SAND2012-1299C

The Water, Energy and Carbon Sequestration Simulation Model (WECSsim©)

Peter H. Kobos (PI),
Jesse D. Roach, Jason E. Heath, Geoff T. Klise, Thomas A. Dewers,
Sean A. McKenna, Len Malczynski, David J. Borns, Karen A. Gutierrez
Sandia National Laboratories

CCS Pressure Management Workshop
Lawrence Livermore National Laboratory
February 22-23, 2012

Acknowledgements: This work is developing under the funding and support of the National Energy Technology Laboratory.

Water, Energy and CO_2 Sequestration (WECS) Model:

(4) H_2O Treatment & Use

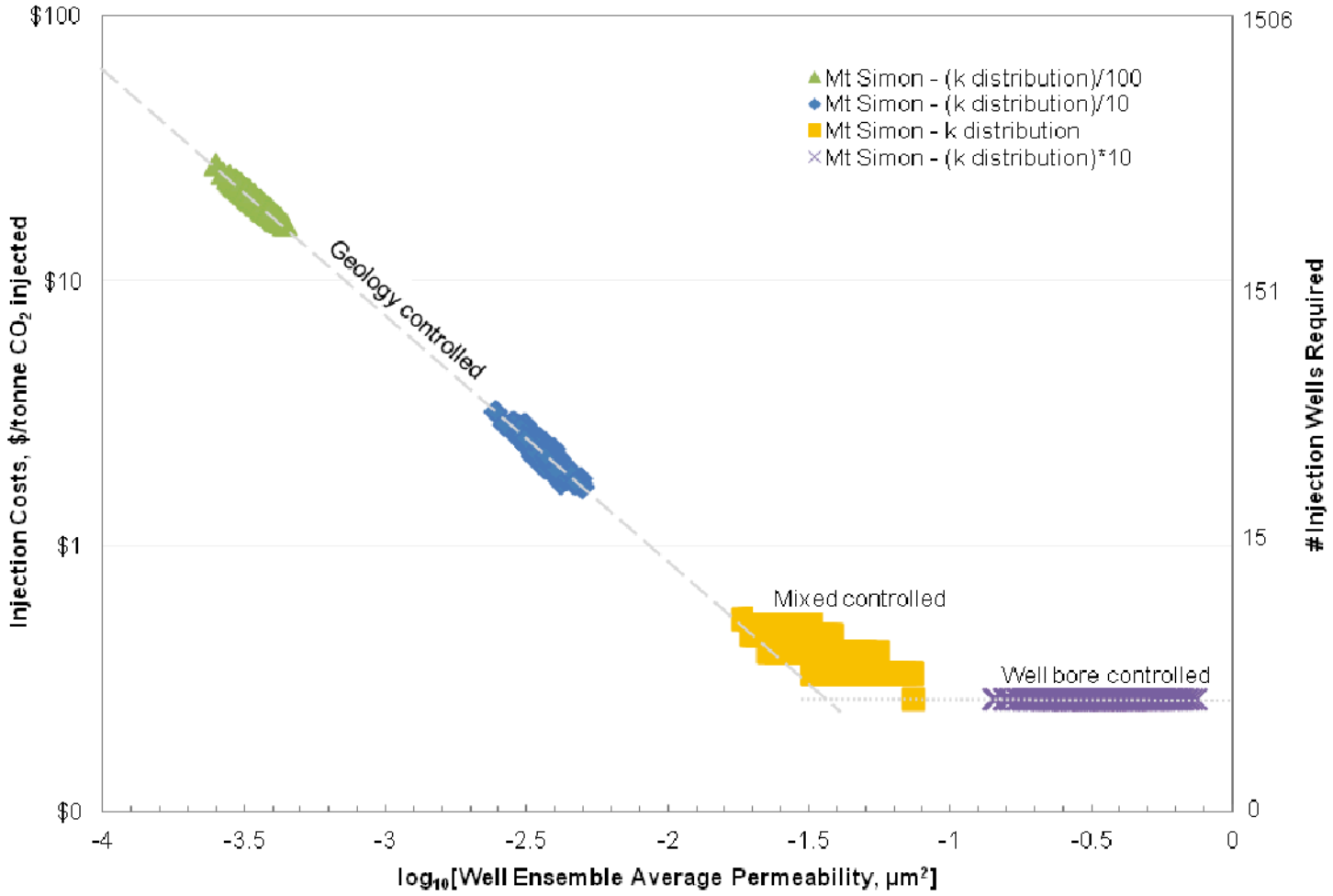
(1) CO_2 Capture

(3) H_2O Extraction

(2) Formation Assessment & CO_2 Storage

Geologic Saline Formation

Permeability & Engineered Constraints Drive Well Costs

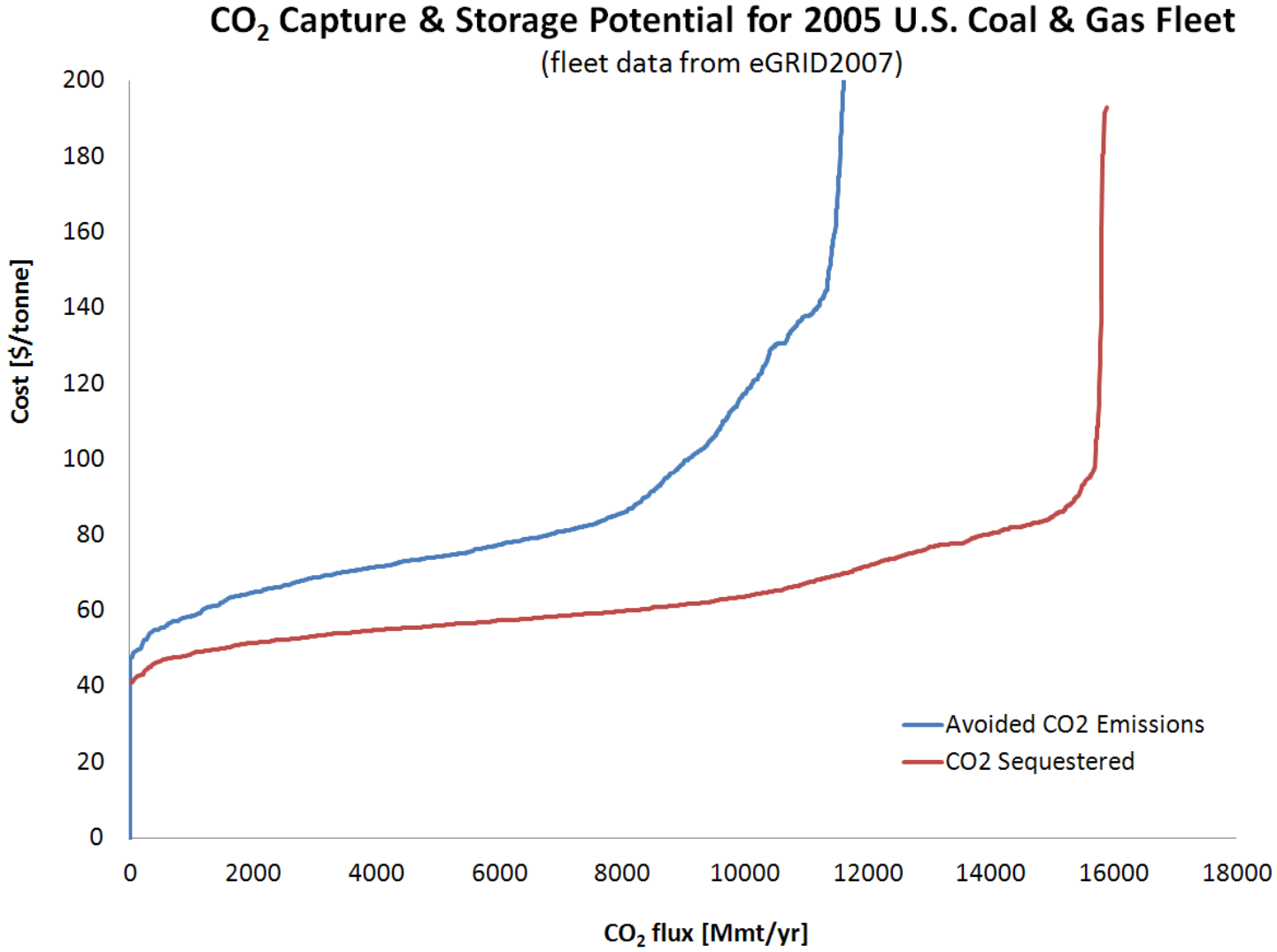


Source: Heath, J.E., Kobos, P.H., Roach, J.D., Dewers, T.A. and S.A. McKenna, 2012, "Geologic Heterogeneity and Economic Uncertainty of Subsurface Carbon Dioxide Storage," SPE Economics & Management Journal, January, pp. 32-41.

Sandia National Laboratories

Working Results:

Developing a National, Dynamic CO_2 Storage Supply Curve



Sandia National Laboratories

Project Timeline & Goals

Timeline

2007
- Developed a Test Case Model (WECS)

2008
- Additional TOUGH2 Analysis

2009
- Developed a single power plant to any saline formation sink in the U.S. systems calculator

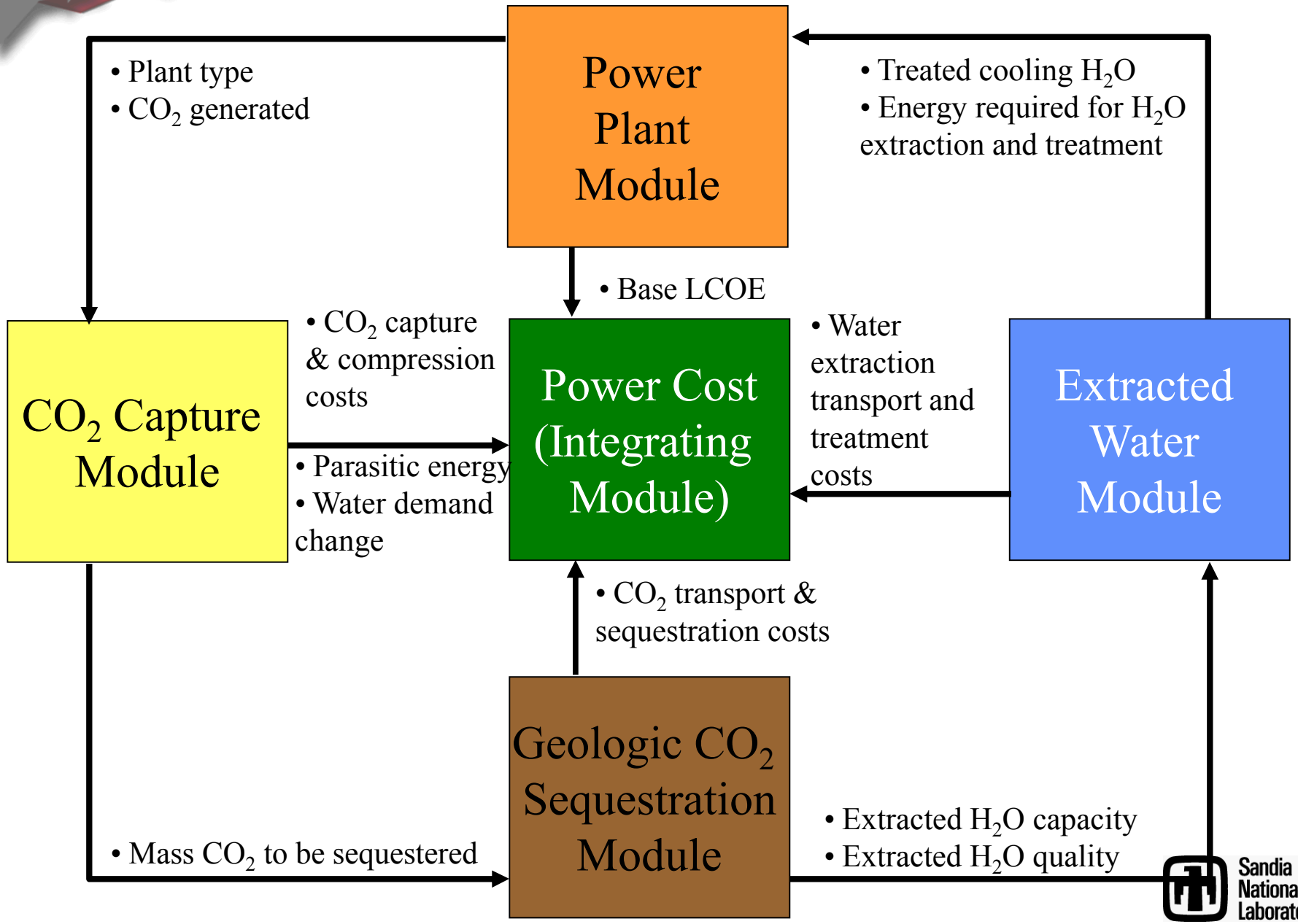
2010
- Expanding the role of uncertainty in the model
  - Several order of magnitude variation in key geologic parameter (permeability)
  - Incorporating uncertainties into costs

2011

2012
- Refining permeability, porosity representation in WECSsim
  - Finalizing WECSsim Interface
  - Develop WECSsim User's manual

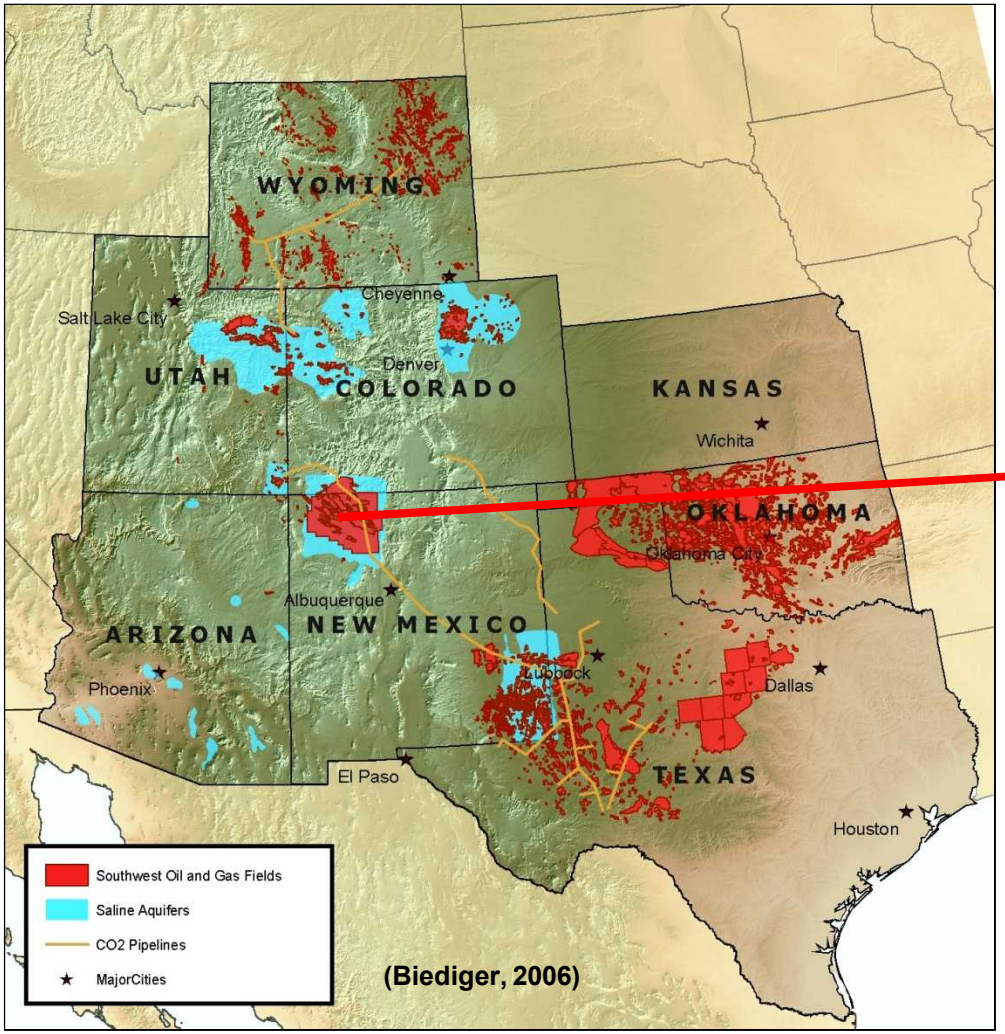
Sandia National Laboratories

WECSsim Modular Structure



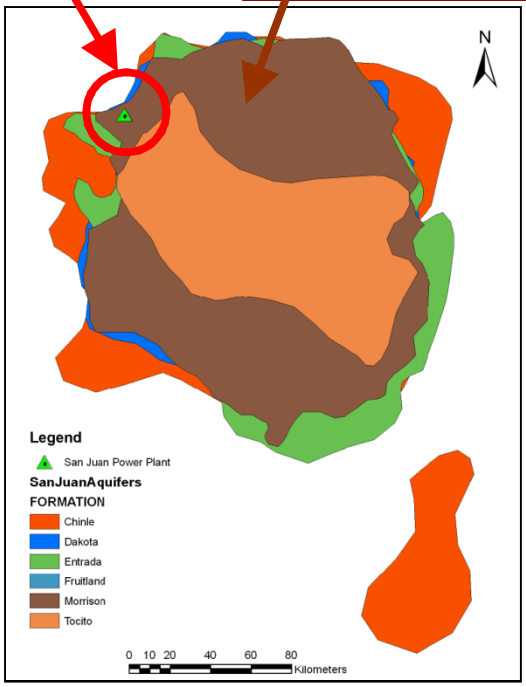
Sandia National Laboratories

The San Juan Power Plant and Morrison Formation



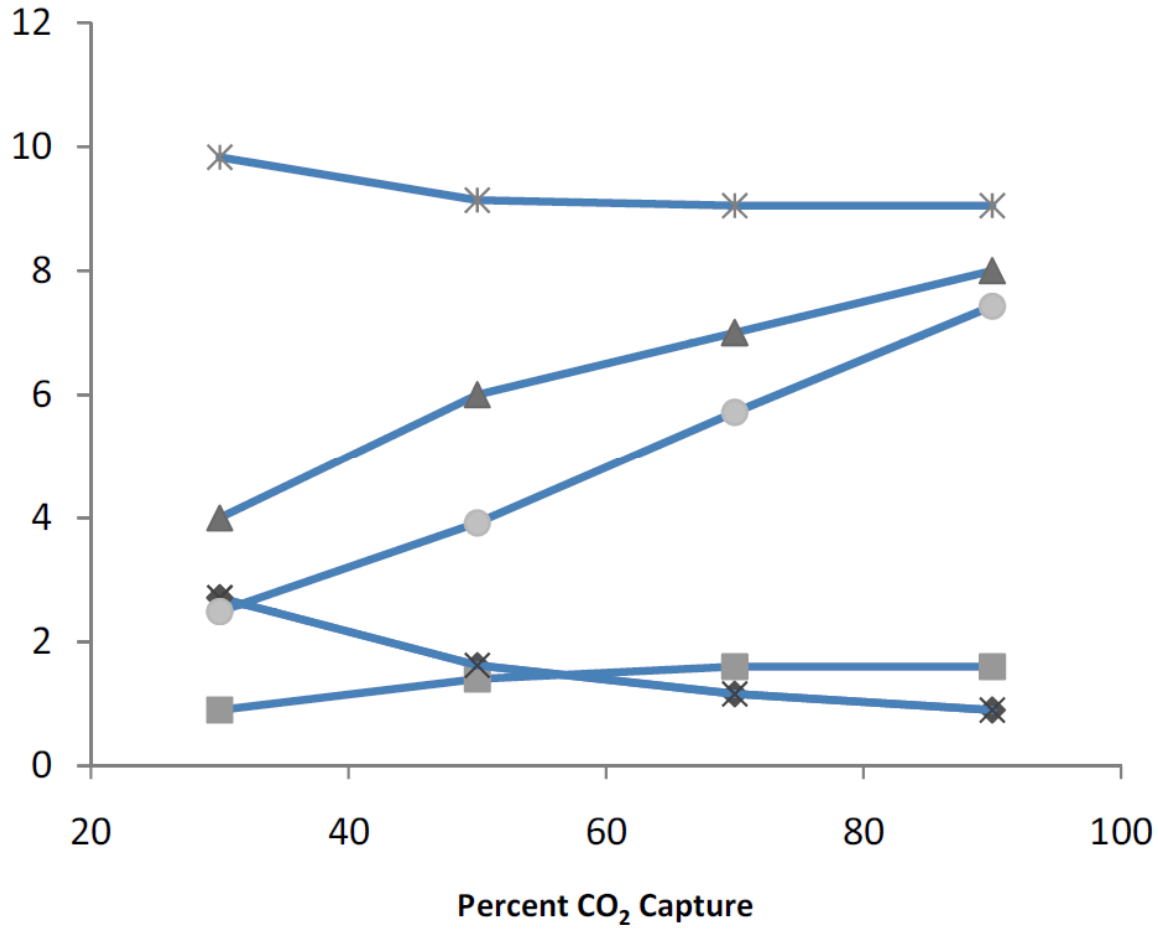
San Juan Power Plant

Morrison Formation



Sandia National Laboratories

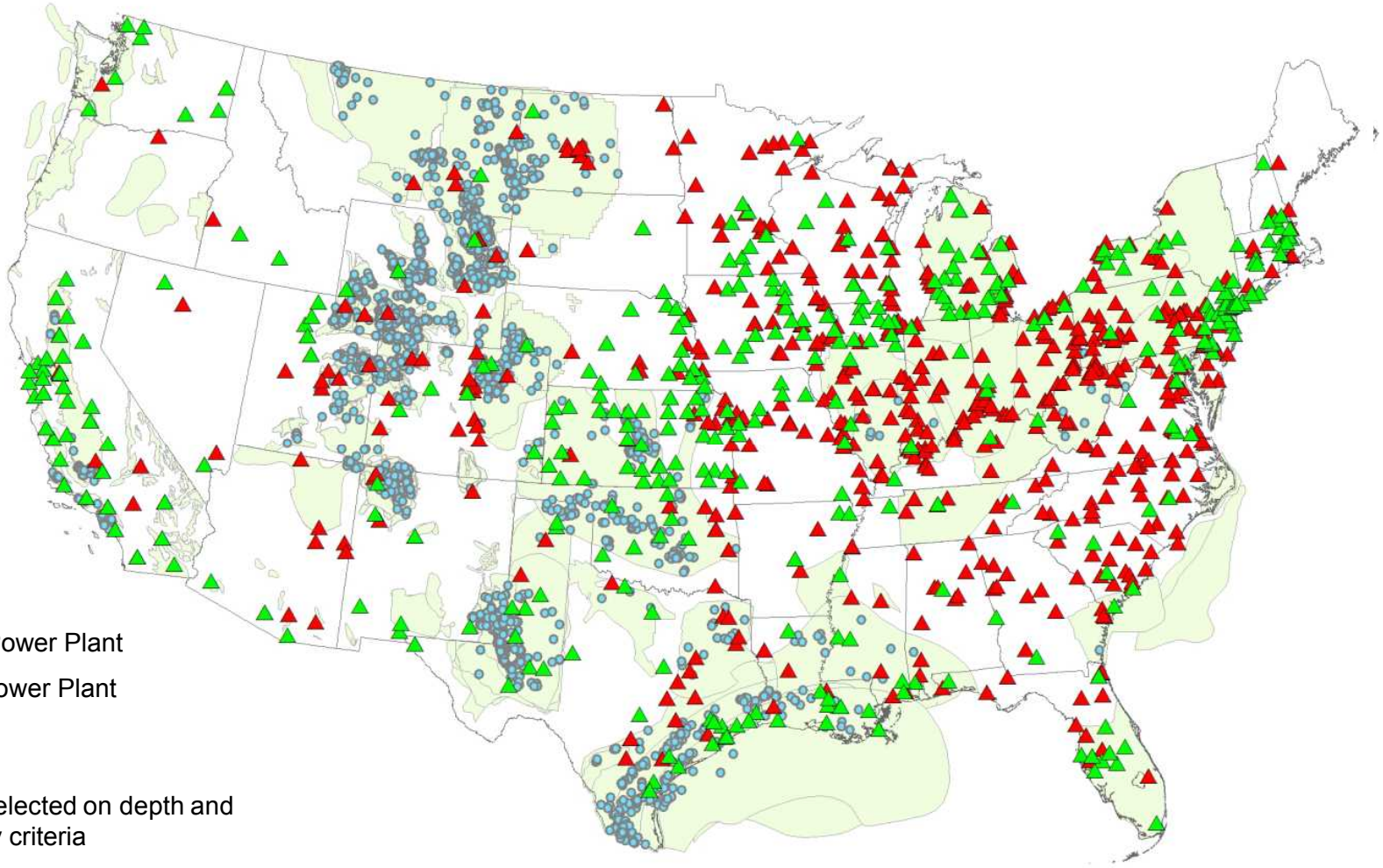
Single Power Plant to Single Geologic Storage Site



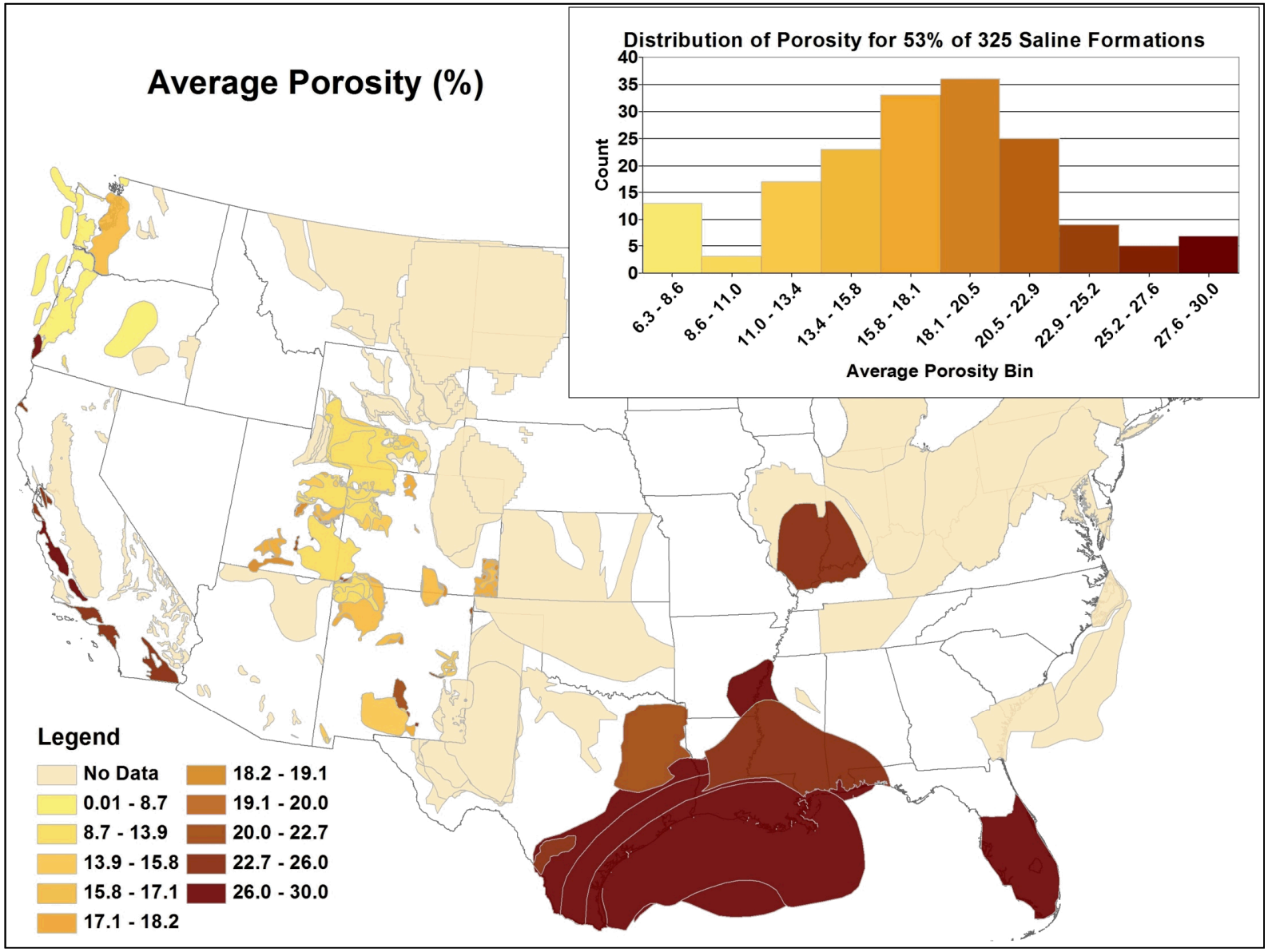
Source: Kobos et al., 2011, *International Journal of Greenhouse Gas Control*, 5, 899-910.

Sandia National Laboratories

Geological CO_2 Storage Database Challenges



Distribution of *Porosity*, & other characteristics

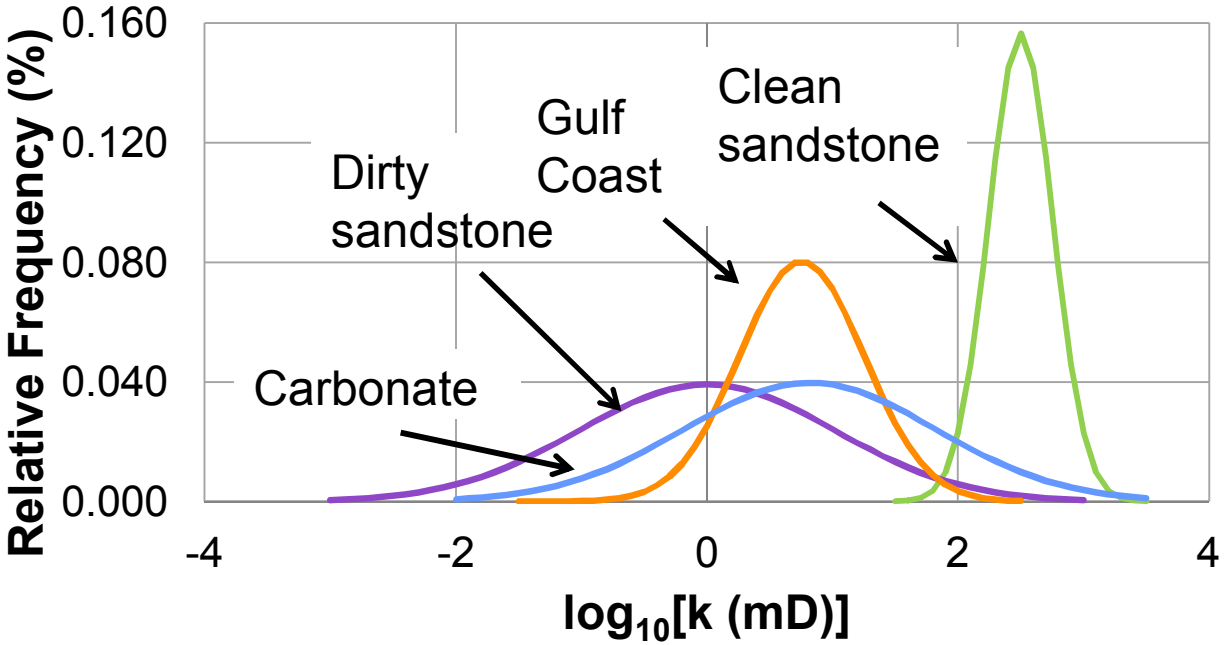


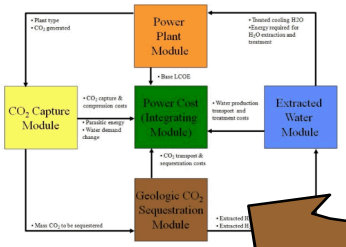
Data Challenge in the Context of Cost

Data Challenge	Required to Calculate	Result
Formation Permeability	→	Injection Rates per Well
Injection Rates Per Well	→	Number of Wells per Power Plant & CO_2 Sink Combo.
Number of Wells	→	Cost of Infrastructure & Well Spacing
Costs & Well Spacing	→	Manage Communication between Wells
Communication Between Wells	→	Calculate the Levelized Lifetime Cost (and years) for the CO_2 Sink & H_2O resource

Expanding the 'Geology Controlled' (Permeability) factor to Cost Relationship across all Sinks

Injectivity equation: permeability sampled from 4 Rock Types





Sandia National Laboratories

Methods behind the Permeability-to-Cost Analysis

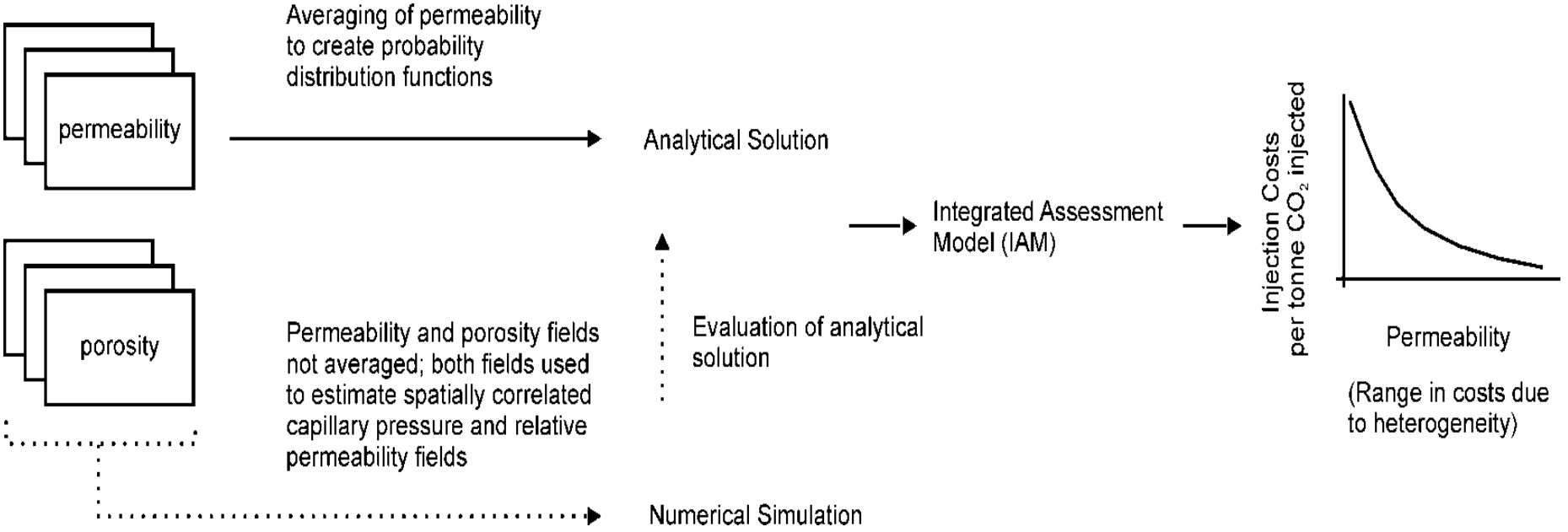
Multiple Realizations of Spatially Correlated Property Fields

Treatment of Heterogeneity

Injectivity Methods

Integrated Assessment Model

Injection Well Costs as a Function of Geologic Permeablity

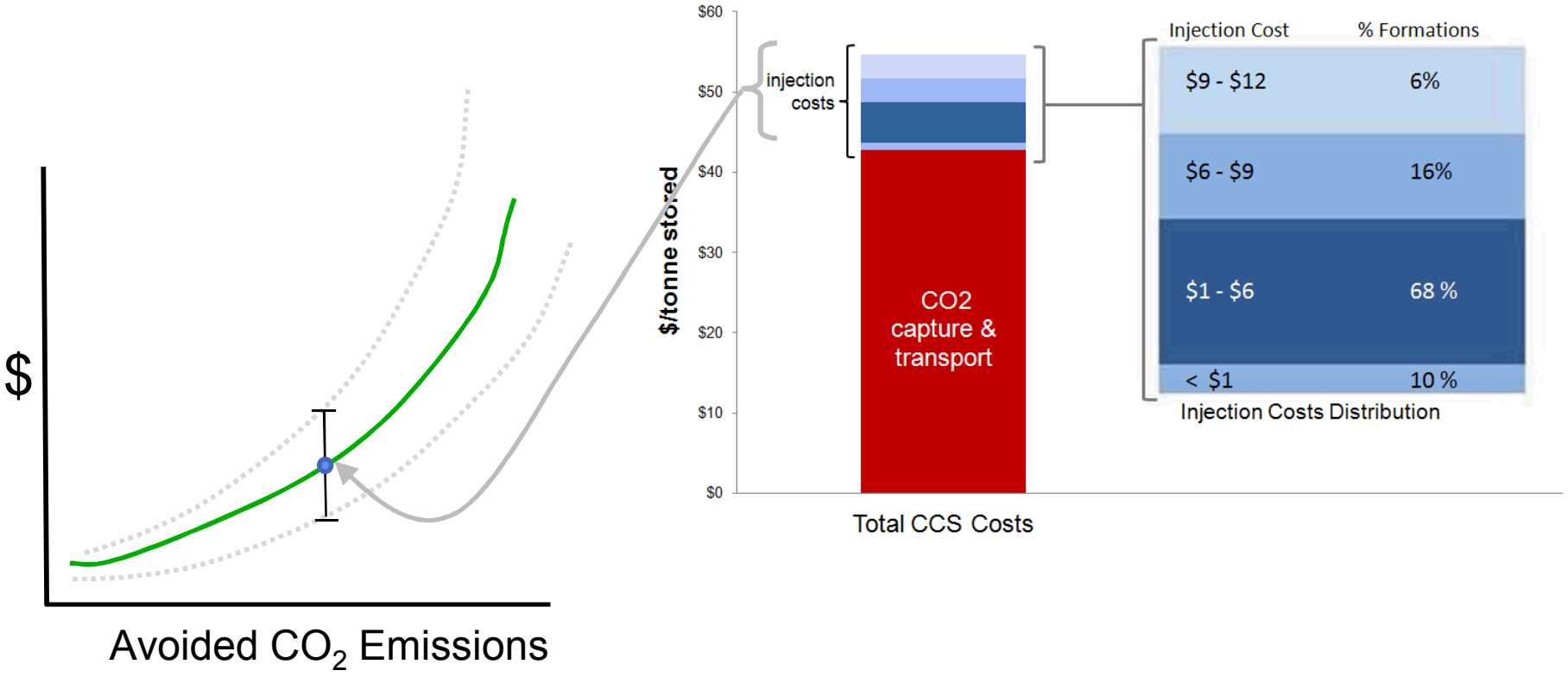


Source: Heath, J.E., Kobos, P.H., Roach, J.D., Dewers, T.A. and S.A. McKenna, 2012, "Geologic Heterogeneity and Economic Uncertainty of Subsurface Carbon Dioxide Storage," SPE Economics & Management Journal, January 32-41.

Sandia National Laboratories

WECSsim Results:

Similar Full Economic Analysis Underway

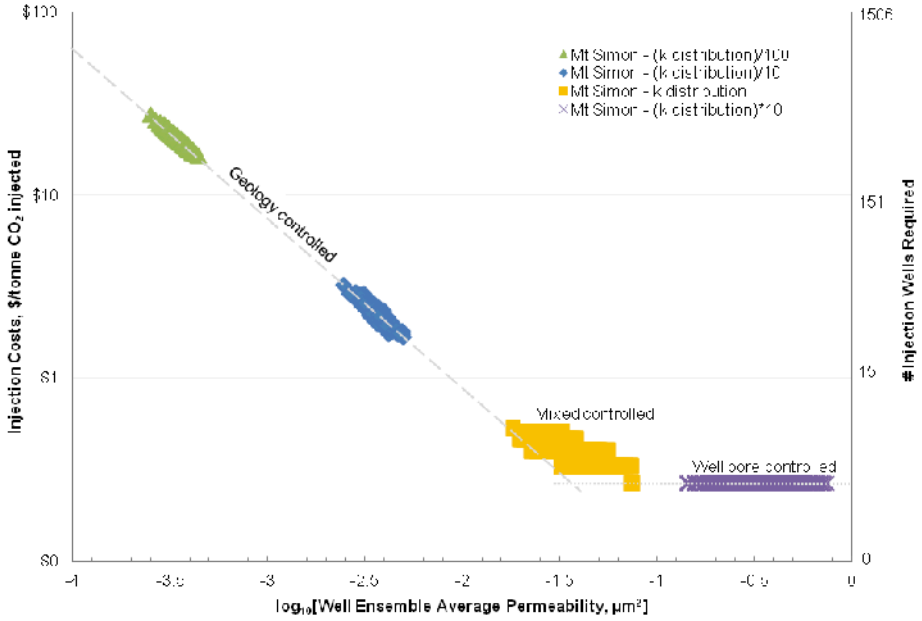


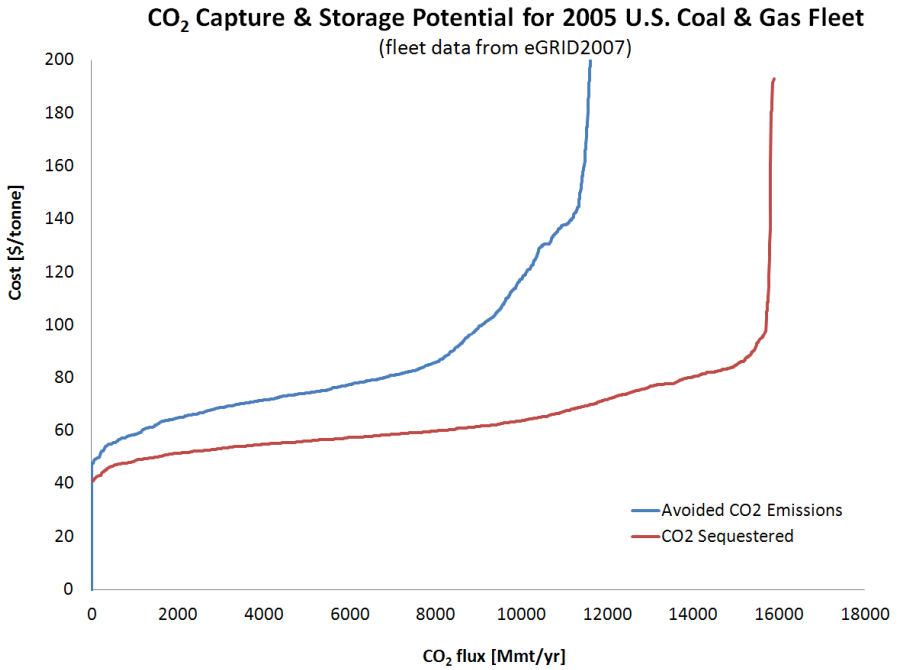
Note: Illustrative Example at this time

Sandia National Laboratories

Summary:

Identifying costs, capacity, and siting criteria





Sandia National Laboratories

Key Messages

Framework for National Level Assessment

- Cost of CCS from any U.S. fossil fuel power plant to any deep saline formation
- Site-specific nature of geologic data challenge

Impact of Geologic Uncertainty on Costs

- Low injectivity requires more injection wells and therefore higher costs
- High permeability reservoirs with low injection costs (< $1/tonne) represent < ~10% of the 325 formations
- Scale-up challenge

Sandia National Laboratories

For Further Information:

Heath, J.E., Kobos, P.H., Roach, J.D., Dewers, T.A. and S.A. McKenna, 2012, "Geologic Heterogeneity and Economic Uncertainty of Subsurface Carbon Dioxide Storage," *SPE Economics & Management Journal*, January, 32-41.

Kobos, P.H., Cappelle, M.A., Krumhansl, J.L., Dewers, T.A., McNemar, A., Borns, D.J., 2011, "Combing power plant water needs and carbon dioxide storage using saline formations: Implications for carbon dioxide and water management policies." *International Journal of Greenhouse Gas Control*, 5, 899-910.

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

Sandia National Laboratories

The Water, Energy and Carbon Sequestration Simulation Model (WECSsim)

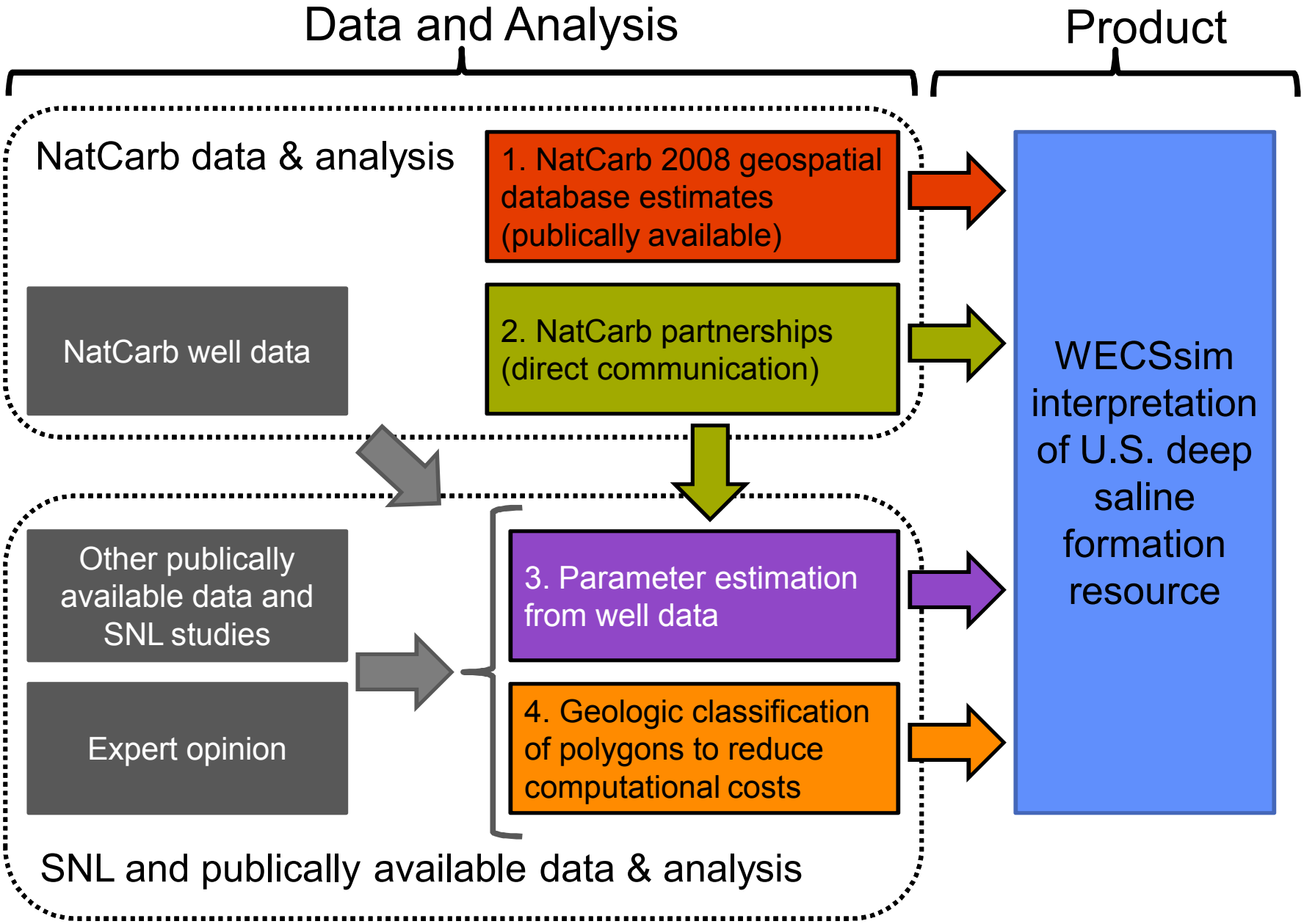
Thank you.

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

National Nuclear Security Administration

Sandia National Laboratories

Assessing U.S. deep saline formations



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	Perm	TDS	Temp	Pressure
NatCarb 2008	42%	100%	0%	0%	0%	0%	0%	0%	0%
Partnerships	42%	100%	62%	64%	55%	0%	18%	44%	45%
Well records	NA	NA	70%[1]	70%[1]	0%	0%	70%[1]	100%[2]	NA
Geologic class	NA	NA	NA	NA	100%	100%	0%	NA	NA
No estimate	**16%** (52)	**0%** (0)	**14%**[3] (47)	**14%**[3] (47)	**0 %** (0)	**0 %** (0)	**14%**[3] (47)	**14%**[3] (47)	**14%**[3] (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. 14% of polygons (47 of 325) have no depth, thickness, or salinity information and no potentially intersecting wells.

Sandia National Laboratories

WECSsim©

Sandia National Laboratories

WECSsim: a dynamic analysis tool

Summary | Power Plant | CO_2 Capture | Carbon Storage | Extracted Water | Power Costs

Module Input

- ***Overview***
- *Power Plant*
- *Carbon Capture*
- *Carbon Storage*
- *Extracted Water*
- *Power Costs*

Specify a Power Plant and Desired Carbon Capture %:

Plant Type & Specific Plant

(•) Pulverized Coal	NM - Four Corners	<-
( ) IGCC	FL - Polk	
( ) NGCC	AL - ExxonMobil Mobile Bay Onshore	
( ) Gas Turbine	AL - ABC Coke	
( ) Hypothetical		

% CO2 Capture

0 40 80

90 %

Carbon Capture and Storage (CCS) with Saline Water Extraction: Where and How Much?

Sequestration Formation:	Southwest - SanJuan - Entrada	
CO2 Stored:	12.90 Mmt/yr base	16.48 Mmt/yr total (w makeup power ccs)
CCS Cost per Mass CO2:	$54.7 per tonne stored	$72.2 per tonne of avoided emissions
Added Energy Cost:	5.48 cents/kWh for CCS	0.38 cents/kWh water related

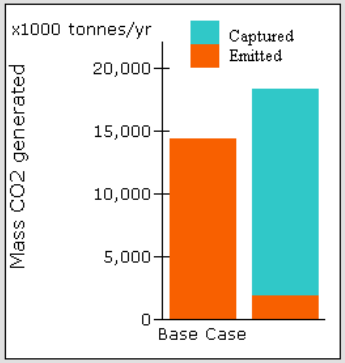
Output

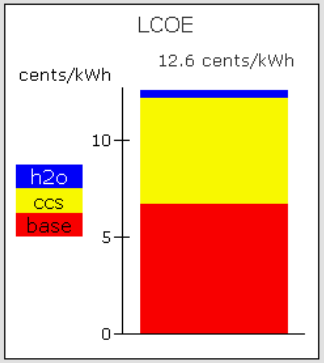
Rescale output graph axes

Locations of Formation & Power Plant

Selected formation centroid

Power plant





Cost of avoided CO2 emissions: $72.2 per tonne

Background and Documentation

Sandia National Laboratories

WECSsim: a dynamic analysis tool

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

Module Input

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

Specify a Power Plant (Existing or Hypothetical):

Plant Type & Specific Plant

(•) Pulverized Coal	NM - Four Corners	<-
( ) IGCC	FL - Polk	
( ) NGCC	AL - ExxonMobil Mobile Bay Onshore	
( ) Gas Turbine	AL - ABC Coke	
( ) Hypothetical		

The radio-buttons and dropdowns set the default power plant parameters to values for any eGRID 2007 plant (first four radio-button options) or an entirely user specified ("Custom") plant. In either case, resulting model defaults can be changed individually as well.

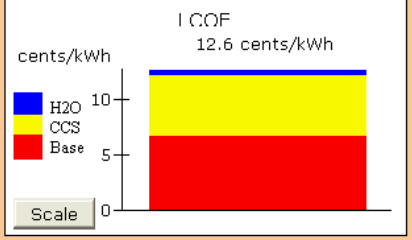
Plant type	PC-Subcritical			
Capacity & Capacity Factor	2,270 MW		0.7854	
CO2 Generation Rate	2,051 lbs/MWh			
Latitude - Longitude	Lat	36°41'24"	Long	-108°28'53"

Output

Key Information from Power Plant Module

Plant type	PC-Subcritical
Base electricity generation	15,403.9 GWh/yr
Base CO2 generation	15,797,847.7 tons/yr
Cooling type	Cooling tower
Base water withdrawals	643.1 MGD
Base water consumption	1.6 MGD

Power Plant Location



Background and Documentation

Sandia National Laboratories

WECSsim: a dynamic analysis tool

Summary | Power Plant | CO_2 Capture | Carbon Storage | Extracted Water | Power Costs

Module Input

- ***Summary***
- *Parasitic Energy*
- *Make-up Power*
- *Direct Water Use*

Carbon Capture Module Inputs Summary

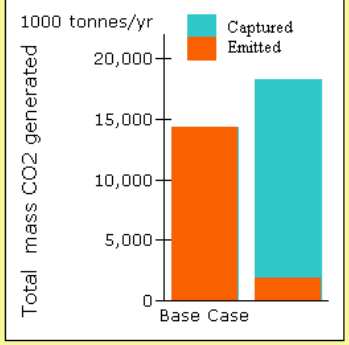
Plant Type	Pulverized coal subcritical
% Base CO2 Captured (CC)	90 %
Water withdrawal demand specific to CC & compression	298 gal/tonne CC
Make-up Power (MUP) Plant Type	PC-Subcritical
MUP CO2 Production Rate	1,900 lbs/MWh
% MUP CO2 Captured	90 %
MUP LCOE	13.1 cents/kWh
MUP Plant Cooling Type	Cooling tower
MUP water withdrawal rate	22.2 MGD

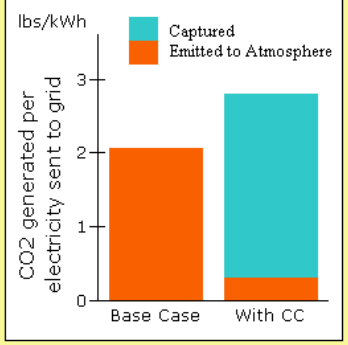
Output

Rescale output graph axes

CO2 Capture Summary Values

Base plant type	PC-Subcritical
% CO2 Captured (CC)	90 %
Parasitic Energy Loss	30 %
=	534,857 kW
Make-up plant type	PC-Subcritical
Make-up plant cooling type	Cooling tower
Added water withdrawal demand	3 %
=	22 MGD
Total CC	16.5 Mmt/yr
LCOE of CC	5.4 cents/kWh





Background and Documentation

Sandia National Laboratories

WECSsim: a dynamic analysis tool

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

Module Input

- ***Summary***
- *Sink ID & Location*
- *Sink Area*
- *Sink Depth & Thickness*
- *Sink TP CO2 D*
- *Sink Porosity*
- *Sink Permeability*
- *Injection Wells*
- *Sink Storage Resource*

Carbon Storage Target (NatCarb Partnership - Basin - Formation)

Southwest - SanJuan - Entrada

Formation Centroid	36°24'35" N -107°42'43" W
Formation footprint area	29,181.6 km²
Formation depth	5,887 ft
Formation thickness	420 ft
Formation average porosity	0.168
Formation geometric mean permeability	396.9 mD
Formation temperature	59°C
Formation pressure	175.8 bar

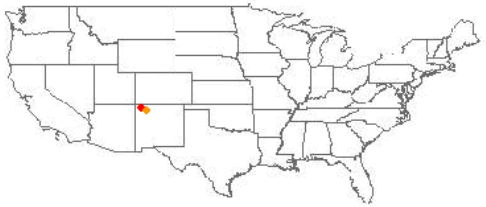
Output

Carbon Storage Target

Southwest - SanJuan - Entrada

Sink life for this CO2 only	550 yr
Sequestration depth	5,887 ft
Initial temp. at seq. depth	59°C
Initial pressure at seq. depth	176 bar
Resulting initial CO2 density	727 kg/m³
CO2 to be sequestered	16.5 Mmt/yr
Power Plant to sink distance	0 mi
# injection wells required	10
LCOE CO2 transport & seq.	0.05 cents/kWh

Locations of Formation & Power Plant



- Selected formation centroid location (36°24'35" N -107°42'43" W)
- Power plant location (set on Power Plant Tab) (36°41'24" N -108°28'53" W)

Background and Documentation

Sandia National Laboratories

WECSsim: a dynamic analysis tool

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

Module Input

- ***Summary***
- *Quantity & Quality*
- *Extraction Wells*
- *Water Treatment*
- *Brine Disposal*

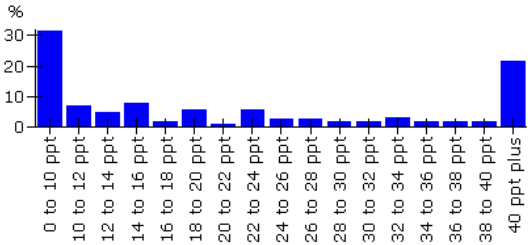
Extracted Water Module Inputs Summary

Saline formation targeted	Southwest - SanJuan - Entrada
Deep saline water extraction rate	25.25 MGD
Number of extraction wells	10
Extraction depth	2500 to 5000 ft
Minimum salinity threshold	10 ppt
Maximum salinity threshold	30 ppt
Average salinity of extracted water	19 ppt
Treated water stream	16.64 MGD
% new (CCS) H2O demands met	75 %
Brine disposal method	injection

Output

Extraction formation:	
Southwest - SanJuan - Entrada	
Holes drilled per extraction well:	2.6
Number of extraction wells:	10
Average TDS of extracted water:	19 ppt
RO treatment plant efficiency:	66 %
Brine concentrate (bc) disposal:	injection
Treated water stream:	16.6 MGD
% new (CCS) H2O demands met:	75 %
Cost of extraction and transport:	$4.66 per 1000 gal
Cost of treatment and bc disposal:	$5.10 per 1000 gal
Total treated water cost:	$9.76 per 1000 gal

Distribution of water quality in target formation at depths of: 2500 to 5000 ft



Rescale

Salinity Intervals

Caution: Distribution is from potentially intersecting well records and thus only an estimate of tds in the formation

Background and Documentation

Sandia National Laboratories

WECSsim: a dynamic analysis tool

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

Module Input

- ***Summary***
- *Base year & cap factors*
- *Base LCOE*
- *CCC Costs - Amine*
- *CCC Costs - Selexol*
- *CO2 Pipeline Costs*
- *Injection Well Costs*
- *H2O Extraction Costs*
- *H2O Pipeline Costs*
- *H2O Treatment Costs*
- *Brine Disposal Costs*

CCS Costs Summary Values

$ Display Year	2010
Power Plant Capitilization Factor	8.02 %/yr
Saline Formation Capitilization Factor	8.02 %/yr
Base LCOE at Plant	6.71 cents/kWh
Make-up Power LCOE	13.1 cents/kWh
CCC Costs Amine Scrubbing	1.5 cents/kWh
CCC Costs Selexol (IGCC)	? cent/kWh
CO2 Pipeline Costs	0 cents/kWh
CO2 Injection Well Costs	0.05 cents/kWh
H2O Extraction Well Costs	0.18 cents/kWh
H2O Pipeline Costs	0 cents/kWh
H20 Treatment Costs	0.19 cents/kWh
Brine Disposal Costs	0.01 cents/kWh

Output

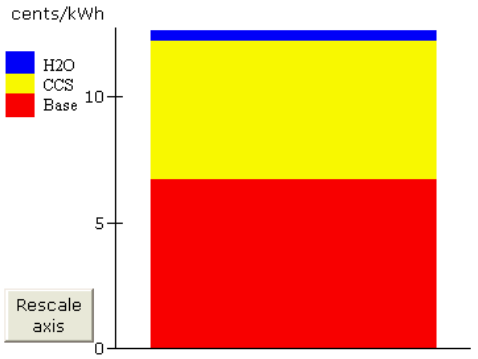
Power Cost Results

In 2010 dollars

(•) $/mass CO2 stored
( ) $/reduced CO2 emissions

Marginal LCOE for treated water:	0.38 cents/kWh
Cost of treated water:	$3.55 per tonne
Marginal LCOE for CO2 transport:	0 cents/kWh
Length of CO2 pipeline:	0 mi
Cost of CO2 transport:	$0 per tonne
Marginal LCOE for CO2 injection:	0.05 cents/kWh
Cost of CO2 injection:	$0.45 per tonne
Marginal LCOE for Make-Up Power:	3.93 cents/kWh
Marginal LCOE for CCC:	1.5 cents/kWh
CCC Cost Including Make-Up Power:	$50.72 per tonne
Base LCOE:	6.71 cents/kWh

Total LCOE with CCS 12.57 cents/kWh



NETL Background and Documentation

Sandia National Laboratories