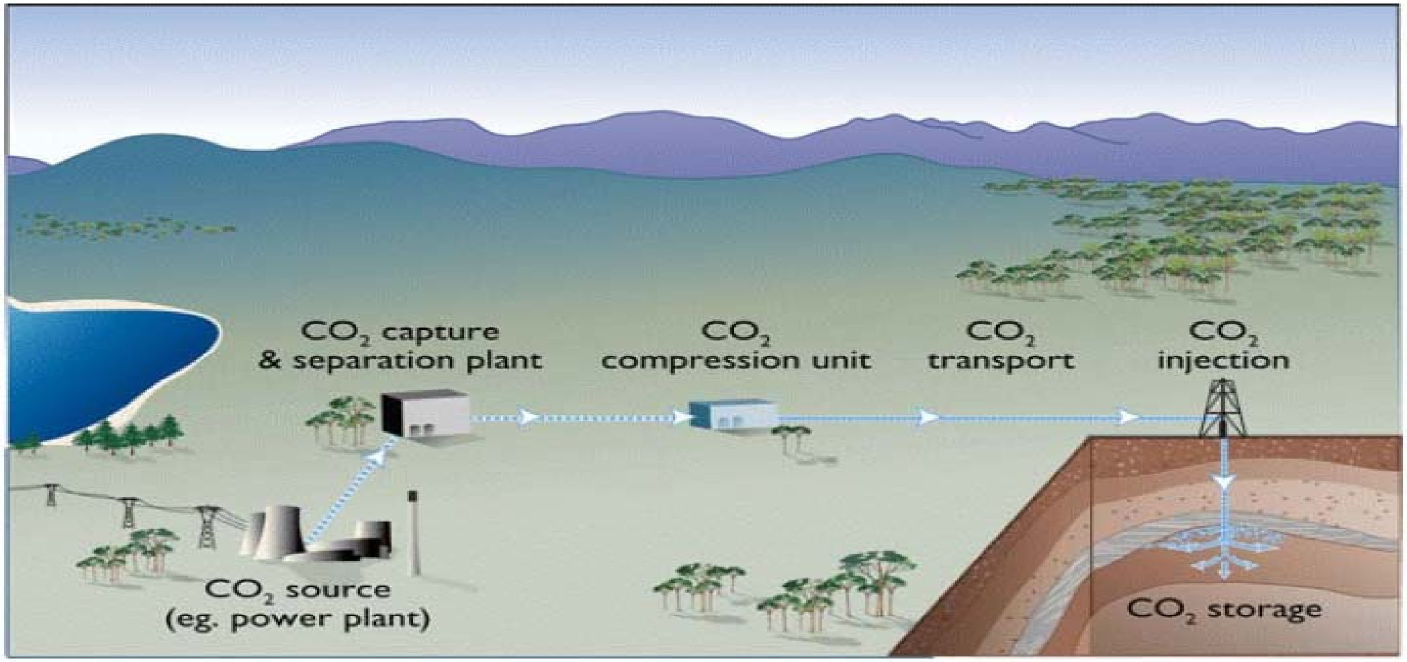
NATIONAL ENERGY TECHNOLOGY LABORATORY



FE/NETL CTS-Saline Cost Model

NRAP Technical Team Meeting – October 17, 2012

Tim Grant and Dave Morgan – National Energy Technology Laboratory

Jason Valenstein, Andrea Poe and Marta Milan – Booz Allen Hamilton, Inc.

Richard Lawrence – Advanced Resources International, Inc.

DOE/NETL-2013/1596

FE/NETL CTS-Saline Cost Model

Introduction

Model Description

Test Matrix Model Runs

Benefits of NETL Carbon Storage R&D

Conclusions

FE/NETL CTS-Saline Cost Model

Purpose of FE/NETL CTS-Saline Cost Model

- **Estimate cost for a single site**
- **Provide data to generate national or regional storage cost supply curves**
- **Provide cost analysis of various sequestration technology**

FE/NETL CTS-Saline Cost Model

Suit of Models for Analysis of Carbon Storage Scenarios

FE/NETL CO_2 Transport & Storage (CTS)-Saline Cost Model

- Point-to-point pipeline transport cost (pending)
- Cost and revenue from CO_2 storage in saline aquifer

FE/NETL CO_2 Transport & Storage (CTS)-EOR Cost Model

- Point-to-point pipeline transport cost (pending)
- Cost and revenue from CO_2 enhanced oil recovery (EOR)

FE/NETL Capture Transport Utilization Storage (CTUS) Model

- Sources of CO_2
- CO_2 pipeline network and storage
- Cost and revenue from CO_2 storage in saline aquifer and from CO_2 EOR

FE/NETL NEMS-Carbon Capture Utilization Storage (CCUS) Model

- Macroeconomic model of US economy
- Detailed model of US energy sector

FE/NETL CTS-Saline Cost Model

Sequence of events for CO_2 storage operations and framework for CO_2 Transportation & Storage Cost Model

Regional evaluation for a specific site	Site selection & characterization	Permitting	Operations	Post-Injection Monitoring	Long-term Stewardship
Negative Cash Flow			Positive Cash Flow Injection Fee	Negative Cash Flow	Trust fund covers costs
Estimate of volume of emissions to sequester and pore space needed over project life.	Assemble data; acquire new data; drill new well(s) & acquire seismic; establish data baselines; get necessary permits.	Submit all plans and financial responsibility for permit application – UIC & State	Finish construction of surface facilities and MVA grid; Tie injection wells to CO_2 supply.	Present PISC & site closure plan to Director; apply for reduced time period	Another entity accepts long-term stewardship
Data research – geologic, geophysical, engineering, financial & social. Initial modeling of potential site.	Finish assembling acreage block.	Director approves drilling of injection wells. State (DEP) approves site permit. Approval of other permits as needed.	Inject Captured CO_2. Annual MIT for injection wells; workovers as needed.	Follow PISC & site closure plan, periodic testing and reporting.	Operator & other parties relieved of liability unless negligent, etc.
Regional geologic evaluation to identify several prospective areas for storage operations .	Prepare plans required for UIC Class VI and state permits. FEED for injection wells, surface facilities and MVA grid.	Drill injection wells, incorporate new well data in plans and present to Director.	Drill additional monitoring wells and remediate existing wells (corrective action) as necessary as plume expands. Well workovers & equip. maintenance as necessary.	Establish non-endangerment; closure approved; P&A all wells & restore site(s).	Other entity oversees trust fund, pays site costs, settles all claims.
Begin to assemble acreage block. Will need more acreage than actually used +30 yrs later. Hopefully first site selected will prove correct.	Assemble financial responsibility package for UIC and state permits.	Director approves injection. Have 180 days to submit MRV plan per Subpart RR regs.	Follow all plans, AoR review every 5 yrs, annual reporting. Pay into to fund for LT Stewardship; P&A injection wells, some financial responsibility instruments released.	With closure of Class VI permit, Director releases financial responsibility instruments. State awards Certificate of Completion & assumes long-term stewardship.	
0.5 to 1 year	3 to 5 years		30 to 50 years	10 to 50+ years	Rest of Civilization

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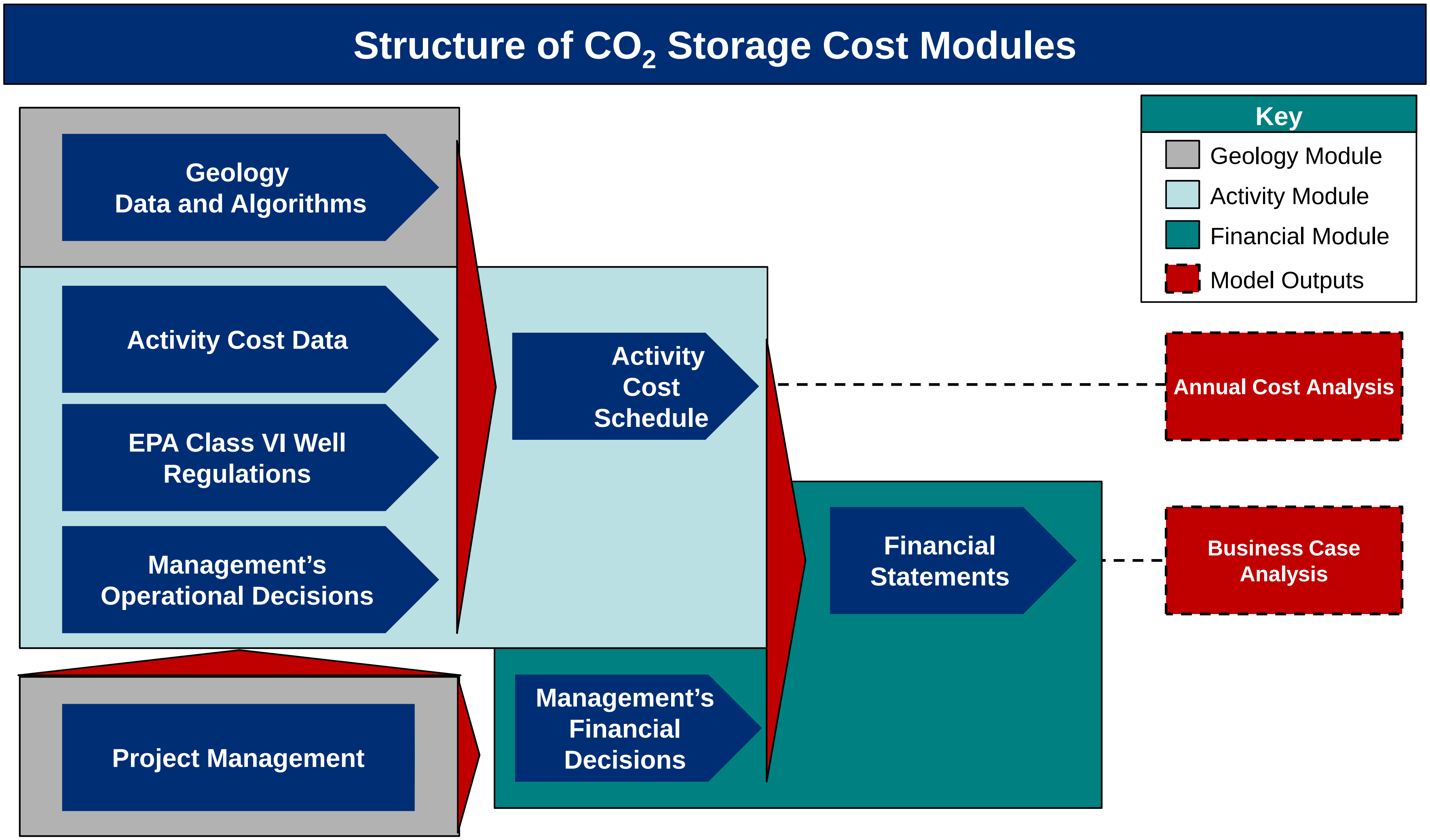


FE/NETL CTS-Saline Cost Model

Input tables allow for various Management decisions that impact project costs.

Project Management Decision	Cost Impact
Volume of CO_2 sequestered annually	Size of the project
Duration of the Storage Project Stages (Site Characterization, Permitting, Operations, Post-Injection Site Care)	Time Value of Money
Instrument(s) of Financial Responsibility	Upfront cost of project and Time Value of Money
Technology choices and application for site characterization and/or MVA	Project costs incurred
Spacing (well density) of Monitoring Wells	Total number of Wells to drilled and operated
Frequency of various activities performed (i.e. how often seismic is run 3,5,7 years.)	Frequency and timing of material costs as they are incurred

FE/NETL CTS-Saline Cost Model

Geology Module Provides Data and Parameters That Drive Storage Costs

Geology Data

Reservoir Formation Data

Parameters Calculated with Geo-engineering Equations

Areal Extent of CO_2 Plume

CO_2 Injectivity and Maximum Rate of CO_2 Injection per Injection Well

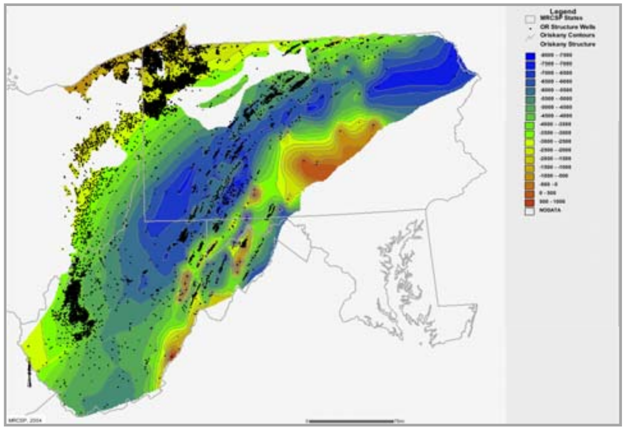
Project Cost informed

- Extent of AoR.
- Extent of leasing activity, secure pore space rights.
- Seismic/MVA Costs relating to AoR.
- Number of monitoring wells to be drilled.
- Corrective Action – Number of old wells within AoR

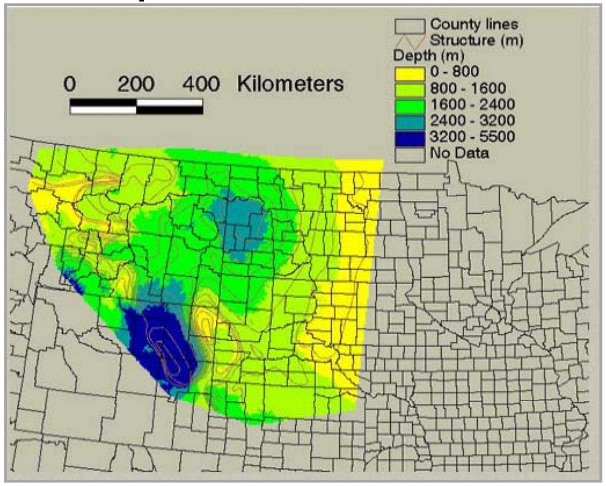
- Number of injection wells needed to inject a user-specified maximum daily mass of CO_2

NETL CO_2 Injection and Storage Cost Model

Example of MRCSP Contour Map - Oriskany Sst Structure



Example of GCCC Contour Map – Madison Group Structure, Williston Basin



Areal *Extent of* Saline Reservoir

- In the model's geologic database, the saline formations were split spatially mainly by state and basin.
- If sufficient geologic study was available to provide a range of reservoir parameters by area, some formations could be further delineated based on those parameters.
- For instance, contoured porosity data of the Mount Simon formation in Michigan was available and allowed division of the state by regions based on areas of high, medium and low porosity. The Midwest Regional Carbon Sequestration Program (MRCSP) extensively contoured formation structure and thickness and made these maps available on their web site.
- The Gulf Coast Carbon Center has similar maps of twenty-one potential storage horizons from all regions of the U.S.
- From these various sources, the potential storage capacity for formations listed in the geologic database could be defined based on to the gross height of the formation with its area in square miles calculated in ArcGIS.

FE/NETL CTS-Saline Cost Model

Geology Database

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	UID	Formation Identifier	Formation Name	State	Region	Basin	RCSP	Reservoir Type	Lithology	Depositional Environment	Geologic Age	Area (sq miles)	Depth - top (ft)	Thickness (ft)	Res. Pressure (psi)	Res. Temp (°F)	Porosity (%)	Permeability (mD)	Salinity (mg/L)	Main Source Reference
2	1	Arbuckle1	Arbuckle	OK	OK - N	Northern Shelf Area	SWP	Saline	Dolomite	Peritidal	Ordovician	10,620	6,562	572	2,640	139	10.0	50.0	150,000	42
3	2	Cedar Keys-Lawson1	Cedar Keys-Lawson	FL	NE-Thin-Shallow	South Florida	SECARB	Saline	Carbonate	Reef	Cretaceous	8,500	3,550	300	NA	101	25.0	25.0	NA	a,14,45
4	3	Cedar Keys-Lawson2	Cedar Keys-Lawson	FL	Central+NW-Thick	South Florida	SECARB	Saline	Carbonate	Reef	Cretaceous	13,500	4,800	500	NA	113	22.0	25.0	NA	a,14,45
5	4	Cedar Keys-Lawson3	Cedar Keys-Lawson	FL	S-Thin-Deep	South Florida	SECARB	Saline	Carbonate	Reef	Cretaceous	6,400	4,600	300	NA	111	23.0	25.0	NA	a,14,45
6	5	Conasauga1	Conasauga	OH	OH - E	Appalachian	MRCSP	Saline	Clastic	Peritidal	Cambrian	21,200	8,000	150	NA	NA	8.0	6.0	NA	21,40,44
7	6	Copper Ridge1	Copper Ridge	OH	OH - SE	Appalachian	MRCSP	Saline	Dolomite	Peritidal	Cambrian	6,000	7,000	75	NA	NA	5.0	5.0	NA	21
8	7	Copper Ridge2	Copper Ridge	PA	PA - SW	Appalachian	MRCSP	Saline	Dolomite	Peritidal	Cambrian	5,500	9,000	75	NA	NA	5.0	5.0	NA	21,41
9	8	Copper Ridge3	Copper Ridge	WV	WV - W	Appalachian	MRCSP	Saline	Dolomite	Peritidal	Cambrian	7,000	8,250	65	NA	NA	10.0	100.0	NA	21
10	9	Dakota1	Dakota	CO	Piceance - S	Piceance	SWP	Saline	Clastic	Strandplain	Cretaceous	2,900	4,715	130	2,216	158	14.0	750.0	35,000	42
11	10	Dakota2	Dakota	CO	Piceance - N	Piceance	SWP	Saline	Clastic	Strandplain	Cretaceous	2,600	4,230	130	1,987	158	14.0	750.0	35,000	42
12	11	Dakota3	Dakota	CO	San Juan - N	San Juan	SWP	Saline	Clastic	Strandplain	Cretaceous	1,300	5,935	190	2,789	203	7.5	0.4	13,500	42
13	12	Dakota4	Dakota	NM	San Juan - S	San Juan	SWP	Saline	Clastic	Strandplain	Cretaceous	10,780	3,000	82	1,410	114	17.0	1.0	10,000	42
14	13	Dakota5	Dakota	UT	Uinta	Uinta	SWP	Saline	Clastic	Strandplain	Cretaceous	5,800	11,500	40	5,365	123	12.0	20.0	23,000	42,52
15	14	Devonian1	Devonian	NM	Permian - NW	Permian	SWP	Saline	Carbonate	Shallow Shelf	Permian	4,960	10,000	100	4,665	160	6.0	10.0	100,000	42
16	15	Domengine	Domengine	CA	Sacremento - S	Sacremento	WESTCARB	Saline	Clastic	Shallow Shelf	Tertiary	2,300	4,200	375	NA	NA	28.0	100.0	NA	3,14,16
17	16	Duperow-Lower1	Duperow - Lower	MT	MT-CENT	Kevin Dome	BSCP	Saline	Carbonate	Peritidal	Devonian	4,850	3,800	300	NA	NA	15.0	20.0	>10,000	5,47
18	17	Duperow-Upper1	Duperow - Upper	MT	MT-CENT	Kevin Dome	BSCP	Saline	Carbonate	Peritidal	Devonian	4,850	3,400	400	NA	NA	7.0	10.0	>10,000	5,47
19	18	Entrada1	Entrada	CO	San Juan - N	San Juan	SWP	Saline	Clastic	Eolian	Jurassic	1,500	5,155	150	2,423	186	24.0	300.0	11,000	42
20	19	Entrada2	Entrada	NM	San Juan - S	San Juan	SWP	Saline	Clastic	Eolian	Jurassic	7,420	3,000	131	1,410	114	24.0	200.0	10,000	42
21	20	Entrada3	Entrada	CO	Sand Wash - S	Sand Wash	SWP	Saline	Clastic	Eolian	Jurassic	2,900	5,025	170	2,362	133	20.0	400.0	8,500	42

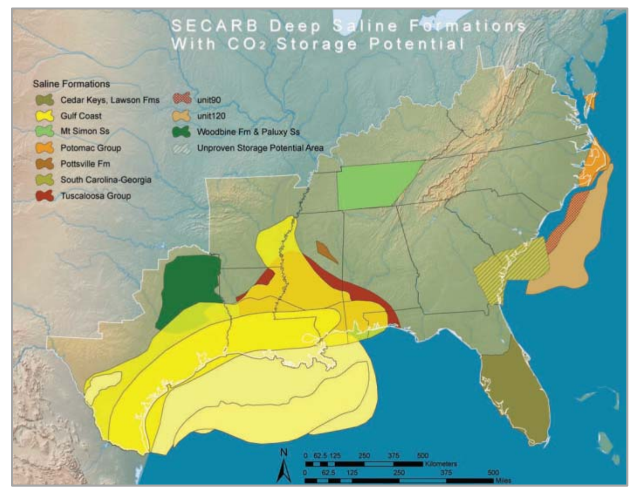
Formation information: State, Region, Basin, RCSP, Lithology, Depositional Environment, Geologic Age, Area, Depth, Thickness, Res. Pressure, Res. Temp, Porosity, Permeability, Salinity

Saline database based on the NATCARB database with formation data provided by numerous sources. Majority of the data is gleaned from publicly available publications and studies by NATCARB Regional Carbon Sequestration Partnerships (RCSPs).

Saline database: 46 Formations in 27 Basins across 22 States = 151 reservoirs

Storage Coefficients: data from IEA GHG 2009 study
  Reported for 12 depositional environments and
  5 structural settings: dome, anticline, 10º, 5º and flat
  1.25% of reservoir area each to dome & anticline[1]; 32.5% each to 10º, 5º & flat

Structural settings applied to reservoirs – 755 reservoir data points



SECARB Delineation of Studied Areas

1 – USGS, 2012, Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources – Bighorn Basin, Wyoming and Montana. OFR 2012-1024-A

FE/NETL CTS-Saline Cost Model

Activity Cost Module

- **Cost data base for all activities and technologies**
- **Generated cost for selected activities on annual basis**
- **Posts cost in year they occur**
- **Generates OPEX, CAPEX, Depreciation and Amortization and an escalation schedule**
- **All of this is picked up by the Financial Module**

FE/NETL CTS-Saline Cost Model

Tables in the Input Sheet develop our Schedule of Activities throughout the project's stages

1. Parameters are consistent across all activities

   ie. Labor rates

2. Activity-Specific Parameters

   ie. Labor hours per activity, activity specific fixed and variable costs

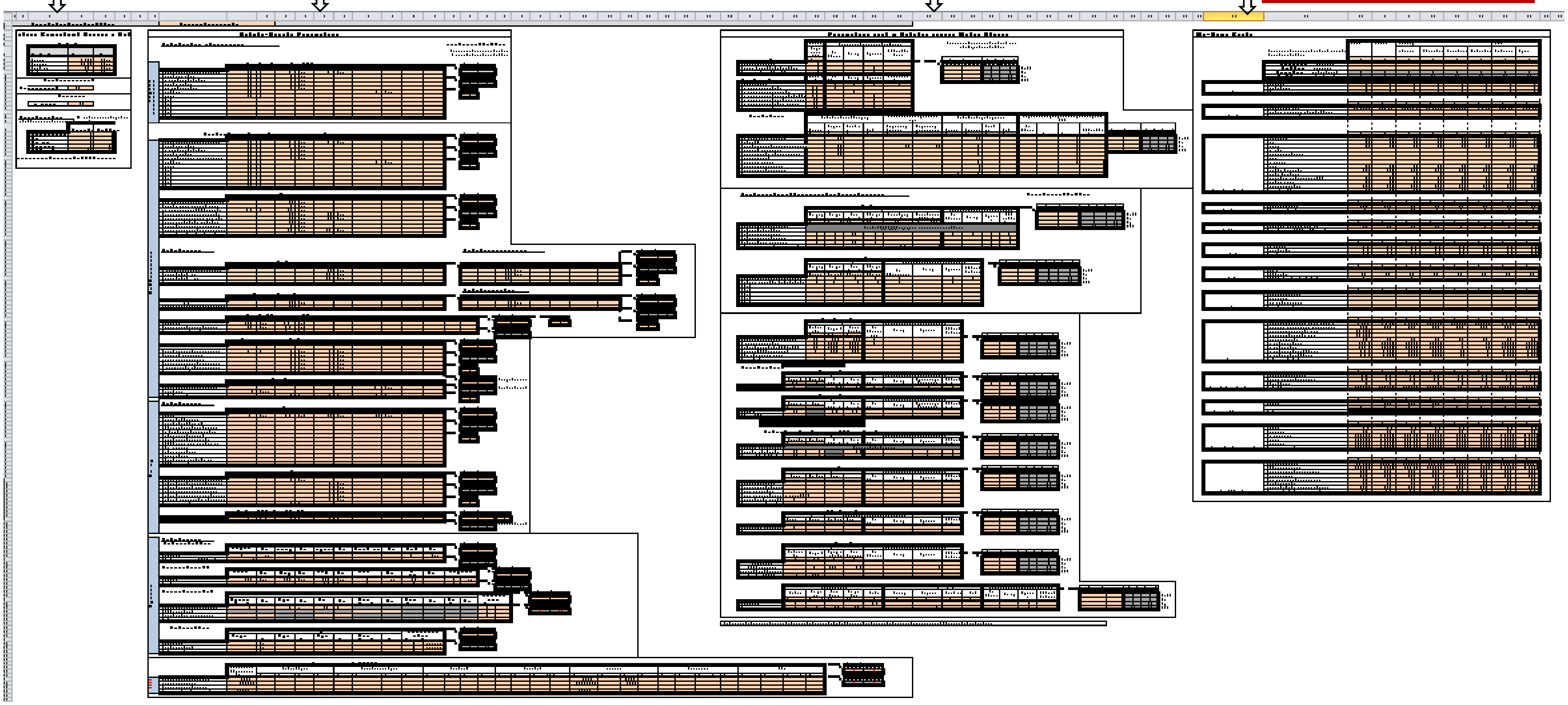
3. Parameters used in Activities across Multiple Stages

   ie. Fluid sampling done before, during and after operations

4. Well Drilling Costs

   ie. Permits, drilling, wireline, core and fluid recovery, equipment, tests, O&M, MIT, etc…

~70 Columns across

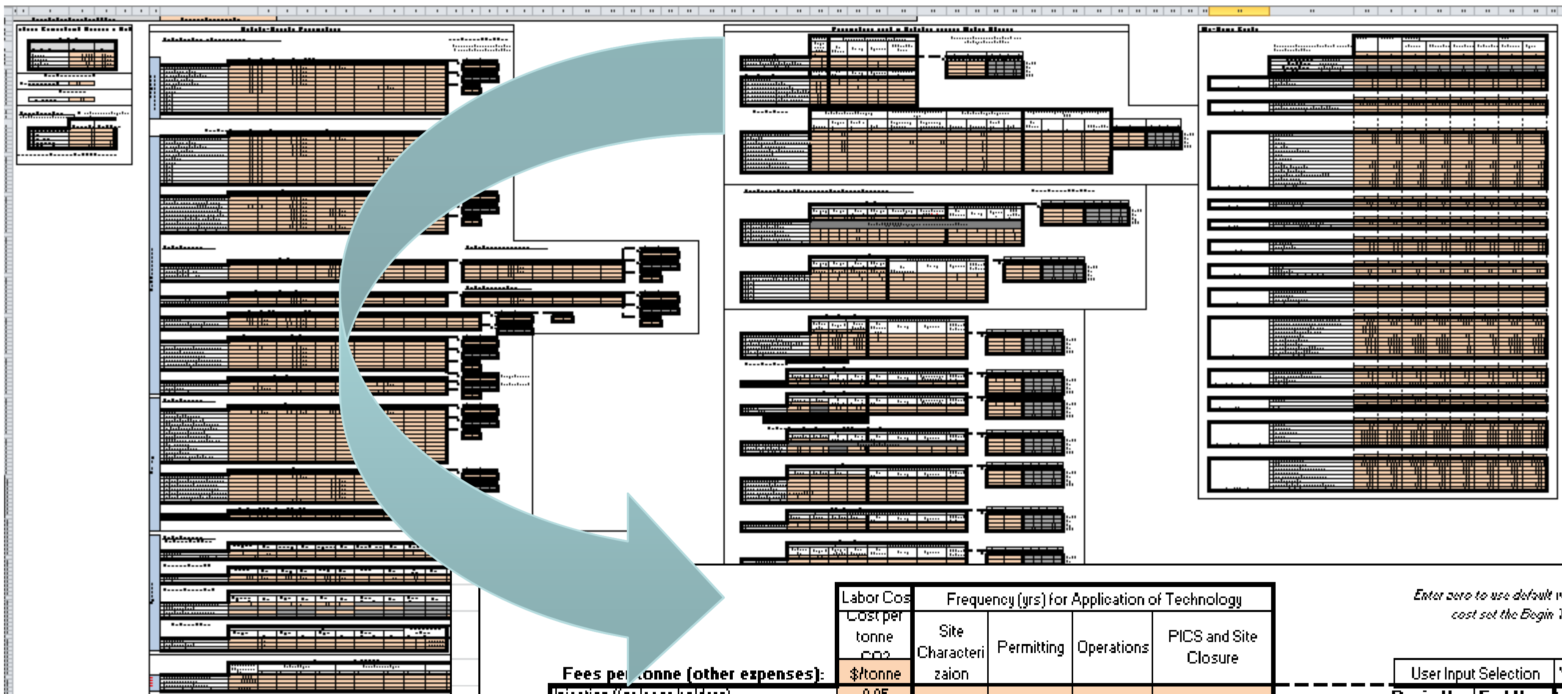


~200 Rows Deep

FE/NETL CTS-Saline Cost Model

Cost database resides in the Activity Cost module

- ***Current cost values are those used by EPA in their economic analysis***
- ***Well costs based on API-JAS 2006 study***
- ***Working on updating cost database***
- ***Model user can enter their own cost data***



	Labor Cos Cost per tonne CO2	Frequency (yrs) for Application of Technology			
Fees per tonne (other expenses):	$/tonne	Site Characterizaion	Permitting	Operations	PICS and Site Closure
Injection (for lease holders)	0.05				
Long-term Stewardship Trust Fund (State)	0.07			1	
Operational Oversight Fund (State)	0.01			1	
Fees, One-Time (other expenses):	One Time Cost	Site Characteri	Permitting	Operations	PICS and Site Closure
Public Outreach		1	1	1	1
Damages for site utilization: Strat Well	10,400.00	1			
Damages for site utilization: Injection Well	10,400.00		1		
Damages for site utilization: Monitoring Wel	10,400.00			1	
Damages for site utilization: Groundwater m	5,200.00			1	
Damages for site utilization: Vadose monito	5,200.00			1	
Damages for site utilization: Surface monito	5,200.00			1	

Enter zero to use default values. For a One-Time cost set the Begin Year=End Year.

User Input Selection		Years that will be used		
Begin Year	**End Year**	**Begin Year**	**End Year**	
0	0	2	4	Site Ch.
0	0	5	5	Permit.
0	0	6	35	Ops.
0	0	36	85	PICS

FE/NETL CTS-Saline Cost Model

Activity Costs are derived from the various management decisions and inputs and are posted in the year(s) that they occur in a separate worksheet in the module.

Activity Cost Schedule Diagram

Activity Cost Schedule Components			Activity Cost Schedule	
First Set of Columns	Second Set of Columns	Third Set of Columns	Fourth Set of Columns	Fifth Set of Columns
Item Name and descriptive information	All Cost information for Item to determine its cost if the Item is selected an activity	Timing information that shows which stage/year(s) the Item is applied/ performed as an activity	The schedule of cost in **real dollars** of the particular item in each row shown in each year it is incurred	The schedule of cost in **escalated dollars** of the particular item in each row shown in each year it is incurred **These Escalated Dollars are fed into the financial module to perform our business case analysis*
8 – 20 Columns	~25 Columns	~10 Columns	200 Columns	200 Columns

Spreadsheet Footprint

FE/NETL CTS-Saline Cost Model

Financial Module:

- **Applies a business scenario against the cost activities to solve for how much money it needs to charge to store a tonne of CO_2 to breakeven**

- **Breakeven means**
  - All project expenses, including financial responsibility are paid for
  - All loans are paid off including interest
  - All taxes are paid
  - The owners receive their required return on capital

FE/NETL CTS-Saline Cost Model

Financial Module Tables:

- **Financial Inputs**
- **Outputs from Activity Module**
- **Escalation and Discounting factors**
- **Financial Responsibility**
  - Table of Funding and Payments
  - Cost of Components of Financial Responsibility
  - Calculations
- **Revenues**
- **Debt**
- **Taxes**
- **Cash Flow Available to Owners**

FE/NETL CTS-Saline Cost Model

Financial Responsibility:

There are 2 types of instruments. The ones we fund and the ones we don't. The latter is cheaper.

Lowest Cost options:

- **Self Insure** – "we're good for it"– Equity makes the payment when due. We do not include unplanned bills in the model.
- **Insure** – We pay someone else a fee to pay for our unplanned expenses if we incur them on top of having Equity pay all of their bills when due.
- **Letter of credit** – We pay a bank something like .15% per year to have access to all the money we'd need to cover something unplanned. If we needed to take money from the bank this would get very expensive because we'd owe them interest on our principal. Equity pays the planned bills when due.

In between:

Surety Bond – either we fund it, or we have a guarantor that basically "Self Insures" it.

Highest cost options:

- **Trust Fund** and **Escrow Accounts** are tied. They both require paying money in upfront. The drivers of how expensive they will be depend on how early the money goes in and how much must go in.
  - The most expensive scenario is to fund 100% of Financial Responsibility in the first year of the project.
  - A lower cost option would be to fund it over the operating period so project revenues could be used rather than equity and debt.

FE/NETL CTS-Saline Cost Model

- **Some caveats and assumptions**
  - This is not a reservoir model, geo-engineering equations are used to estimate parameters that impact costs.
  - Reservoir architecture is defined by porosity, permeability and height.
  - Storage coefficients reflect different depositional facies.
  - Injection rate of CO_2 over life of project is assumed to be constant.
  - Injected CO_2 in reservoir is assumed to roughly occupy the area of a cylinder defined by the height of the reservoir and the radius of the surface area of the plume.
  - Circular area of the plume defines the extent of the Area of Review (AoR).
  - Growth of CO_2 plume is uniform over the operational period.
  - AoR review – data/seismic acquisition, interpretation, report preparation and presentation to EPA occur in same year.
  - Field equipment, field pipelines, initial monitoring wells/corrective action wells and MVA grid constructed and operational/sampled in first year of operations.
  - Monitoring wells are drilled and full year sampling occur in same year.
  - Annual injection rate, time span of stages and costs are applied to all reservoirs comprising the cost supply curve.

FE/NETL CTS-Saline Cost Model

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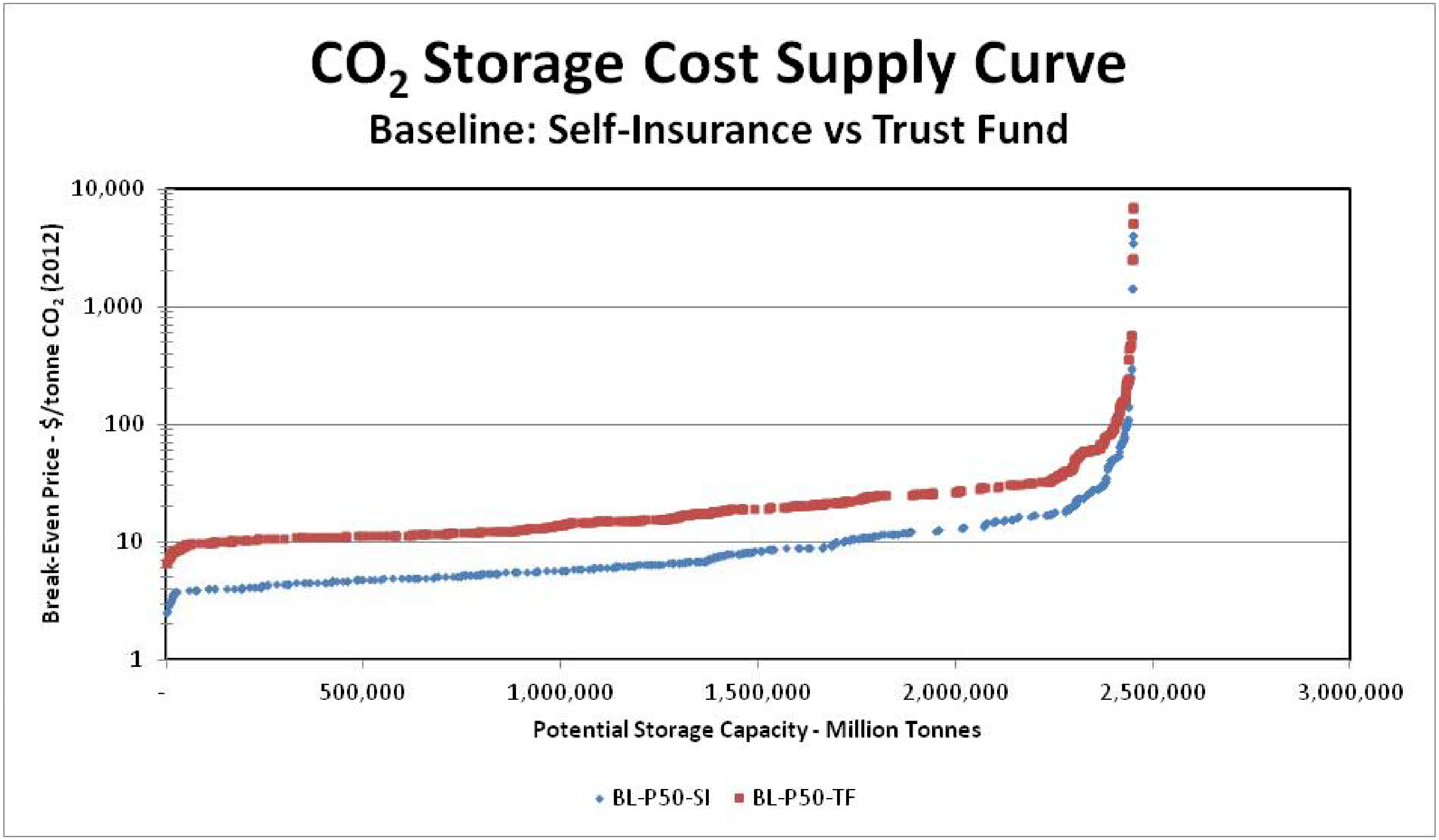
FE/NETL CTS-Saline Cost Model

Saline Test #	P90, 50, 10 Storage Coefficient	Project Stage (years); Modify MVA applied during Operations				Business Model	
		Site Characterization	Permitting	Operations	PISC & Site Closure	Business - Financials	Financial Responsibility
Six Tests	P90	4 sites characterized simultaneously over 3 years: 3 failed sites each with 1 - Strat-well and 2-D. 1 successful site with 2-Strat-wells, 2-D & 3-D Seismic to cover AoR.	2 years	BASELINE SCENARIO 30 years 3-D Seismic, all applications: \$160K/mi^2. Monitor wells to Reservoir 1 per 4 mi^2 & dual completed above seal; 1 per 4 mi^2 above seal. Corrective Action: Assume 1 old well per 4 mi^2 requires CA.	50 years; default time period per §146.93(b)(1) unless alternate timeframe approved.	Debt/Equity = 45%/55%; Debt = 5.5%, IRR = 12%; Escalation = 3%	Self-Insurance or Trust Fund
	P50						
	P10						
28 Tests	P50	As above but site characterization staggared over 6 years and 9 years.	4 years and 6 years	Increase & decrease 3-D seismic cost from baseline	25 years and 10 years	Debt/Equity: 70%/30% and 15%/85%	
				No dual-completions for monitor wells & reduce density of dual-completions for			
				Increase and decrease density of corrective action wells.			

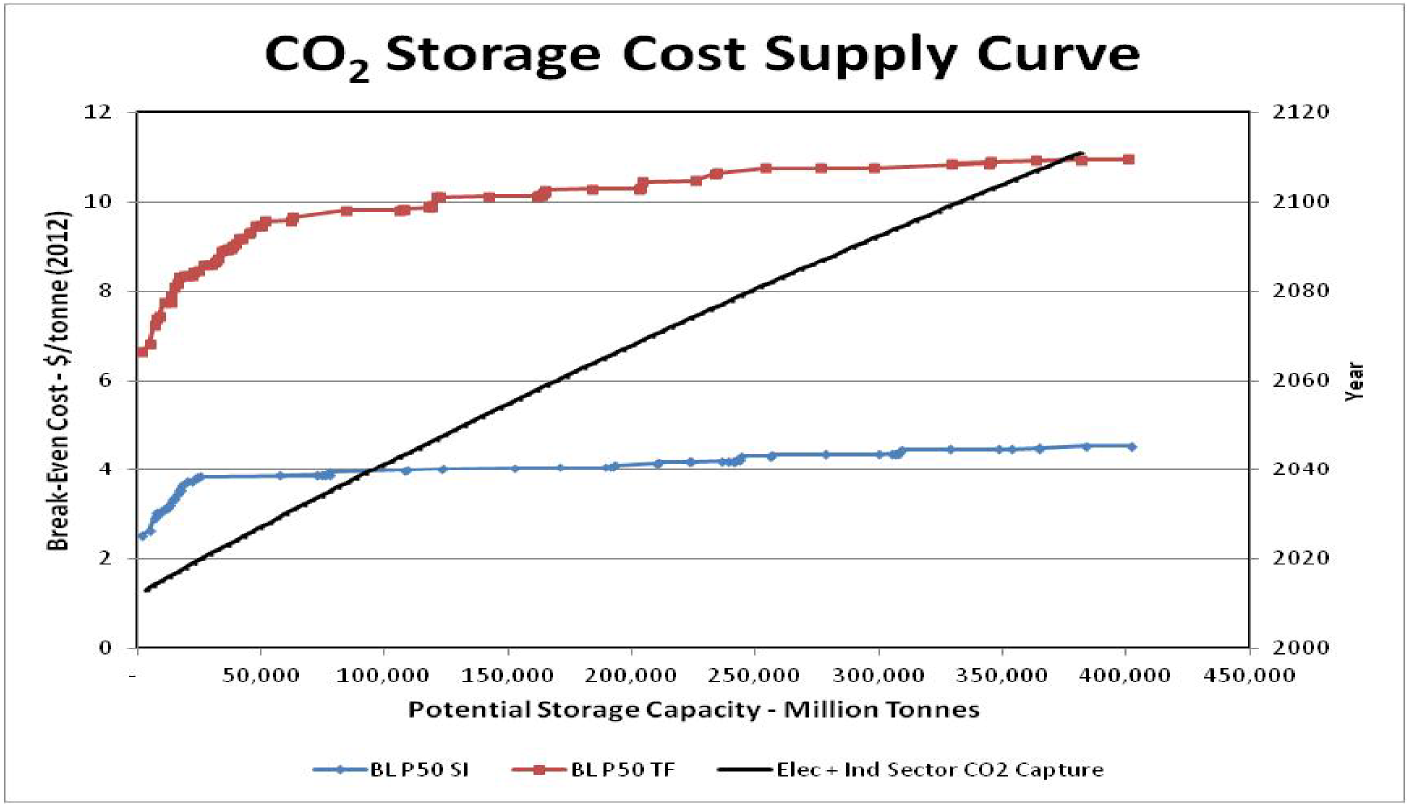
- 34 matrix test runs for the FE/NETL CTS-Saline Cost Model
- Test functional capabilities of model
- Initial analysis of potential major cost drivers: Storage, Time, Technology
- Two model runs for each scenario model for Financial Responsibility (FR): one each for Self-Insurance and Trust Fund

FE/NETL CTS-Saline Cost Model



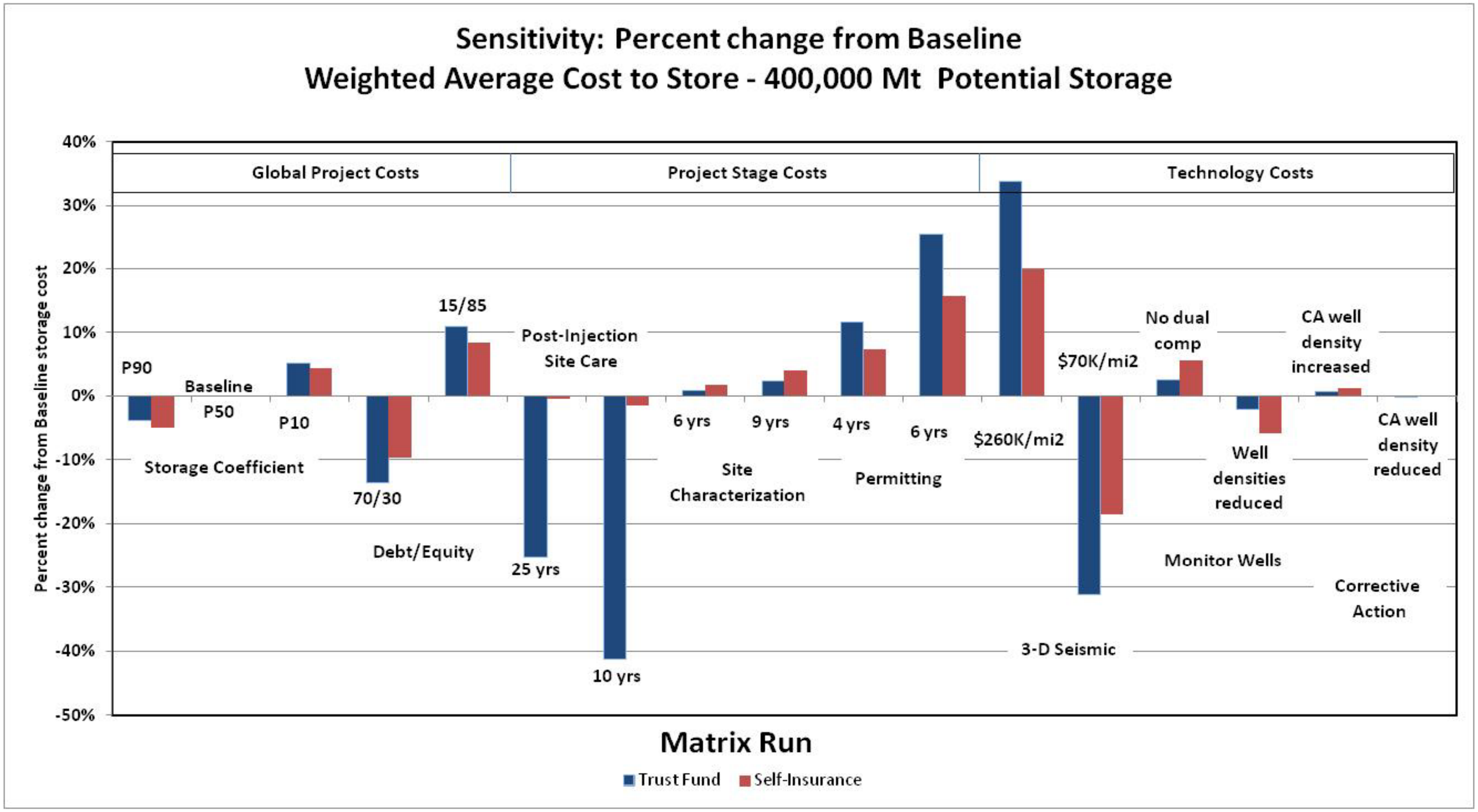
- **Saline storage potential – onshore Lower 48 – 1,123,430 to 13,406,090 Million Tonnes (Atlas 3rd)**
- **Analysis focuses on the low cost end of the cost supply curve**

FE/NETL CTS-Saline Cost Model



- Over next century projected potential for captured emissions less than 400,000 Mt
- Low cost storage: Texas Gulf Coast & East Texas
  Illinois Basin
  Alabama Gulf Coast
  Sacremento Basin
- Frio, Lower Tuscaloosa and Mt. Simon about 90% of storage potential
- Regional trapping provides +/- 85% of storage potential

FE/NETL CTS-Saline Cost Model



- Cost: Global Project, Project Stage, Technology
- Critical time periods: Post-Injection Site Care – directly impacts FR
  Permitting – FR in place but no earnings until injection

FE/NETL CTS-Saline Cost Model

Trust Fund			Self Insurance		
wt. avg. $/tonne	%Δ from baseline	Change from Baseline	Change from Baseline	%Δ from baseline	wt. avg. $/tonne
5.99	**-41.3%**	**PISC = 10 years**	3D seismic = $70,000/mi2	-18.6%	3.38
7.01	-31.2%	3D seismic = $70,000/mi2	D/E = 70%/30%	-9.7%	3.74
7.63	**-25.2%**	**PISC = 25 years**	Monitoring well densities reduced	-5.9%	3.90
8.81	-13.7%	D/E = 70%/30%	P90 Storage Coefficient	-4.9%	3.94
9.81	**-3.8%**	**P90 Storage Coefficient**	PISC = 10 years	-1.5%	4.09
9.99	-2.1%	Monitoring well densities reduced	PISC = 25 years	-0.4%	4.13
10.20	**0.0%**	**Corrective action well density decrease**	Corrective action well density decreased	-0.1%	4.14
10.20	0.0%	P50 Baseline	P50 Baseline	0.0%	4.15
10.27	**0.7%**	**Corrective action well density increase**	Corrective action well density increased:	1.2%	4.20
10.29	0.9%	Site Characterization = 6 years	Site Characterization = 6 years	1.7%	4.22
10.45	**2.4%**	**Site Characterization = 9 years**	Site Characterization = 9 years	4.1%	4.32
10.46	2.6%	No dual completion wells	P10 Storage Coefficient	4.4%	4.33
10.74	**5.3%**	**P10 Storage Coefficient**	No dual completion wells	5.7%	4.39
11.33	11.0%	D/E = 15%/85%	Permitting = 4 years	7.4%	4.45
11.39	**11.7%**	**Permitting = 4 years**	D/E = 15%/85%	8.5%	4.50
12.79	25.3%	Permitting = 6 years	Permitting = 6 years	15.7%	4.80
13.65	**33.8%**	**3D seismic = $260,000/mi2**	3D seismic = $260,000/mi2	19.8%	4.97

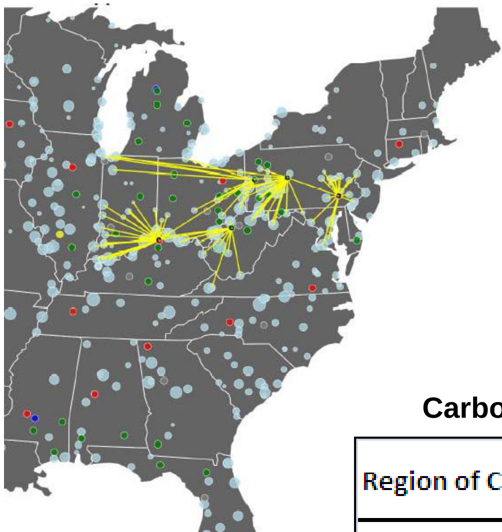
NETL-CTUS Model

<table>
<tr><th>Combined Test #</th><th>Scenario</th><th>Financial Responsibility</th><th>Geology/Geography</th><th>Source - Sink</th><th>Pipeline Configuration</th><th>Comments/Notes</th></tr>
<tr><td>35</td><td rowspan="4">MR-2 P-50 Saline Basecase</td><td rowspan="4">Self-Insurance</td><td rowspan="2">Intra-Basin: Appalachian</td><td rowspan="4">Multiple Sources; Multiple Sinks</td><td>Dedicated Pipelines</td><td rowspan="2">Compare costs: between dedicated and network pipeline configurations.</td></tr>
<tr><td>36</td><td>Network (Trunkline(s))</td></tr>
<tr><td>37</td><td>Inter-Basin: Appalachian sources to Gulf Coast Sinks</td><td rowspan="2">Network (Trunkline(s))</td><td>Compare Inter-regional costs versus Intra-regional costs.</td></tr>
<tr><td>38</td><td>National - Lower 48</td><td>Compare Lower-48 versus Inter-regional costs.</td></tr>
</table>

FE/NETL CTUS Model

- **Modeled period 2012 - 2040**
- **Plant locations and pipeline nodes in database**
  - Capture via retro-fits, no new plants
- **Incorporate geologic data from FE/NETL CTS-Saline Cost Model**
  - Utilize lat/long centroids for storage
- **Aggregate costs from FE/NETL CTS-Saline Cost Model**
- **Self-Insurance only Financial Responsibility selection at moment**
- **MR-2 baseline scenario basis for FE/NETL CTUS Model matrix test runs**

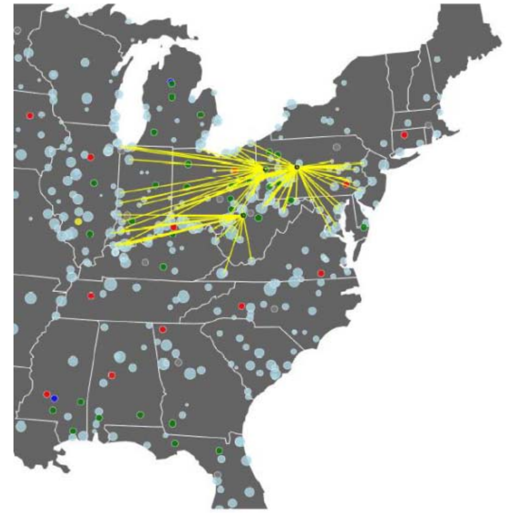
NETL-CTUS Model



Appalachian Dedicated
& Pipeline Network

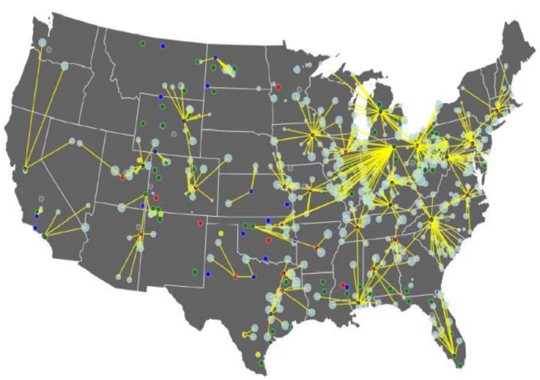
Carbon Capture Utilization and Storage

Region of Capture/Storage		CCUS $/tonne	Storage Sites
Appalachian Dedicated		56.07	3
Appalachian Network		54.46	3
Appalachian-Gulf	Appalachian	49.89	1
	Gulf	51.26	1
National		49.77	22

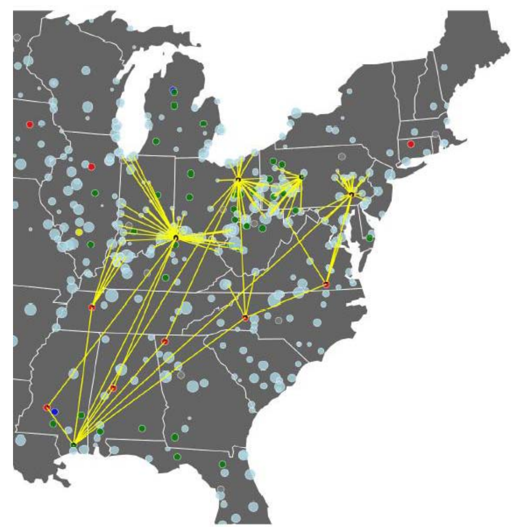


Appalachian Dedicated
Pipelines

NETL CTUS GeoViewer - National 2040



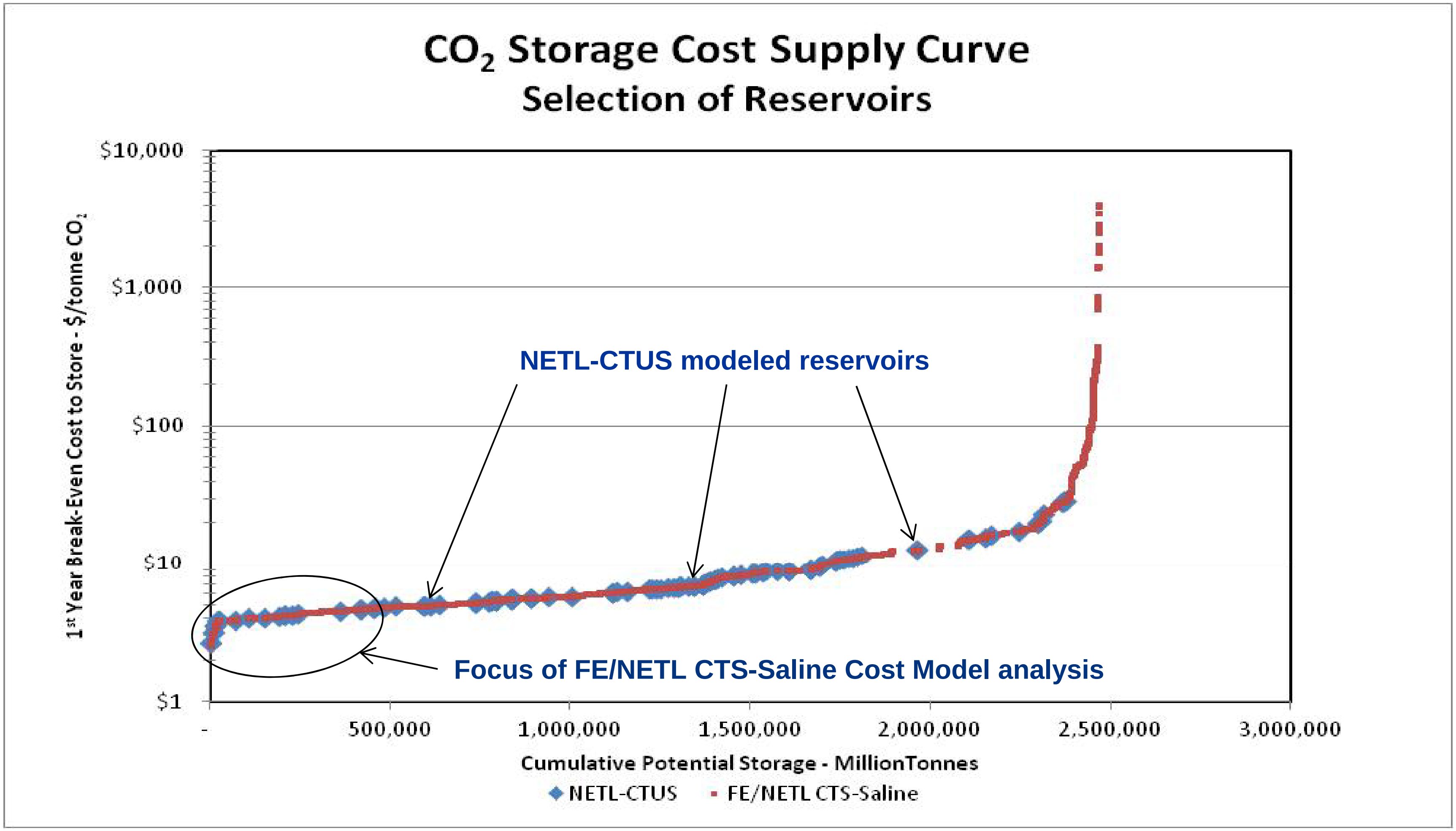
National network delivers lower costs.



Appalachian –Gulf Coast
Pipeline Network

Preliminary modeling cost values subject to change with further modeling.

FE/NETL CTS-Saline Cost Model



- **CTUS reservoirs for national network plotted on CTS Storage Cost Supply Curve.**
- **The low cost reservoir may not be the best fit for source and transportation.**
- **Location, location, location.**

FE/NETL CTS-Saline Cost Model

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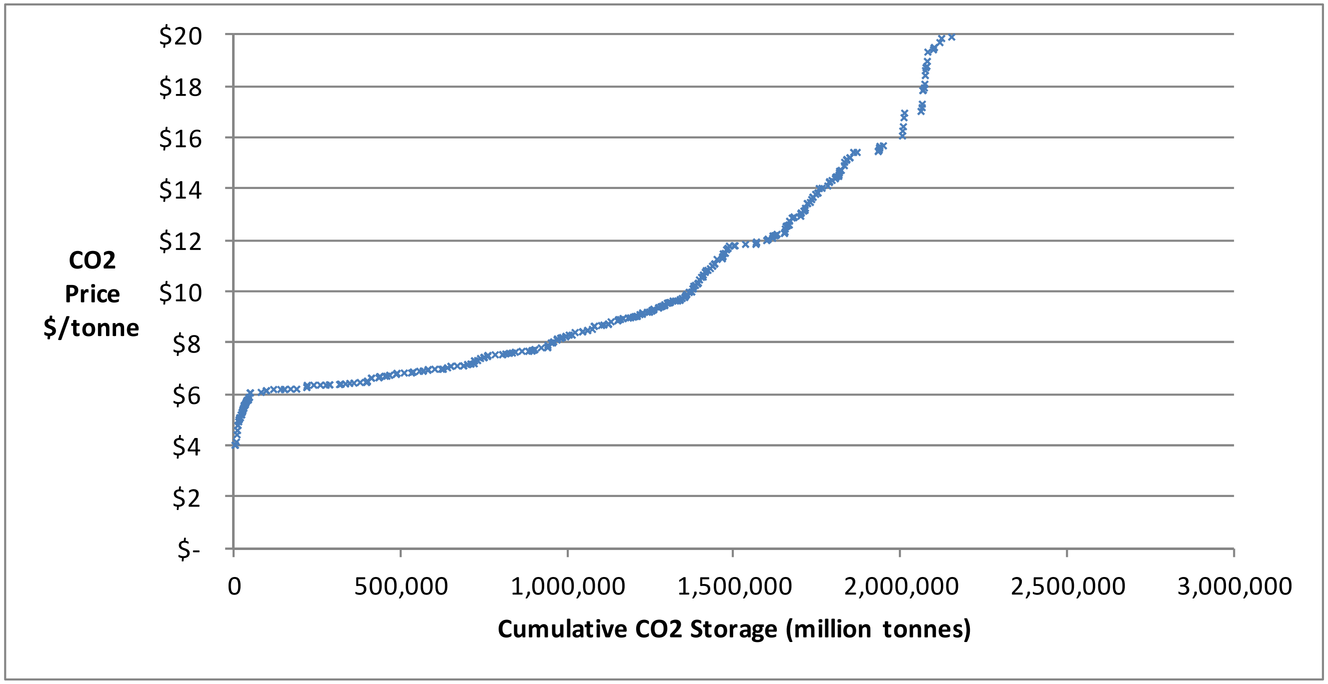
Approach to Benefits Analysis

- **Baseline Case**
  - Estimate cost of CO_2 storage in saline aquifer in absence of NETL R&D
- **R&D Case**
  - Review R&D projects in Carbon Storage Program to determine how R&D can influence costs
  - Develop scenarios reflecting influence of R&D on CO_2 storage and estimate cost of CO_2 storage assuming R&D is successful
- **Difference in costs between Baseline Case and scenarios in R&D Case is measure of benefit**

Baseline Cost-Supply Curve

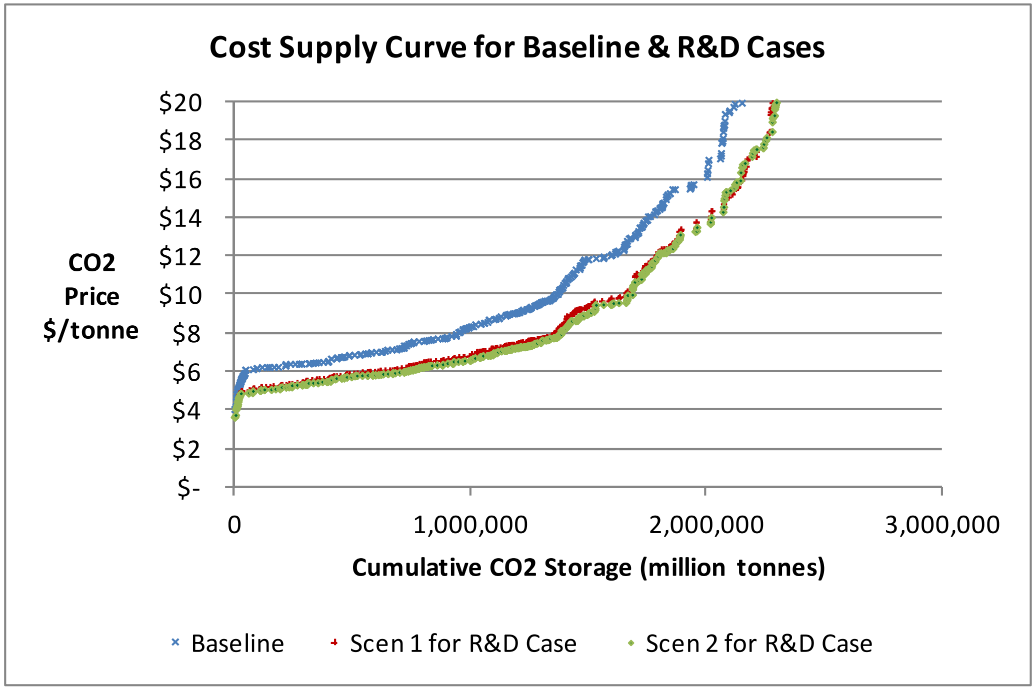


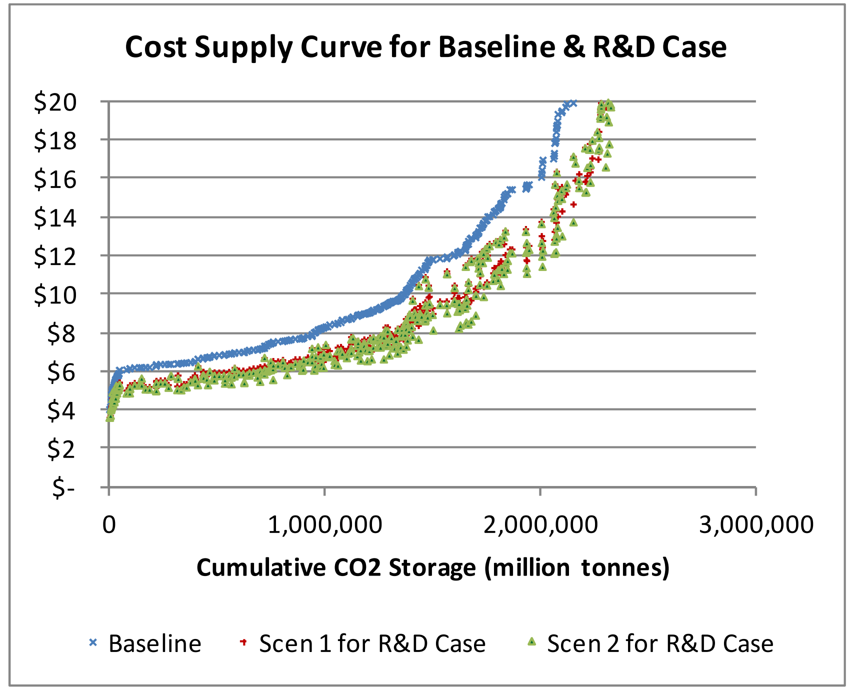
- **Cost drivers (percent of total capital and O&M costs in 2012 dollars):**
  - Strat-wells: about 10% of total costs
  - Injection wells: about 20% of total costs
  - Deep monitoring wells: about 20% of total costs
  - 3-D seismic: about 30% of total costs
  - Other: about 20% of total costs

Scenarios for R&D Case

- **Scenario 1**
  - Improved processing of seismic data thru lab tests and better software allows lower 3-D seismic intensity
  - Improved systems for integrating geology, monitoring data, reservoir modeling allows fewer deep monitoring wells
  - Better risk management allows lower insurance premium for emergency and remedial response (ERR)
- **Scenario 2**
  - Improved processing of seismic data thru lab tests and better software allows substitution of 2-D seismic for 3-D seismic
  - Improved systems for integrating geology, monitoring data, reservoir modeling allows same density of deep monitoring wells; partially compensates for 2-D seismic
  - Better risk management allows lower insurance premium for ERR

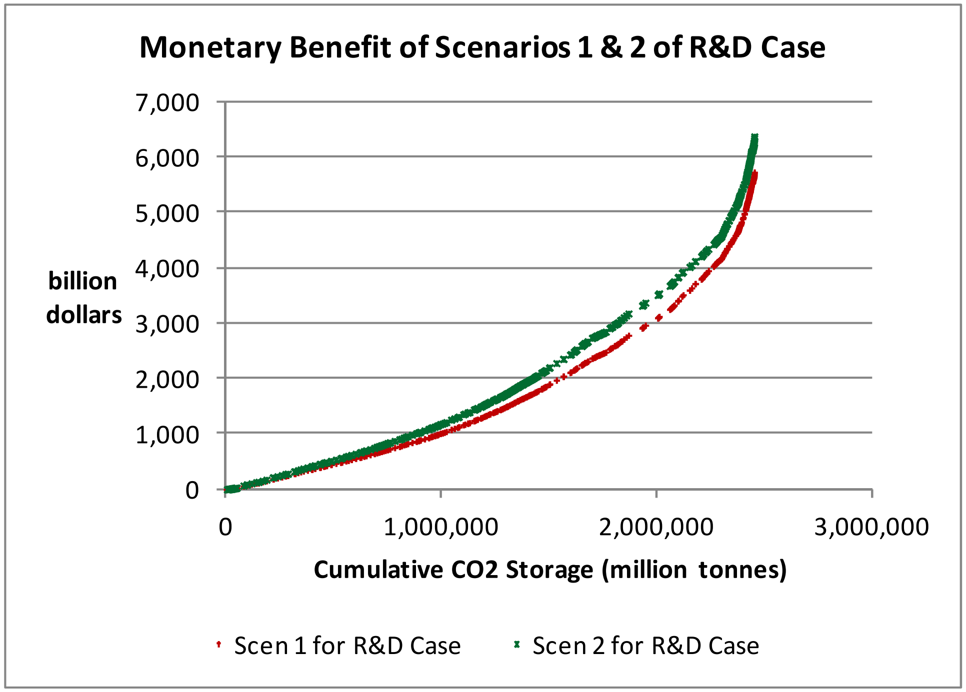
Cost-Supply Curves for R&D Case

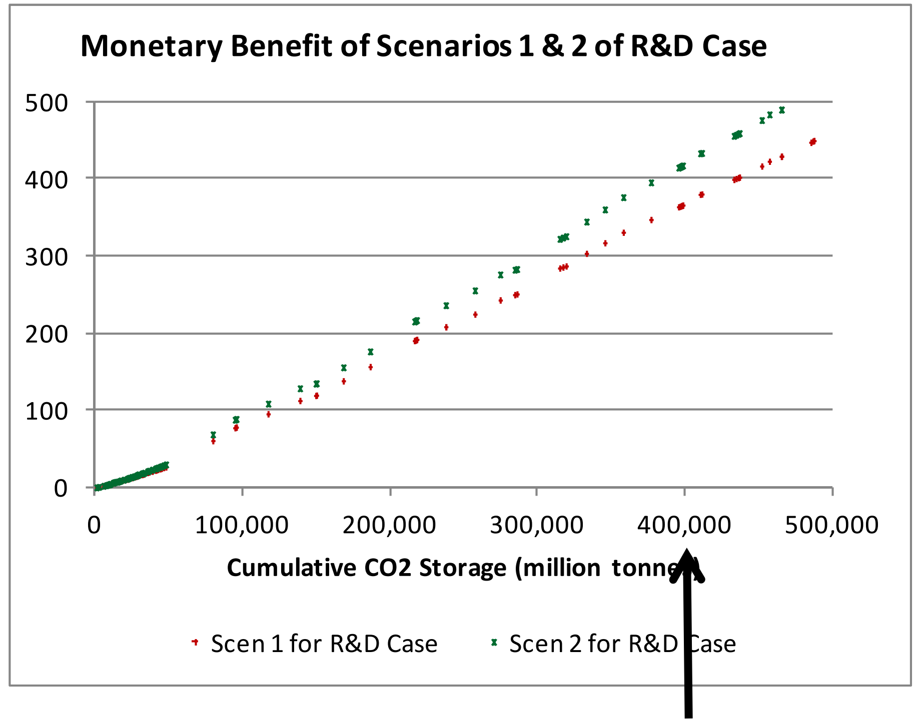




- **Costs reduced 10 to 17%**
- **These results are for illustrative purposes!**

Monetized Benefit of R&D





- **90% of CO_2 emissions from electric power generation and industrial sources for next 100 years: 400,000 million tonnes**
- **Benefit could be tens of billions of dollars depending on:**
  - Number of CO_2 storage projects implemented
  - When CO_2 storage sites begin development
  - Where CO_2 storage projects are implemented

Next Steps in Benefits Evaluation (FY2013)

- **Continue to map R&D projects to technologies (activities) in FE/NETL CTS-Saline Cost Model**
- **Add technologies (activities) to FE/NETL CTS-Saline Cost Model, as necessary**
- **Work with NETL project managers and Principal Investigators to**
  - Estimate possible impact of R&D projects on costs
  - Improve cost estimates for technologies (activities)

FE/NETL CTS-Saline Cost Model

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Concluding comments:

- Purpose of FE/NETL CTS-Saline Cost Model is to understand the composition of costs that impact CO_2 sequestration operations.
- Initial use of FE/NETL CTS-Saline Cost Model met general expectations – changes in parameters provide cost changes moving in the right direction.
- Purpose of NETL-CTUS Model is to understand cost and policy impacts on national CCUS networks.
- Fair agreement on reservoirs between time static FE/NETL CTS-Saline Cost Model and time dynamic FE/NETL-CTUS Model.
- Both recognize importance of common key formations for storage potential.
- FE/NETL-CTUS can select higher cost basins with less storage potential for local sources with lower emissions.
- Further work to refine models and examine CCS scenarios with respect to reservoirs, transportation distance, MVA technologies and financial responsibility instruments.

FE/NETL CTS-Saline Cost Model

Acknowledgements

NETL Strategic Center for Coal:

Sean Plasynski – Director Office of Coal & Power R&D
John Litynski – Technology Manager – Carbon Storage
John Wimer – Director Office of Program Planning & Analysis (OPPA)
Chuck Zelek – Director Benefits Division OPPA

Contractors (ESPA):

Booz Allen Hamilton
Advanced Resources International

FE/NETL CTS-Saline Cost Model

Questions?