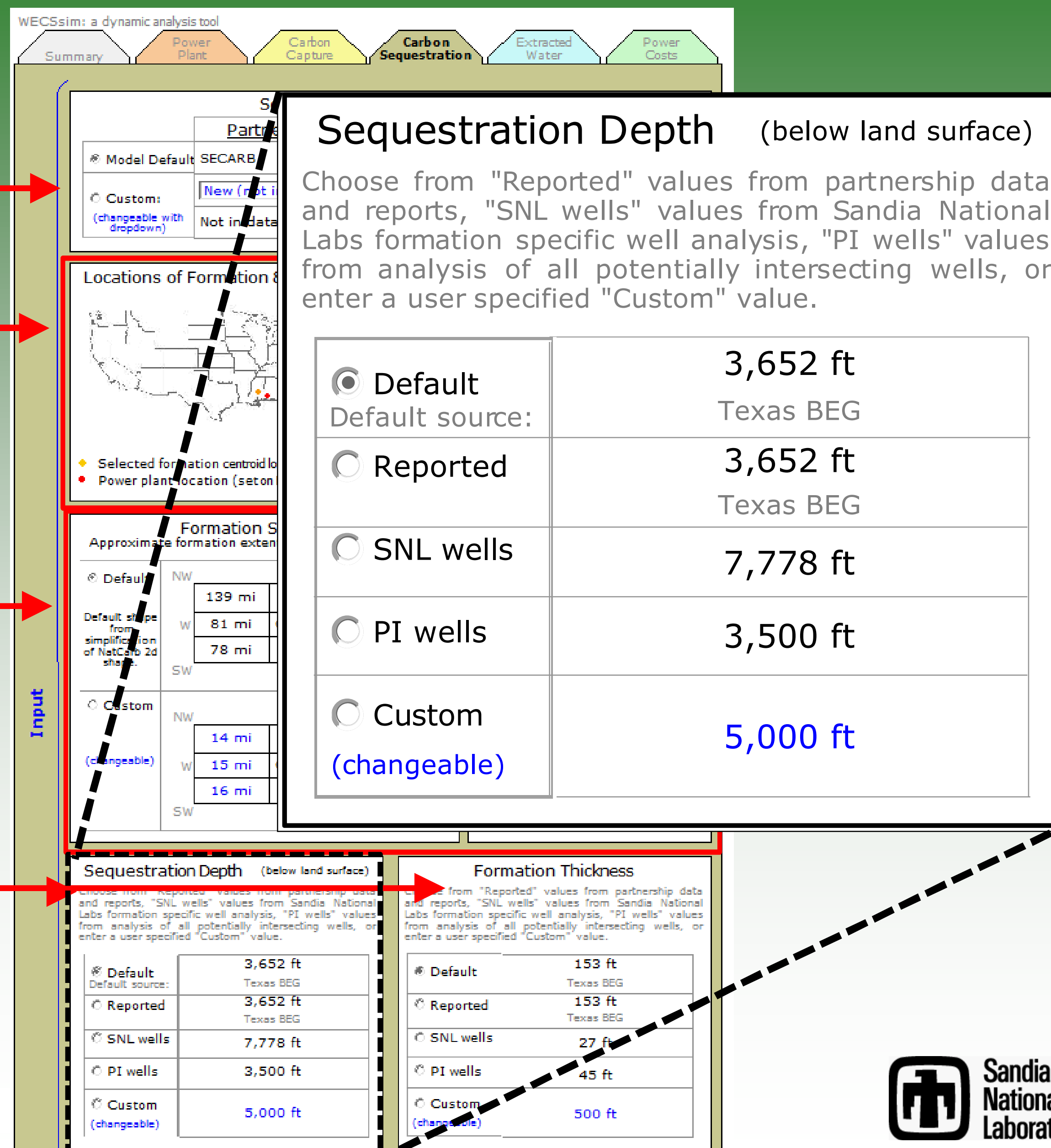


Model Inputs may be Customized

CO_2 Storage Module Inputs - 1

User Specified Saline Formation Info.:

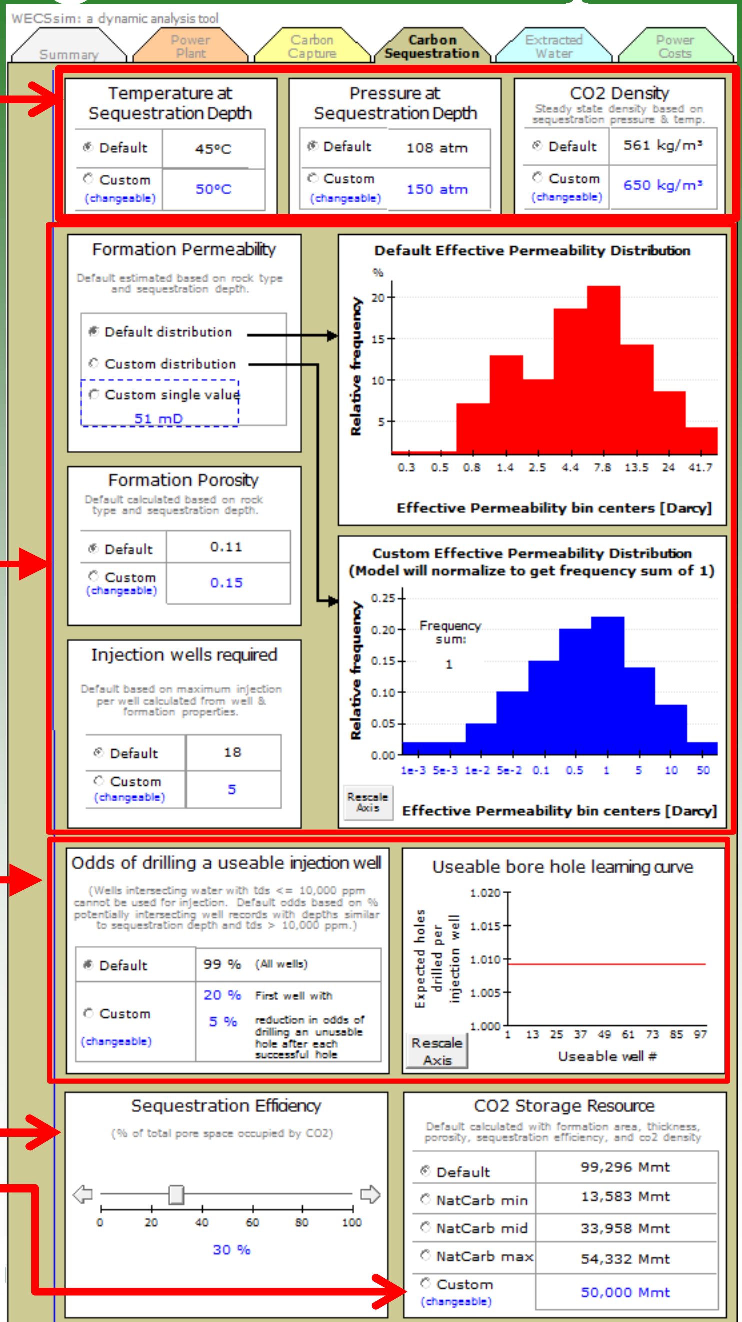
- Formation utilized
- Location related
- Shape and area
- Sequestration depth & formation thickness



CO_2 Storage Module Inputs - 2

Including Uncertainty:

- Temperature, pressure, CO_2 density
- Permeability, porosity, # of injection wells
- Odds of drilling a useable injection well (water quality related)
- Sweep efficiency
- Total storage resource



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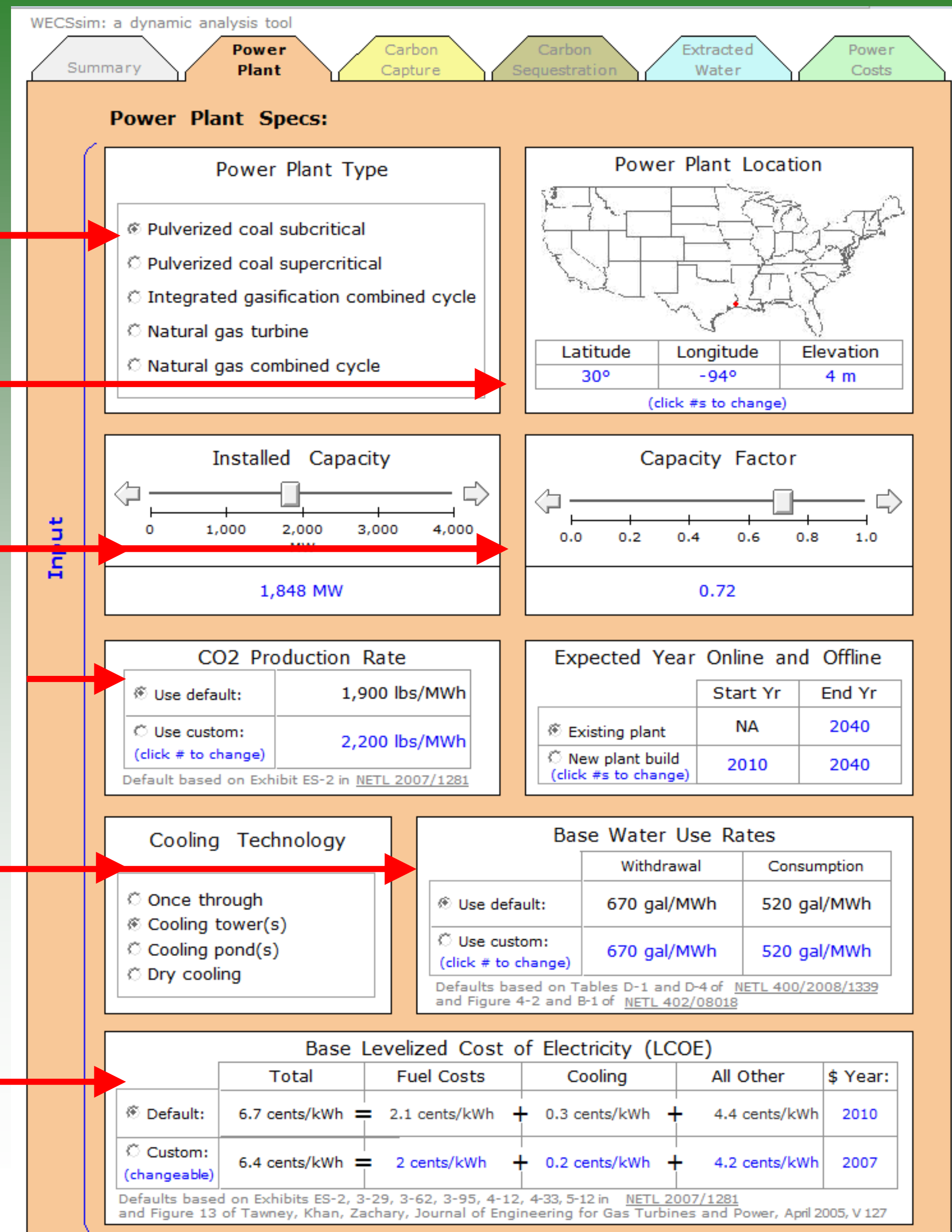
Power Plant Module Inputs

User Specified Power Plant Info.:

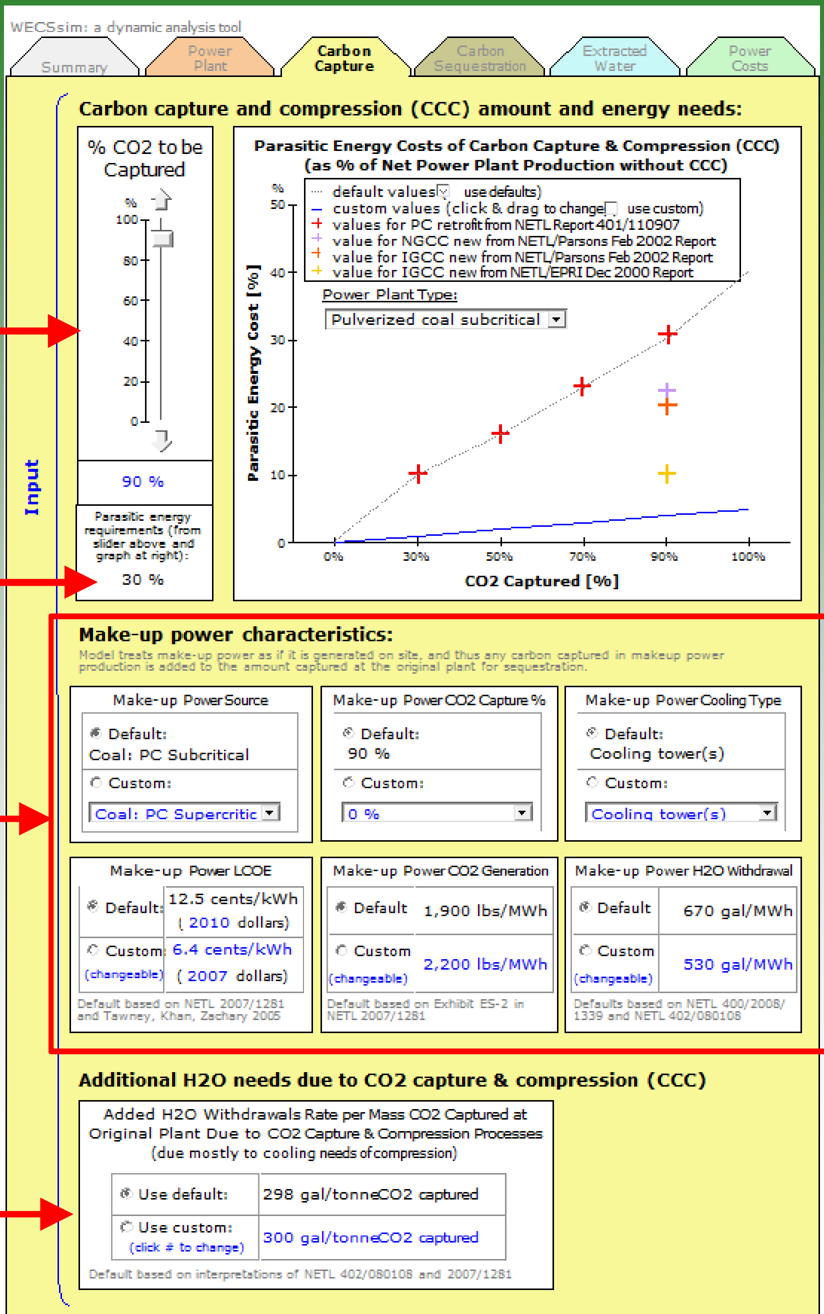
- Type
- Location
- Size
- CO2 production
- Water use
- LCOE



CO_2 Capture Module Inputs

User Specified Carbon Capture Information:

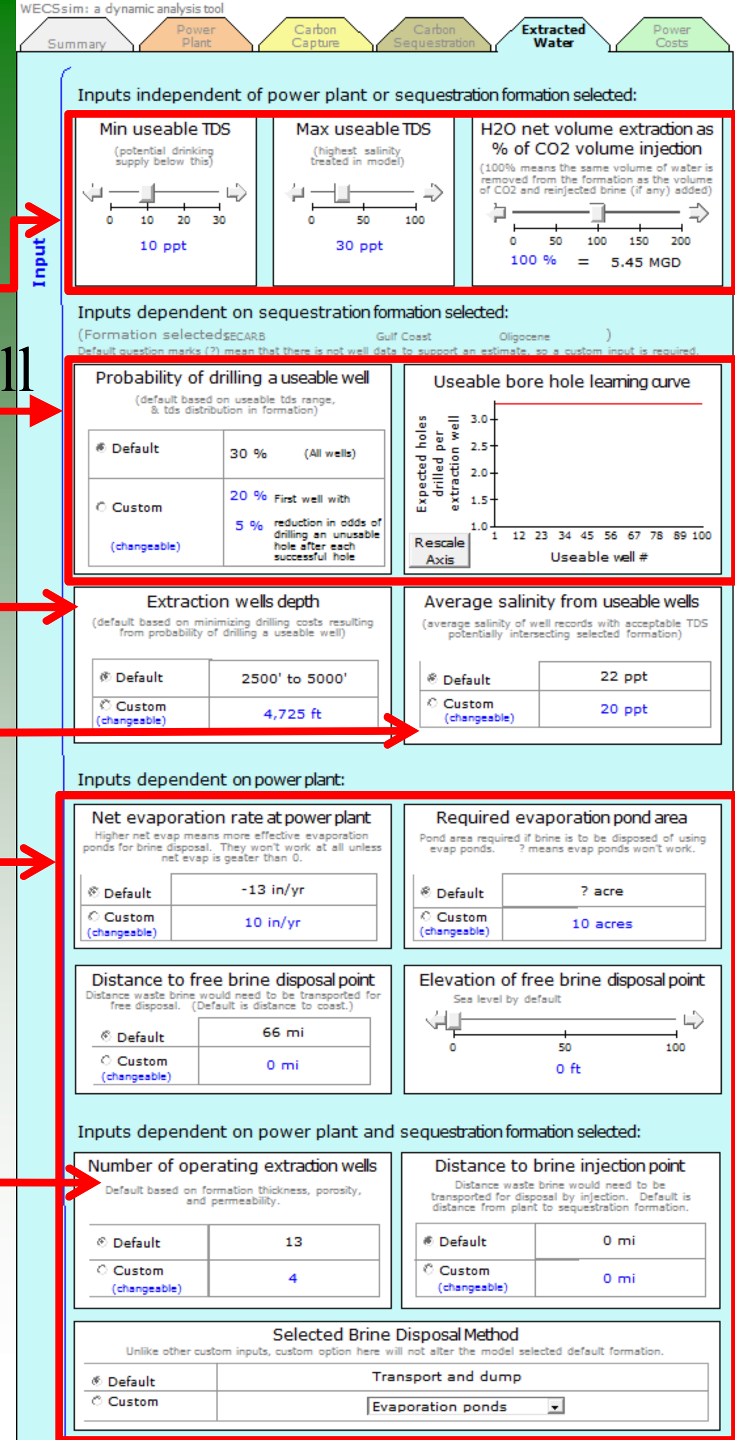
- % to be captured
- Energy required
- Make-up power characteristics
- Additional H_2O use



Extracted H_2O Module

User Specified Water Treatment Info.:

- TDS range & extraction amount
- Probability, drilling a useable extraction well
- Extraction depth
- Expected extracted TDS
- Brine disposal related
- Number of extraction wells required



Power Costs Module Inputs - 3

User Specified Cost Info.:

- Display year for $ amounts
- Capitalization factors
- Base LCOE (same as before)
- CO_2 capture, compression, & MUP costs
- CO_2 transport and injection costs
- Water extraction and transport costs
- Water treatment costs
- Brine disposal costs

WECSsim: a dynamic analysis tool

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

Input

Water treatment cost parameters	
High Eff. Reverse Osmosis plant capital costs per feed flow	$3,535,545 per MGD
Recieving, transfer, dist piping capital costs per feed flow	$779,931 per MGD
Dollar year for capital costs listed above	2004
Annual labor costs coefficient per treatment plant capacity	171,778 (USD/yr)/(MGD)
Annual labor costs plant capacity exponential	0.2322
Dollar year for labor costs listed above	2000
High Efficiency Reverse Osmosis (HERO) base electricity use	2.41 kWh/1000gal
HERO water quality dependent marginal electricity use	0.6 kWh/1000gal/ppt
HERO membrane replacement costs (2000 $)	8 cents/1000gal
HERO chemical replacement costs (2004 $)	59 cents/1000gal
HERO other O&M as a function of capital costs	1.5 %/yr

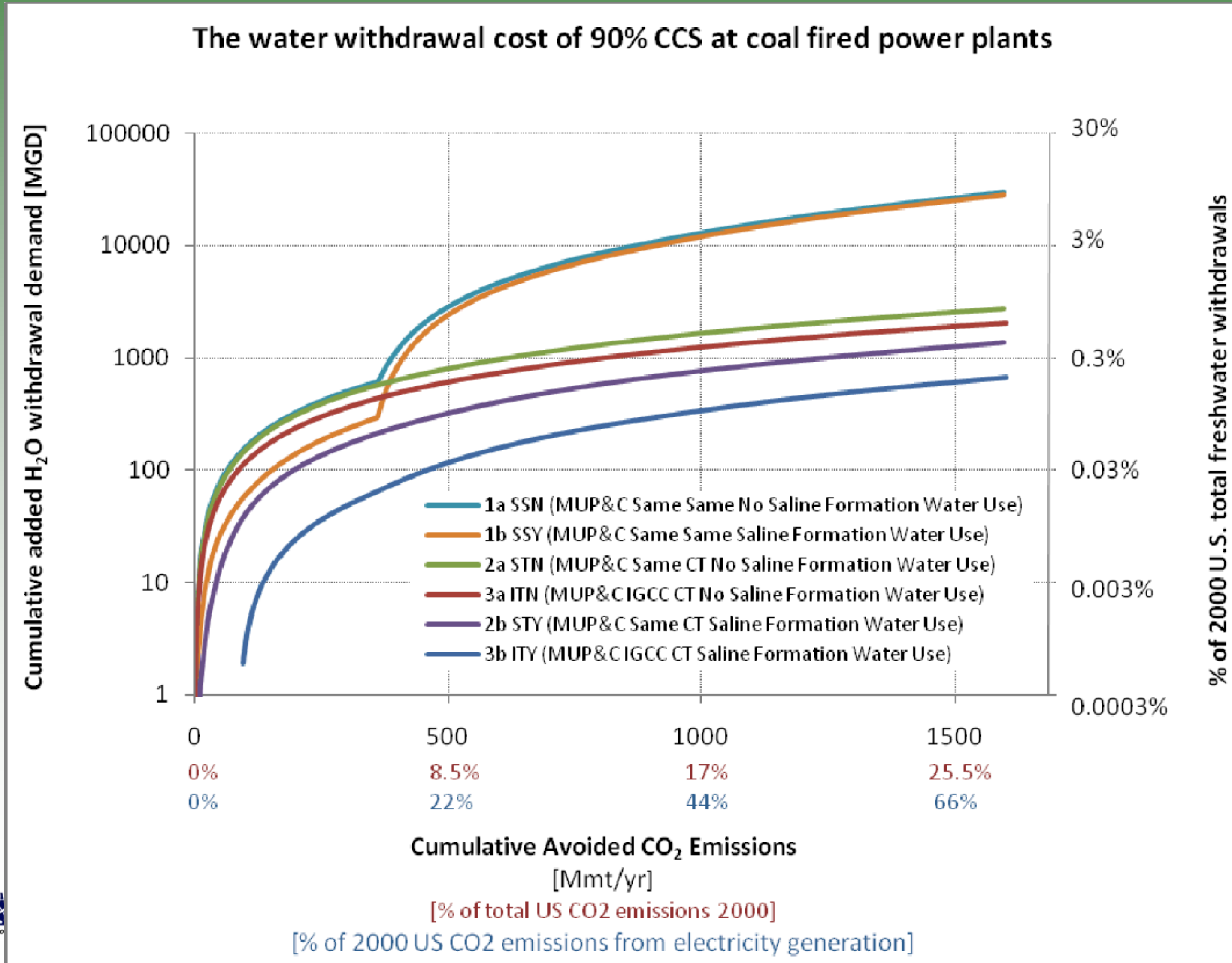
Capital costs and chemical replacement costs from Zammit and DiFillipo 2004 estimates of costs for a HERO plant with 1316 gpm model feed flow. "Use of Produced Water in Recirculating Cooling Systems at Power Generating Facilities" Deliverable #3
Labor costs from best fit exponential equation based on data in Figure 9-37 of "Desalting Handbook for Planners" 3rd Edition, July 2003. US Bureau of Reclamation (USBR) Desalination and Water Purification Research & Development Program Report No. 72. http://www.usbr.gov/pmts/water/media/pdfs/report072.pdf
Best fit equation: cost = $171778*PlantCapacity^0.2322
HERO electricity use parameters based on data in Figure 7-8 of the same USBR report.
Membrane replacement costs also based on data in the same USBR report.
Other O&M costs as a function of capital costs is a model assumption.

Brine disposal cost parameters	
Evaporation ponds fixed capital cost:	$19,600
Evaporation ponds variable capital cost:	$244,900 per acre
Evaporation ponds O&M as % of capital cost:	1.5 %/yr
Injection wells fixed capital cost:	$2,359,271
Injection wells variable capital cost:	$194,893 per MGD
Injection pipelines and wells O&M as % of capital cost:	1.5 %/yr
Dollar year for evaporation ponds and injection well costs:	2000
All brine pipeline cost parameters are the same as for the water supply pipeline	

Evaporation ponds capital costs from best fit equation to data in Figure 9-12 of "Desalting Handbook for Planners" 3rd Edition, July 2003. US Bureau of Reclamation (USBR) Desalination and Water Purification Research & Development Program Report No. 72. http://www.usbr.gov/pmts/water/media/pdfs/report072.pdf
Injection wells capital costs from best fit equation to data in Figure 9-13 of the same.
Other O&M costs as a function of capital costs is a model assumption.

WECSsim Results:

Represents 6 Least Water Intensive paths to reduced CO_2 emissions for given technology



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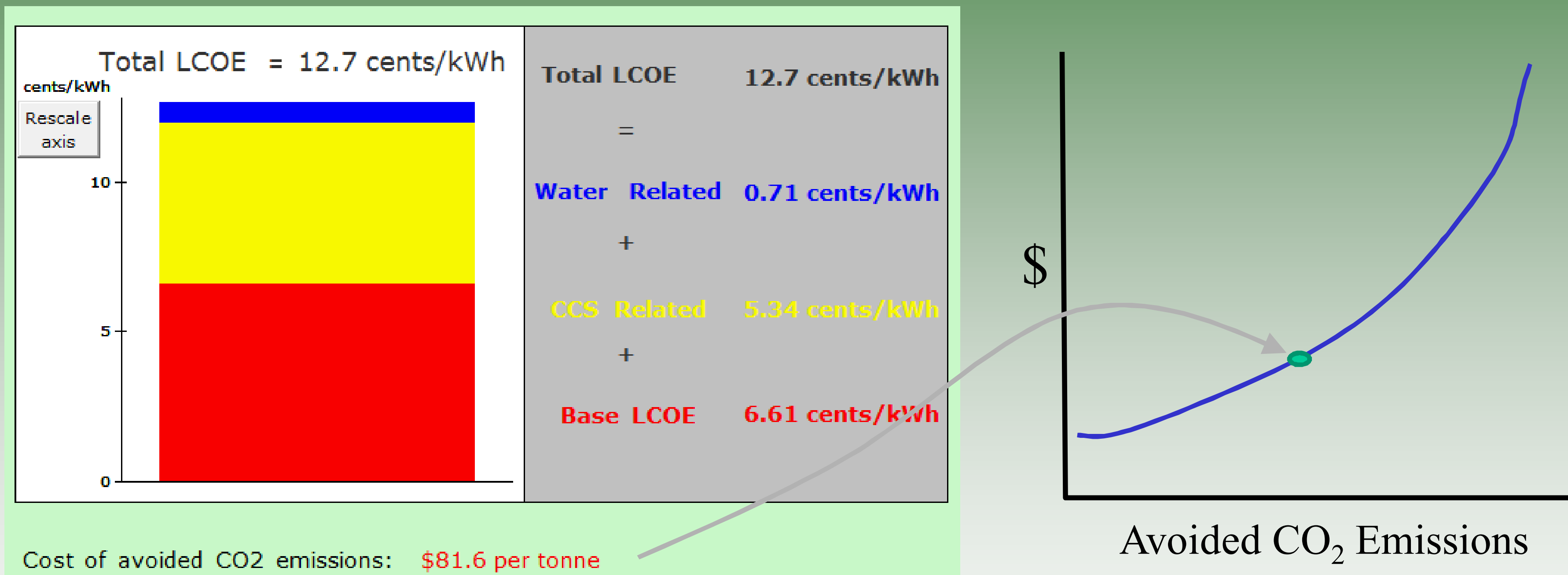
WECSsim Results:

Similar Full Economic Analysis Underway



Note: Illustrative Example at this time

Conclusions

- **Refining the National WECSsim Model**
  - ➢ Coupled CCS and Water Extraction/Treatment for Power Plant Cooling

- **Uncertainty in the Saline Formation Data**
  - ➢ Limits the possible Analysis

- **Using a national-level systems approach**
  - ➢ Illustrate the distribution of the CO_2 storage resource and magnitude of costs associated with CCS

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Thank You.

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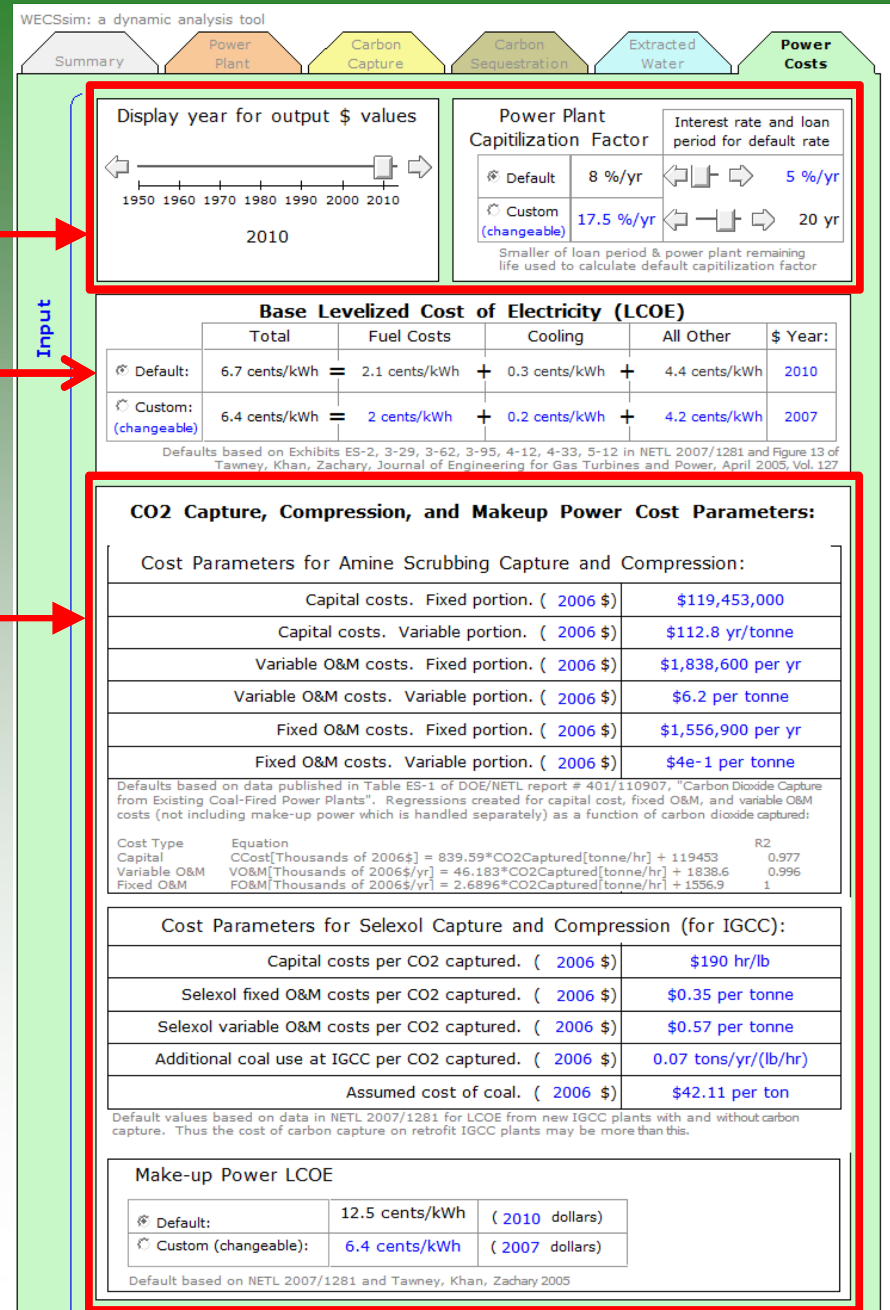
Backup Slide: Power Costs Module Inputs

User Specified Cost Information: - 1

- Display year for $ amounts
- Capitalization factors
- Base LCOE (same as before)
- CO_2 capture, compression, and MUP costs
- CO_2 transport and injection costs
- Water extraction and transport costs
- Water treatment costs
- Brine disposal costs



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Backup Slide: Power Costs Module Inputs - 2

User Specified Cost Information:

- Display year for $ amounts
- Capitalization factors
- Base LCOE (same as before)
- CO_2 capture, compression, and MUP costs
- CO_2 transport and injection costs
- Water extraction and transport costs
- Water treatment costs
- Brine disposal costs

WECSsim: a dynamic analysis tool

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

Input

CO2 Pipeline Cost Parameters:

Reference CO2 pipeline length	100 km
Reference CO2 pipeline flow rate	16,000 tonnes/da
Reference CO2 pipeline unit capital cost (2001 $)	$700 per m
Change to unit capital cost per change to length	0.24
Change to unit cost per change in flow rate	0.48
CO2 pipeline O&M as % of capital costs	4 %/yr

Default equation and values: Cost (Q,L) = $700/m x (Q/Qo)0.48 x (L/Lo)0.24
from Ogden, J.M. (2002): Modeling Infrastructure For a Fossil Hydrogen Energy System with CO2 Sequestration. Sixth Greenhouse Gas Control Technologies Conference, Kyoto, Japan, 9/30 – 10/4.

Injection Well Cost Parameters:

Fixed cost per injection well, Ogden method. (2001 $)	$1,250,000
Injection well variable costs by depth, Ogden method. (2001 $)	$1,560,000 per km

Default equation: Capital ($/well) = $1.56 million x well depth (km) + $1.25 million.
from Ogden, J.M. (2002): Modeling Infrastructure For a Fossil Hydrogen Energy System with CO2 Sequestration. Sixth Greenhouse Gas Control Technologies Conference, Kyoto, Japan, 9/30 – 10/4

Water collection cost parameters

Well field capital cost per depth and flow rate (2000 $)	375 USD/ft/MGD
Percent of the cost above due to drilling only	75 %
Well pump efficiency (to estimate well energy use)	68 %
Wells other O&M as a function of capital cost	1.5 %/yr

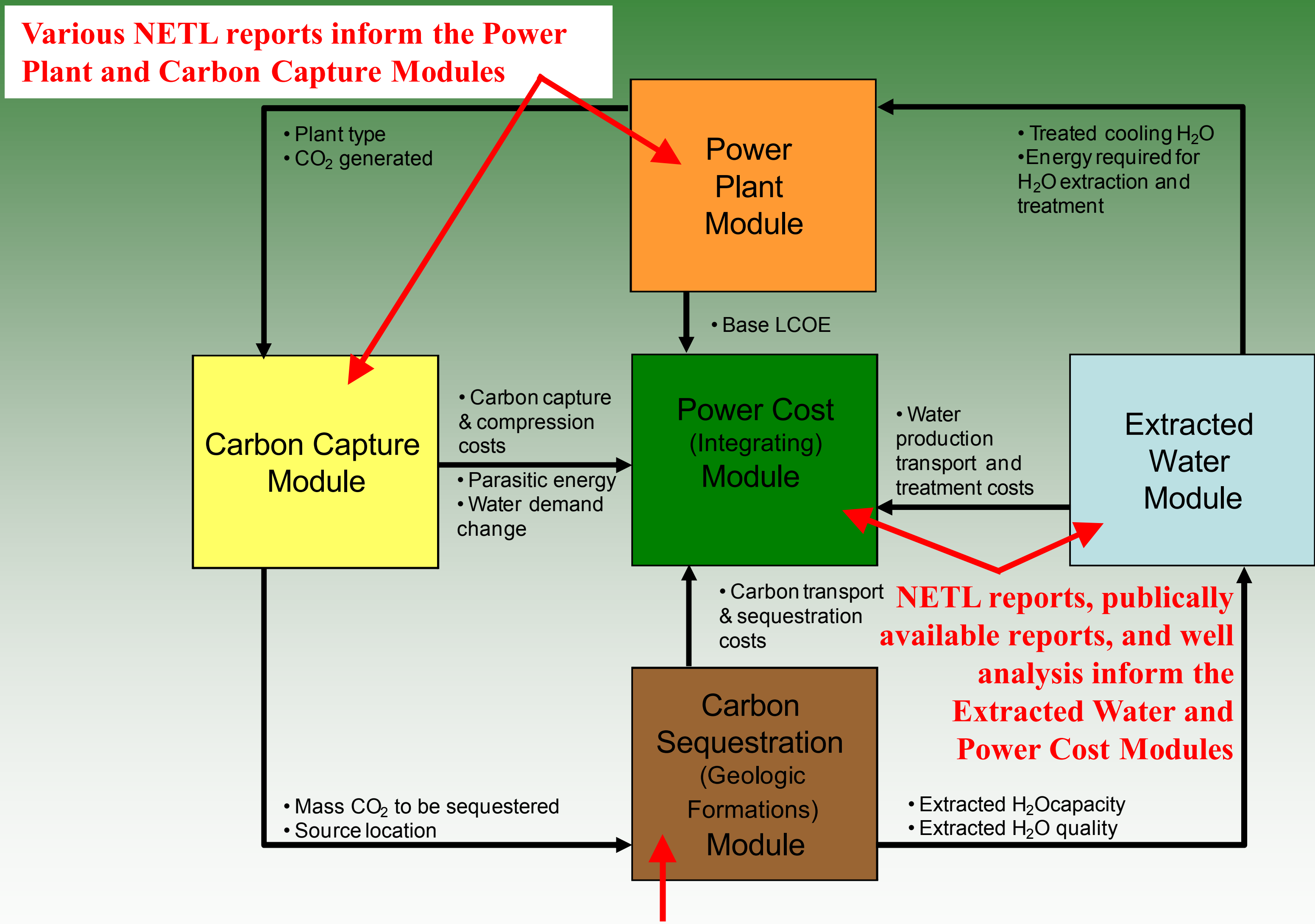
Well field capital cost estimate from a regression of data shown in Figure 9-18 of "Desalting Handbook for Planners" 3rd Edition, July 2003. US Bureau of Reclamation Desalination and Water Purification Research and Development Program Report No. 72. http://www.usbr.gov/pmts/water/media/pdfs/report072.pdf
Regression shown on page 62 and 63 of the June 1, 2009 report from SNL to NETL: "Study of the Use of Saline Formations for Combined Thermoelectric Power Plant Water Needs and Carbon Sequestration at a Regional Scale"
Percent of cost due to drilling only, pump efficiency, and other O&M costs are model assumptions

Water transport cost parameters

Pipeline base cost (2000 $)	$111,314 per mi
Pipeline marginal cost depending on flow rate (2000 $)	35,761 USD/mi/MGD
Pipeline friction coefficient (for pipeline losses)	0.003
Pipeline pump efficiency	68 %

Pipeline capital cost estimates from a regression of data shown in Figure 9-11 of "Desalting Handbook for Planners" 3rd Edition, July 2003. US Bureau of Reclamation Desalination and Water Purification Research and Development Program Report No. 72. http://www.usbr.gov/pmts/water/media/pdfs/report072.pdf
Pipeline friction and pump efficiencies are model assumptions.

Backup: WECSsim Modular Structure



NatCarb Atlas polygon analysis, well data analysis, and heterogeneous formation characterization described above inform the Carbon Sequestration Module