
New Options in the IECM Power Plant Simulation Model

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Presentation to the DOE/NETL

CO₂ Capture Technology Meeting
Pittsburgh, Pennsylvania

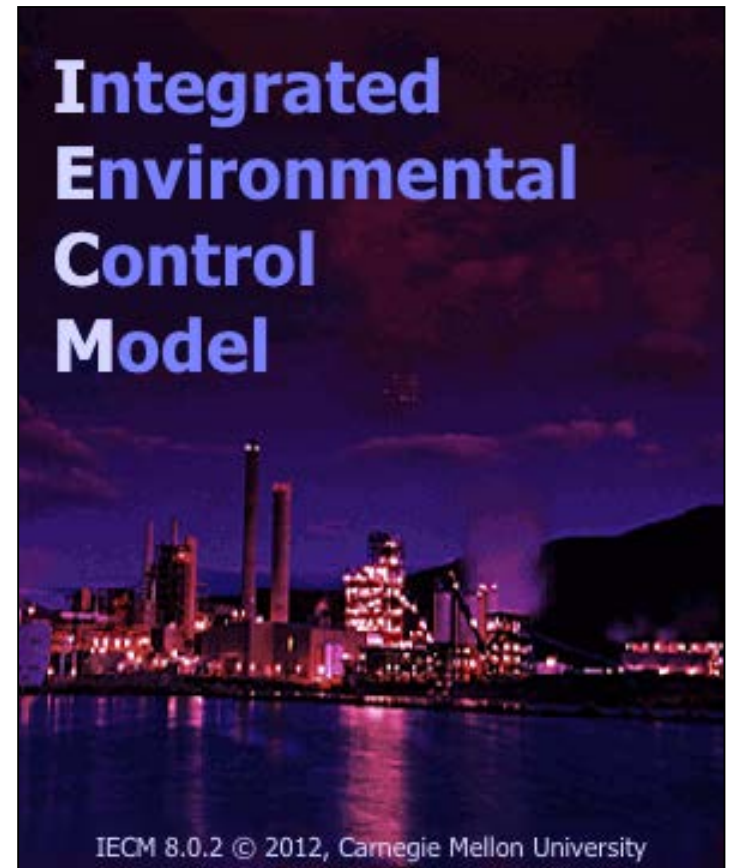
June 23, 2015

Outline of Talk

- Overview of the IECM
- Recent developments
- Future developments

IECM: A Tool for Analyzing Power Plant Design Options

- A versatile computer simulation model developed for DOE/NETL (runs quickly on a laptop or desktop)
- Provides systematic estimates of performance, emissions, costs and uncertainties for preliminary design of:
 - PC, IGCC and NGCC plants
 - All flue/fuel gas treatment systems
 - CO₂ capture and storage options (pre- and post-combustion, oxy-combustion; transport, storage)
- Free and publicly available at:
www.iecm-online.com



IECM Modeling Approach

- Systems Analysis Approach
- Process Performance Models
- Engineering Economic Models
- Advanced Software Capabilities
 - Probabilistic analysis capability
 - User-friendly graphical interface
 - Versatile input/output features

IECM Software Package

Fuel Properties

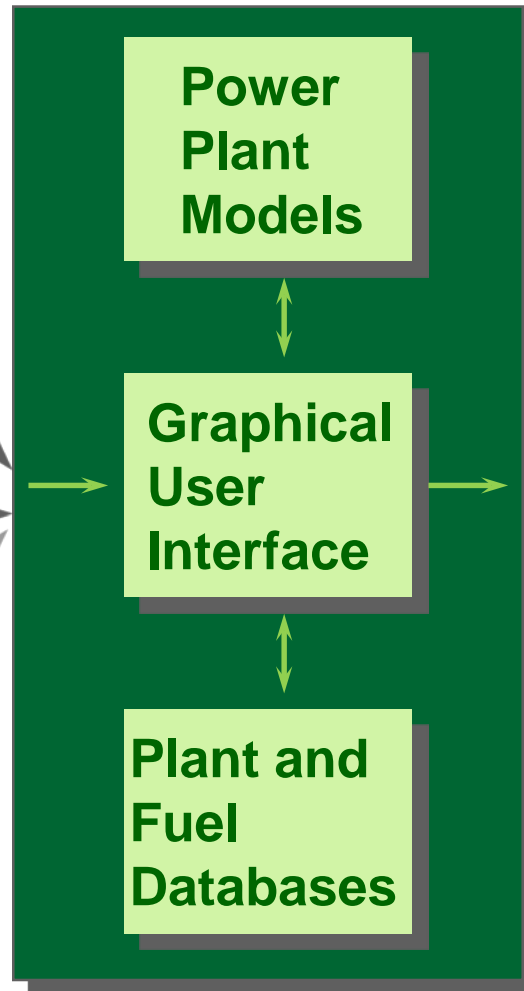
- Heating Value
- Composition
- Delivered Cost

Plant Design

- Conversion Process
- Emission Controls
- Solid Waste Mgmt
- Chemical Inputs

Cost Factors

- O&M Costs
- Capital Costs
- Financial Factors



Plant & Process Performance

- Efficiency
- Resource use

Environmental Emissions

- Air, water, land

Plant & Process Costs

- Capital
- O&M
- COE

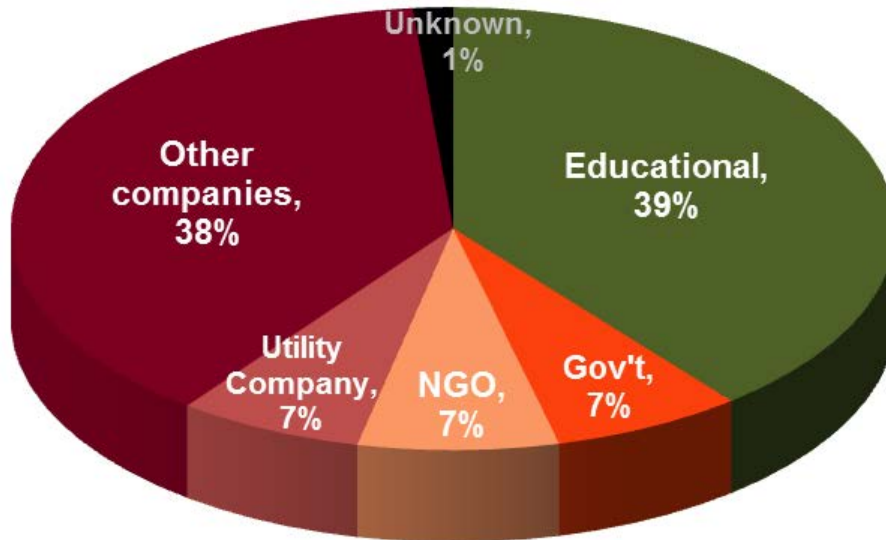
Inputs and results can be either deterministic or probabilistic

Technologies in IECM v.8.0.2

CO ₂ Capture & Storage Systems*	Coal Combustion Plants		Gasification Plants (IGCC)	IGCC and NGCC Plants
<p><u>Post-Combustion Capture</u> Conv. Amine; Adv. amines (FG+); Chilled ammonia; Membrane systems; Aux. NG steam or power gen. (optional)</p> <p><u>Oxy-Combustion Capture</u> Flue gas recycle; ASU; Chemical processing units</p> <p><u>Pre-Combustion Capture</u> Water gas shift + Selexol Chemical looping</p> <p><u>CO₂ Compressor</u></p> <p><u>CO₂ Transport</u> Pipelines (6 U.S. regions); Other (user-specified)</p> <p><u>CO₂ Storage</u> Deep saline formation; Geol.Storage w/ EOR; Other (user-specified)</p>	<p><u>Boiler/Turbine Systems</u> Subcritical; Supercritical; Ultra-supercritical</p> <p><u>Furnace Firing</u> Tangential; Wall; Cyclone</p> <p><u>Furnace NOx Control</u> LNB; SNCR; SNCR+LNB; Gas reburn</p> <p><u>Flue Gas NOx Removal</u> Hot-side SCR</p> <p><u>Mercury Removal</u> Carbon/sorbent injection</p>	<p><u>Particulate Removal</u> Cold-side ESP; Fabric filter (Reverse air; Pulse jet)</p> <p><u>SO₂ Removal</u> Wet limestone (Conv.; F. oxidation; Additives); Wet lime; Lime spray dry</p> <p><u>Solids Management</u> Ash pond; Landfill; Co-mixing; useful byproducts</p> <p><u>Cooling and Wastewater Systems</u> Once-thru cooling; Wet cooling tower; Dry cooling; Chemical treatment; Mech. treatment</p>	<p><u>Air Separation Unit</u> Cryogenic</p> <p><u>Slurry Preparation & Coal Pretreatment</u></p> <p><u>Gasification</u> Slurry-fed gasifier (GE-Q); Dry-fed gasifier (Shell)</p> <p><u>Syngas Cooling and Particulate Removal</u></p> <p><u>Mercury Removal</u> Activated carbon</p> <p><u>H₂S Removal</u> Selexol; Sulfinol</p> <p><u>Sulfur Recovery</u> Claus plant; Beavon-Stretford unit</p>	<p><u>Gas Turbine</u> GE 7FA; GE 7FB</p> <p><u>Heat Recovery Steam Generator</u></p> <p><u>Steam Turbine</u></p> <p><u>Boiler Feedwater System</u></p> <p><u>Process Condensate Treatment</u></p> <p><u>Cooling Water System</u> Once-through; Wet cooling tower; Dry cooling</p> <p><u>Aux. Equipment</u></p>

IECM Users and Uses

- ~ 2000 Individuals
- ~ 600 Organizations
- ~ 60 Countries



Based on number of unique organizations in each category
(as of March 24, 2015)

IECM IS USED FOR:

- Process design
- Technology evaluation
- Cost estimation
- R&D management
- Risk analysis
- Environmental compliance
- Marketing studies
- Strategic planning
- Teaching/Education



Recent Developments

New IECM Options and Features (v.9.0 beta)

NEW SOFTWARE FEATURES

- A new collapsible menu for navigation (instead of "tabs")
- A "Configure Session" menu, including unit conversion options
- An "Analysis Tools" menu with cool new analytical options
- Addition of process flow diagrams to Set Parameters screens
- Adjustments to GUI screens for better readability and consistency

New Interface: Set Parameters

*New Interface Screens_PC Plant [IECM Interface 9.0.1 Beta]

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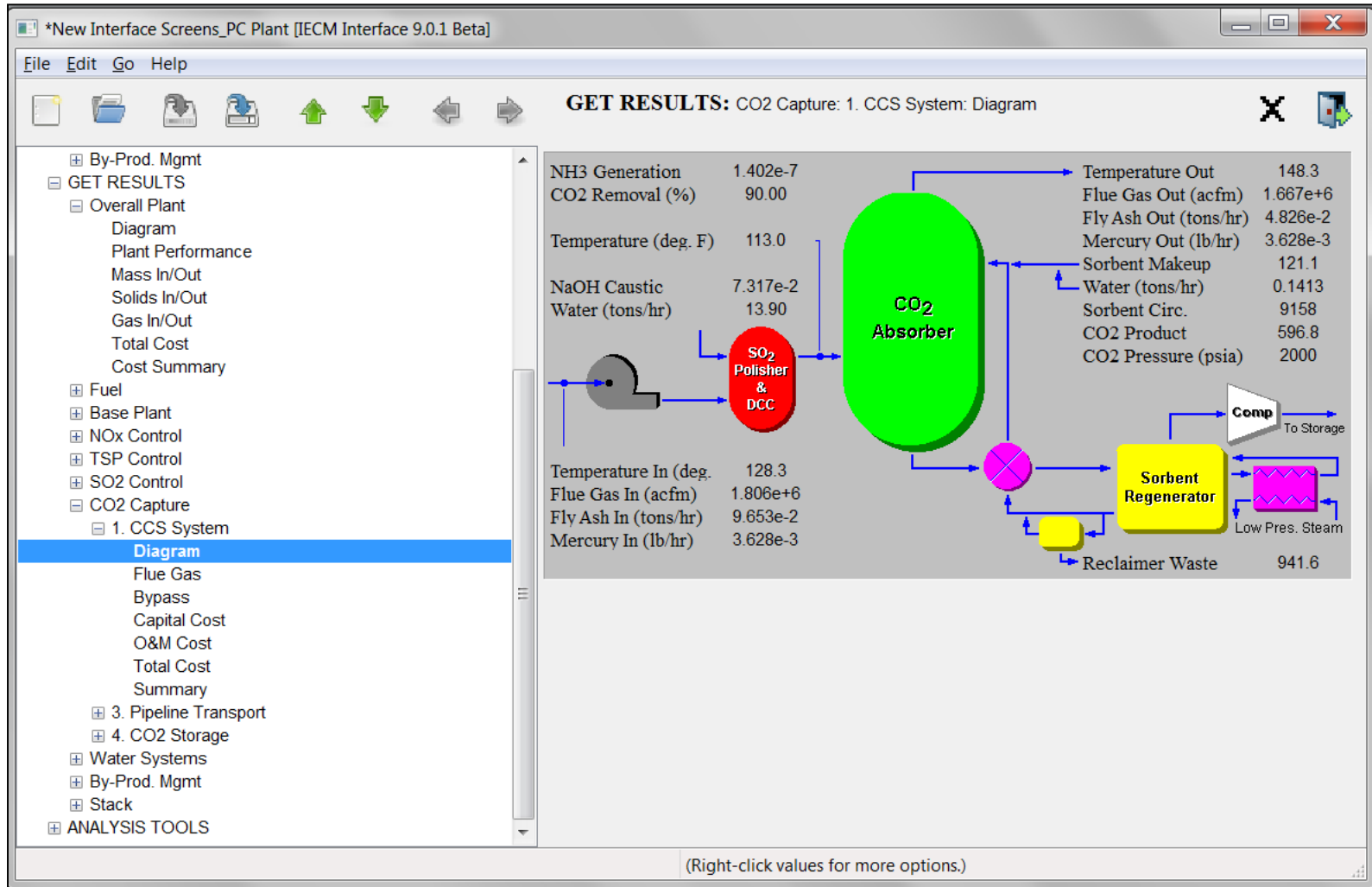
SET PARAMETERS: CO2 Capture: 1. CCS System: Capture

- New Interface Screens_PC Plant
 - CONFIGURE SESSION
 - Plant Design
 - Unit Systems
 - SET PARAMETERS
 - Overall Plant
 - Fuel
 - Base Plant
 - NOx Control
 - TSP Control
 - SO2 Control
 - CO2 Capture
 - 1. CCS System
 - Amine System Diagram
 - Config
 - Performance
 - Capture**
 - T&S Config
 - Capital Cost
 - O&M Cost
 - Retrofit Factors
 - 3. Pipeline Transport
 - 4. CO2 Storage
 - Water Systems
 - By-Prod. Mgmt
 - GET RESULTS
 - ANALYSIS TOOLS

Title	Unc	Value	Calc	Min	Max	Default
<u>Absorber</u>						
Sorbent Concentration (wt %)	<input type="checkbox"/>	30.00	<input checked="" type="checkbox"/>	15.00	40.00	Calc
Lean CO2 Loading (mol CO2/mol sorb)	<input type="checkbox"/>	0.1900	<input checked="" type="checkbox"/>	0.0	0.3000	Calc
Sorbent Losses (excluding acid gasses) (lb/...	<input type="checkbox"/>	0.6002	<input checked="" type="checkbox"/>	0.0	10.00	Calc
Sorbent Recovered (lb/ton CO2)	<input type="checkbox"/>	0.3970	<input checked="" type="checkbox"/>	0.0	10.00	Calc
Liquid-to-Gas Ratio (ratio)	<input type="checkbox"/>	3.090	<input checked="" type="checkbox"/>	0.0	10.00	Calc
Ammonia Generation (mol NH3/mol sorb)	<input type="checkbox"/>	1.000	<input checked="" type="checkbox"/>	0.0	2.000	Calc
Gas Phase Pressure Drop (psia)	<input type="checkbox"/>	1.000	<input checked="" type="checkbox"/>	0.0	5.000	Calc
ID Fan Efficiency (%)	<input type="checkbox"/>	75.00		50.00	100.0	75.00
Makeup Water for Wash Section (% raw flue...	<input type="checkbox"/>	0.8000		0.0	10.00	0.8000
<u>Regenerator</u>						
Regenerator Heat Requirement (Btu/lb CO2)	<input type="checkbox"/>	1519	<input checked="" type="checkbox"/>	500.0	5000	Calc
Regenerator Steam Heat Content (Btu/lb ste...	<input type="checkbox"/>	1373	<input checked="" type="checkbox"/>	500.0	1500	Calc
Heat-to-Electricity Efficiency (%)	<input type="checkbox"/>	18.70	<input checked="" type="checkbox"/>	0.0	40.00	Calc
Solvent Pumping Head (psia)	<input type="checkbox"/>	30.00		0.0	80.00	30.00
Pump Efficiency (%)	<input type="checkbox"/>	75.00		50.00	100.0	75.00
Percent Solids in Reclaimer Waste (%)	<input type="checkbox"/>	40.00	<input checked="" type="checkbox"/>	0.0	100.0	Calc
Capture System Cooling Duty (t H2O/t CO2)	<input type="checkbox"/>	90.87	<input checked="" type="checkbox"/>	0.0	200.0	Calc

(Right-click values for more options.)

New Interface: Get Results (*diagram*)



New Interface: Get Results (*table*)

GET RESULTS: Overall Plant: Cost Summary

	A	B	C	D	E
1	Technology	Capital Required (M\$)	Capital Required (\$/kW-net)	Revenue Required (M\$/yr)	Revenue Required (\$/MWh)
2	Combustion NOx Control	9.429	17.84	1.205	0.3468
3	Post-Combustion NOx Control	33.99	64.32	7.012	2.018
4	Mercury Control	0.0	0.0	0.0	0.0
5	TSP Control	26.61	50.36	5.861	1.687
6	SO2 Control	170.1	321.9	41.60	11.97
7	Combined SOx/NOx Control	0.0	0.0	0.0	0.0
8	CO2 Control	537.2	1016	114.2	32.86
9	Subtotal	777.4	1471	169.9	48.89
10	Cooling Tower	79.86	151.1	21.33	6.139
11	Wastewater Control	0.0	0.0	0.0	0.0
12	Base Plant	1006	1903	178.8	51.45
13	Emission Taxes	0.0	0.0	0.0	0.0
14	Total	1863	3525	370.0	106.5
15					
16					

(Right-click values for more options.)

New Interface: Analysis Tools (*sensitivity*)

*New Interface Screens_PC Plant [IECM Interface 9.0.1 Beta]

File Edit Go Help

ANALYSIS TOOLS: Sensitivity Analysis: Choose Dependent Variable(s)

Please select dependent variable(s) below:
(Variables that are not affected by the independent variable are not included in this list.)

- Base Plant Revenue Required (\$/MWh)
- Total Capital Required (M\$)
- Total Capital Required (\$/kW-net)
- Total Revenue Required (M\$/yr)
- Total Revenue Required (\$/MWh)

Copy Table to Clipboard

Copy Detailed Graph to Clipboard

Show Detailed Graph

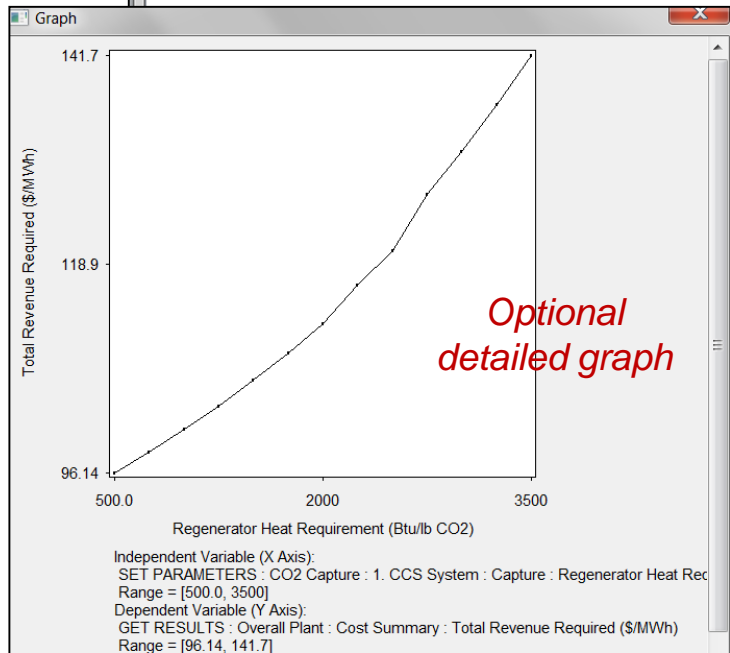
Summary:

Independent Variable (X Axis):
SET PARAMETERS : CO2 Capture : 1. CCS System : Capture : Regenerator Heat Requirement (Btu/lb CO2)
Range = [500.0, 3500]

Dependent Variable (Y Axis):

	Independent Variable (X Axis)	Dependent Variable (Y Axis)
1	500.0	96.14
2	750.0	98.47
3	1000	100.9
4	1250	103.5
5	1500	106.3
6	1750	109.2
7	2000	112.4
8	2250	116.6
9	2500	120.4

(Right-click values for more options.)



New IECM Options and Features (v.9.0 beta)

NEW TECHNOLOGY OPTIONS

For PC Plants:

- Calcium looping system model for post-combustion CO₂ capture
- Enhanced oxy-combustion system performance and cost models

For IGCC Plants:

- Updated chemical looping system cost model for pre-combustion capture
- Ability to specify custom fuels and syngas composition for IGCC plants
- Updated direct capital cost default values for IGCC plants

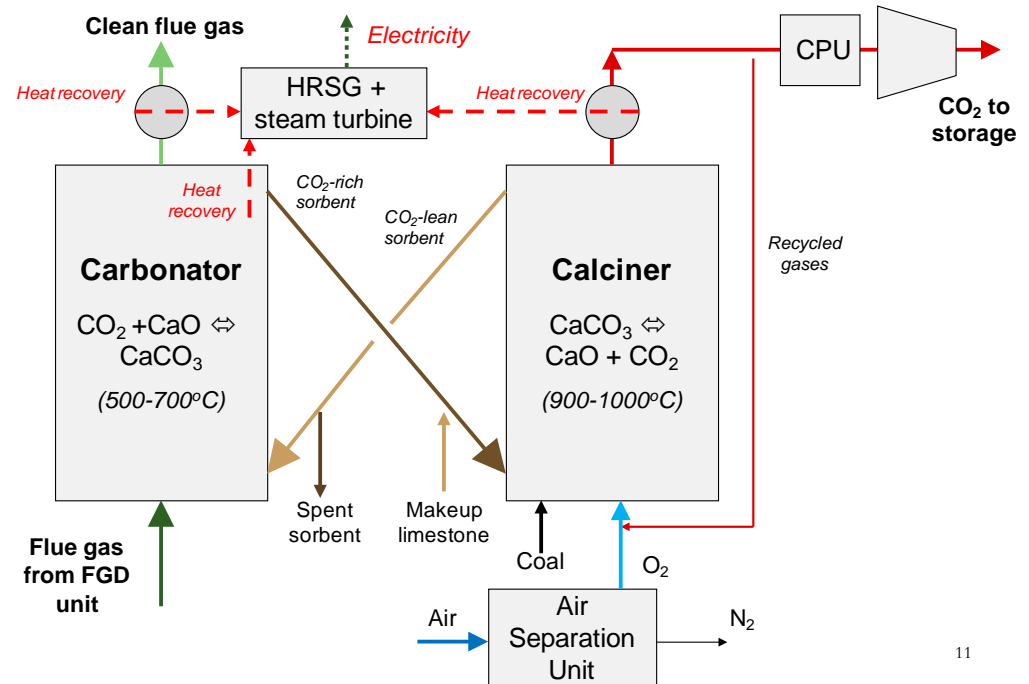
For All Plant Types:

- Updated process and project contingency cost factor default values (based on current level of maturity and cost estimating basis)
- Site-specific CO₂ storage cost model and geological reservoir database

Post-Combustion CaL Process Model



Calcium looping pilot plant at La Pereda coal-fired station, Asturias, Spain (March 2015)



Post-Combustion CaL Process Model

SET PARAMETERS: CO2 Capture: 1. Chemical Looping: Carbonator

Title	Unc	Value	Calc	Min	Max	Default
Carbonator Temperature (deg. C)	<input type="checkbox"/>	650.0		600.0	700.0	650.0
Degree of Carbonation (fraction)	<input type="checkbox"/>	0.8000		0.0	1.000	0.8000
Makeup Limestone/Recirculating Sorbent (mol/mol)	<input type="checkbox"/>	2.500e-2		1.000e-2	1.000	2.500e-2
Maximum CaO Conversion (fraction)	<input type="checkbox"/>	0.2083	<input checked="" type="checkbox"/>	0.0	1.000	Calc
Actual CaO Conversion (fraction)	<input type="checkbox"/>	0.1683	<input checked="" type="checkbox"/>	0.0	1.000	Calc
Residence Time of Solids (seconds)	<input type="checkbox"/>	267.1	<input checked="" type="checkbox"/>	0.0	None	Calc
Gas Phase Pressure Drop (bar)	<input type="checkbox"/>	0.015e-2	<input checked="" type="checkbox"/>	0.0	5.000	Calc

SET PARAMETERS: CO2 Capture: 1. Chemical Looping: Calclner

Title	Unc	Value	Calc	Min	Max	Default
Calclner Temperature (deg. C)	<input type="checkbox"/>	900.0		850.0	950.0	900.0
Degree of Calcination (fraction)	<input type="checkbox"/>	0.9500		0.1000	0.9900	0.9500
CaCO3 Conversion in Calclner (fraction)	<input type="checkbox"/>	8.415e-3	<input checked="" type="checkbox"/>	0.0	1.000	Calc
Residence Time of Solids (seconds)	<input type="checkbox"/>	132.3	<input checked="" type="checkbox"/>	50.00	500.0	Calc
Gas Phase Pressure Drop (bar)	<input type="checkbox"/>	0.015e-2	<input checked="" type="checkbox"/>	0.0	5.000	Calc
Fraction of Gas Recycling (fraction)	<input type="checkbox"/>	0.6000		0.0	1.000	0.6000
Calclner Recycling Stream Temperature (deg. C)	<input type="checkbox"/>	120.0		100.0	200.0	120.0
System Heat Recovery Power Credit (% MWg)	<input type="checkbox"/>	95.86	<input checked="" type="checkbox"/>	0.0	None	Calc
Capture System Cooling Duty (t H2O/t CO2)	<input type="checkbox"/>	12.35	<input checked="" type="checkbox"/>	0.0	200.0	Calc

Post-Combustion CaL Process Model

SET PARAMETERS: CO2 Capture: 1. Chemical Looping: Carbonator

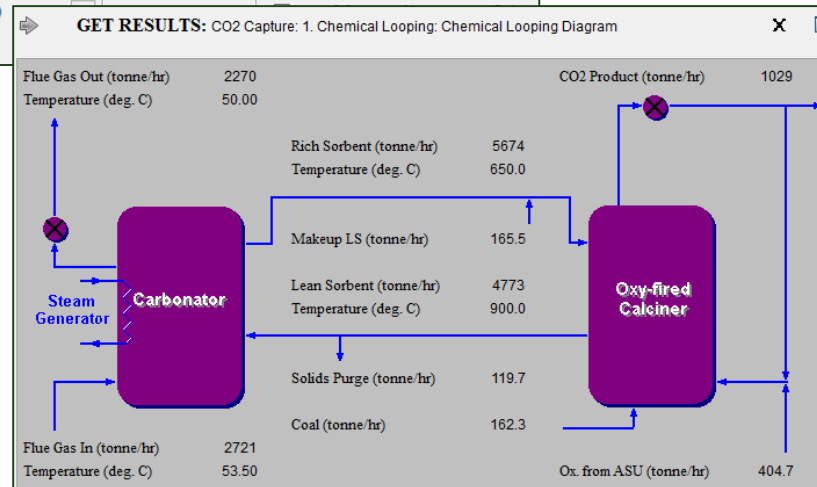
Title	Unc	Value	Calc	Min	Max	Default
Carbonator Temperature (deg. C)	<input type="checkbox"/>	650.0		600.0	700.0	650.0
Degree of Carbonation (fraction)	<input type="checkbox"/>	0.8000		0.0	1.000	0.8000
Makeup Limestone/Recirculating Sorbent (mol/mol)	<input type="checkbox"/>	2.500e-2		1.000e-2	1.000	2.500e-2
Maximum CaO Conversion (fraction)	<input type="checkbox"/>	0.2083	<input checked="" type="checkbox"/>	0.0	1.000	Calc
Actual CaO Conversion (fraction)	<input type="checkbox"/>	0.1683	<input checked="" type="checkbox"/>	0.0	1.000	Calc
Residence Time of Solids (seconds)	<input type="checkbox"/>	267.1	<input checked="" type="checkbox"/>	0.0	None	Calc
Gas Phase Pressure Drop (bar)	<input type="checkbox"/>	0.1406	<input checked="" type="checkbox"/>	0.0	5.000	Calc

SET PARAMETERS: CO2 Capture: 1. Chemical Looping: Calciner

Title	Unc	Value	Calc	Min	Max	Default
Calciner Temperature (deg. C)	<input type="checkbox"/>	900.0		850.0	950.0	900.0
Degree of Calcination (fraction)	<input type="checkbox"/>	0.9500		0.1000	0.9900	0.9500
CaCO3 Conversion in Calciner (fraction)	<input type="checkbox"/>	8.415e-3	<input checked="" type="checkbox"/>	0.0	1.000	Calc
Residence Time of Solids (seconds)	<input type="checkbox"/>	132.3	<input checked="" type="checkbox"/>	50.00	500.0	Calc
Gas Phase Pressure Drop (bar)	<input type="checkbox"/>	9.015e-2	<input checked="" type="checkbox"/>	0.0	5.000	Calc
Fraction of Gas Recycling (fraction)	<input type="checkbox"/>	0.6000		0.0	1.000	0.6000
Calciner Recycling Stream Temperature (deg. C)	<input type="checkbox"/>	120.0		100.0	200.0	120.0

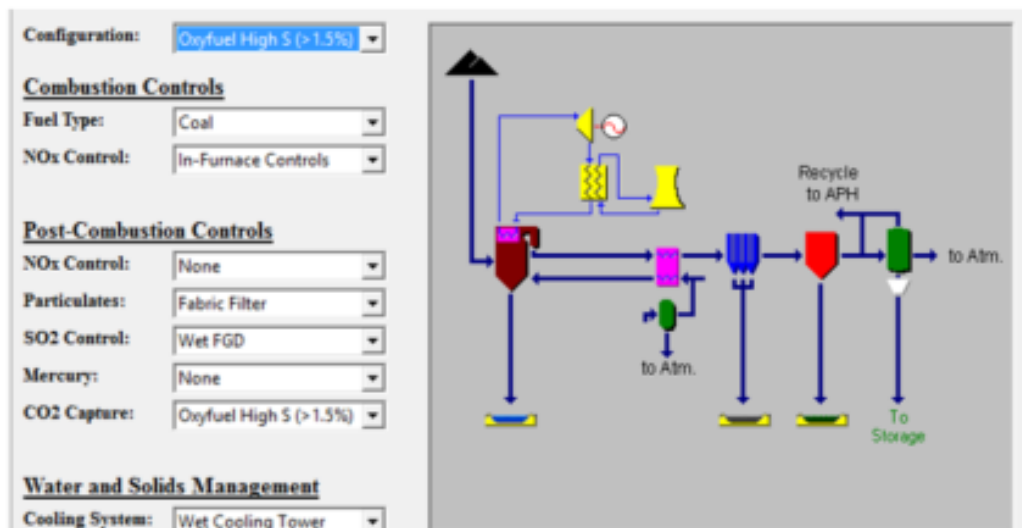
GET RESULTS: CO2 Capture: 1. Chemical Looping: Capital Cost

	A	B		A	B
1	CO2 Capture Process Area Costs	Capital Cost (\$/kW-net)	1	CO2 Capture Plant Costs	Capital Cost (\$/kW-net)
2	Carbonator	501.1	2	Process Facilities Capital	1980
3	Calciner	279.9	3	General Facilities Capital	198.0
4	ASU	233.8	4	Engineering & Home Office Fees	138.7
5	Blowers	6.317	5	Process Contingency Cost	438.3
6	CO2 Product Compressor	105.8	6	Project Contingency Cost	516.7
7	CO2 Cryogenic Purification Unit	236.7	7	Interest Charges (AFUDC)	237.5
8	Heat Recovery Steam Generator	152.1	8	Royalty Fees	9.904
9	Coal Handling Equipment for ASU	76.45	9	Preproduction (Startup) Cost	83.74
10	Solids Handling Equipment	114.7	10	Inventory (Working) Capital	16.36
11	Steam Turbine for Power Generation	273.4	11	Total Capital Requirement (TCR)	3619
12	Process Facilities Capital	1980	12		
13			13		
14			14		
15			15		
16			16	Effective TCR	3619



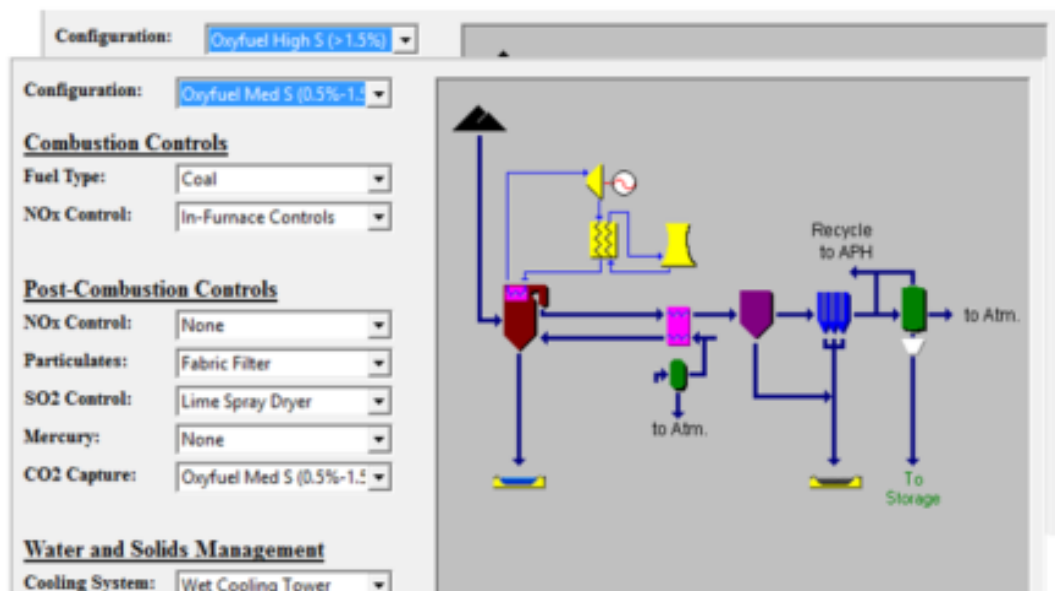
Oxy-Combustion Process Model

- New detailed models for performance and cost of:
 - Air separation unit (ASU)
 - Direct contact cooler/polishing scrubber(DCC/PS)
 - Carbon Processing Unit (CPU)
 - System integration (overall mass & energy balances)
- Three system configurations
(High/med/low %S; cool or warm recycle)



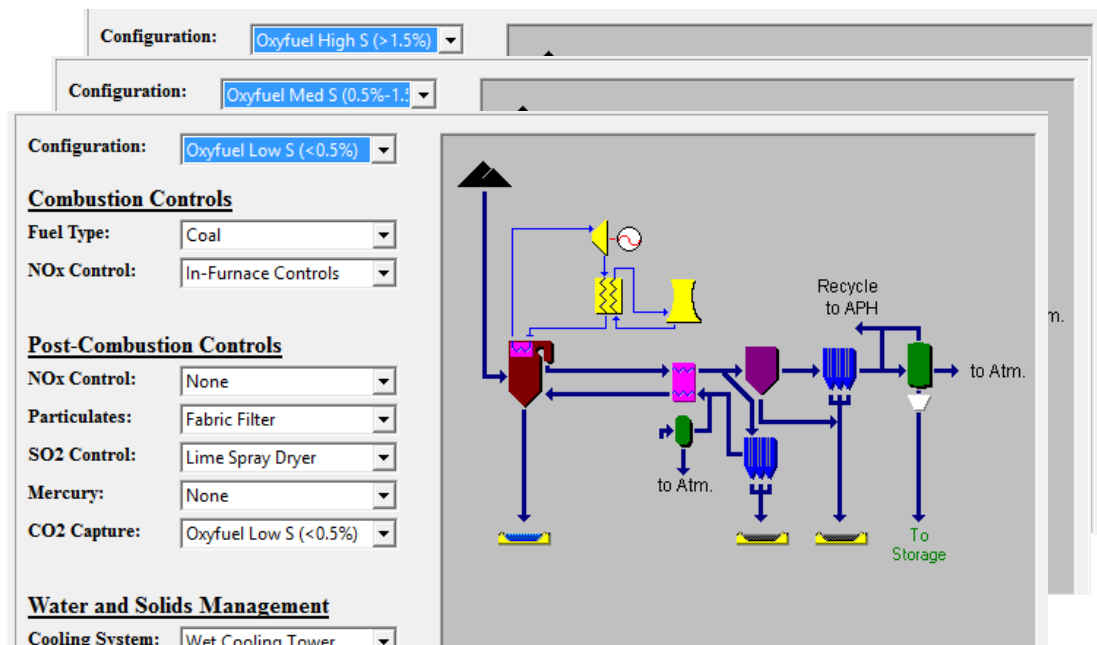
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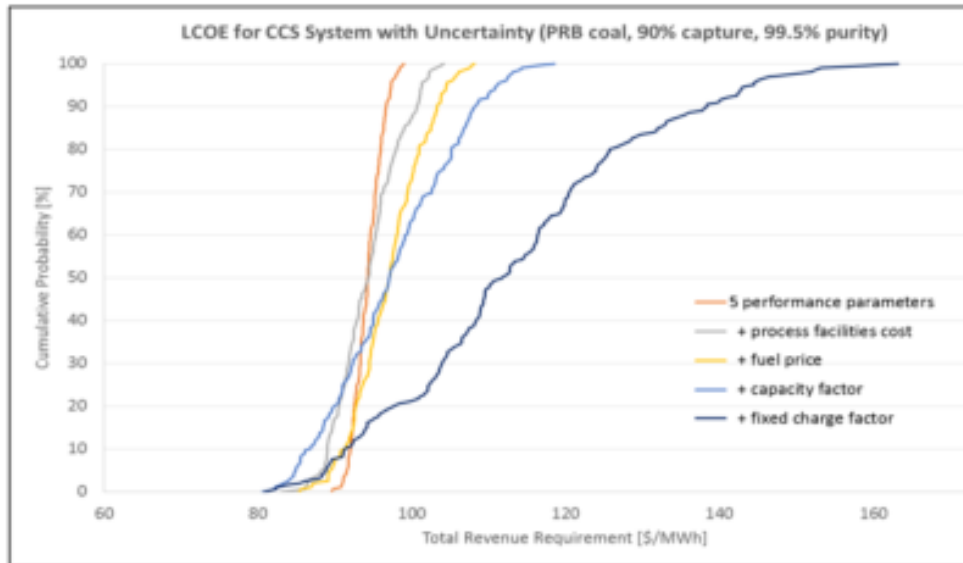


Oxy-Combustion Process Model

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 - ❑ Air separation unit (ASU)
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 - ❑ System integration (overall mass & energy balances)
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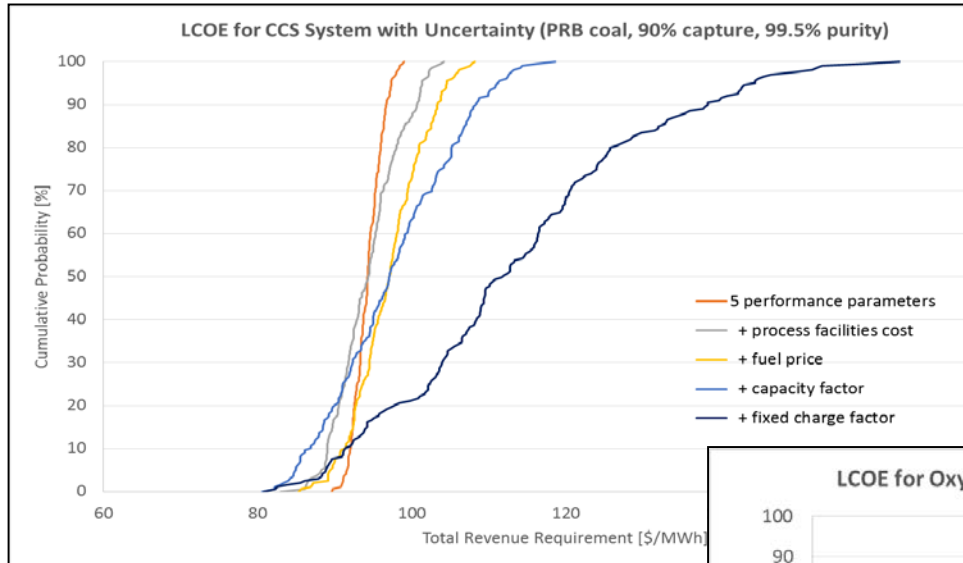


Oxy-Combustion Process Model: Examples of uncertainty analysis, LCOE



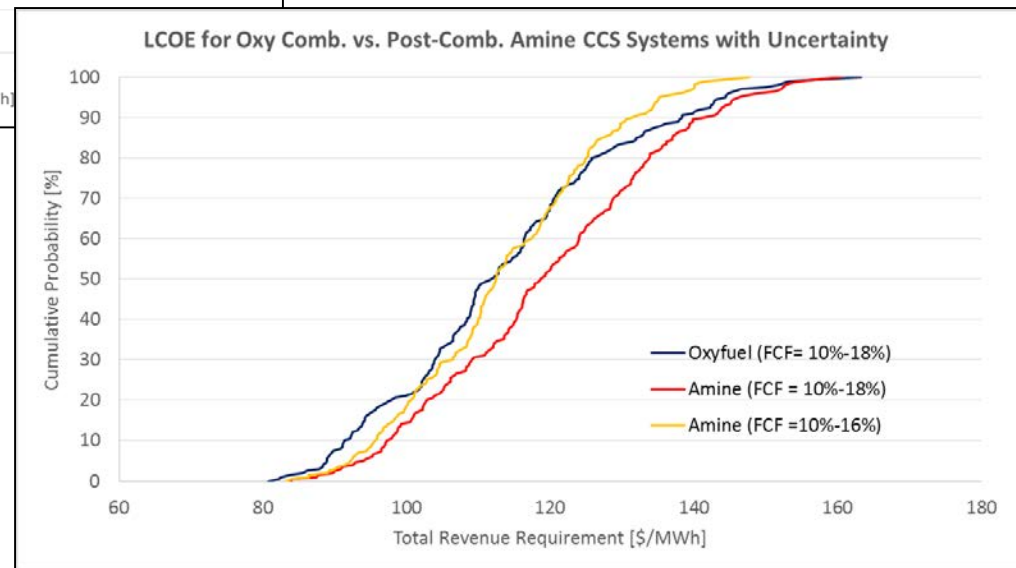
Decomposition of probability distribution function to show contributions from different sources of uncertainty

Oxy-Combustion Process Model: Examples of uncertainty analysis, LCOE



Decomposition of probability distribution function to show contributions from different sources of uncertainty

Comparative analysis of oxy- vs. post-combustion CCS for two uncertainty ranges of FCF for amine-based system



CO₂ Storage Cost Model

- Detailed site-specific models and geological database developed by DOE/NETL are now in IECM v.9.0

The screenshot shows the 'SET PARAMETERS' window for 'CO2 Capture: 4. CO2 Storage: Performance'. The left sidebar contains a tree view with categories like Performance, Regulations & Taxes, Financing, Fuel Cost, O&M Cost, Reference Plant, Fuel, Base Plant, NOx Control, TSP Control, SO2 Control, CO2 Capture, 1. CCS System, 3. Pipeline Transport, 4. CO2 Storage, CO2 Storage Diagram, Financing, Reservoir, Performance, Pre-injection Cost, Operations Cost, Post-injection Cost, Water Systems, and Pre-Prod. Maint.

The main area displays a table of parameters with columns for Title, Unc, Value, and Calc. The 'Performance Model' dropdown menu is open, showing options: Law & Bachu (selected), Law & Bachu, and Advanced Research In.

Title	Unc	Value	Calc
Performance Model	<input type="checkbox"/>	Law & Bachu	
Project Average Injection Rate (Mt CO2/yr)	<input type="checkbox"/>	Law & Bachu	<input checked="" type="checkbox"/>
Design Maximum Injection Rate per Well (Mt CO2/yr)	<input type="checkbox"/>	3.768	<input checked="" type="checkbox"/>
<u>Monitoring Well Density</u>			
Wells in Reservoir (sq km/well)	<input type="checkbox"/>	10.36	
Wells Above Seal (sq km/well)	<input type="checkbox"/>	5.180	
Wells that are Dual Completed (sq km/well)	<input type="checkbox"/>	10.36	
Wells Groundwater (Wells/Inj. Well)	<input type="checkbox"/>	3.000	
Wells Vadose Zone (Wells/Inj. Well)	<input type="checkbox"/>	3.000	
Dual Completed Wells in Reservoir (%)	<input type="checkbox"/>	100.0	
<u>Margins</u>			
AOR Margin 3D (% of Plume)	<input type="checkbox"/>	30.00	

CO₂ Storage Cost Model

Reservoir Database Lookup

Mode: View

Reservoir Selection:

Database: model_default_reservoirs.db

Region: Central

State: CO

Formation: Dakota1

Reservoir Properties:

Basin: Dakota1
Dakota2
Entrada1
Entrada3
Fountain1b
Fountain2b
Hermosa1a
Hermosa1b
Lyons1
Lyons2
Morrison1
Morrison2
Morrison3
Morrison4
Morrison5
Morrison6
Weber1
Weber2
Weber3

Depth (feet): 2900.00

Thickness (feet): 2900.00

Permeability (mD): 2900.00

Porosity (%): 2900.00

Storage Coefficient (%): 2900.00

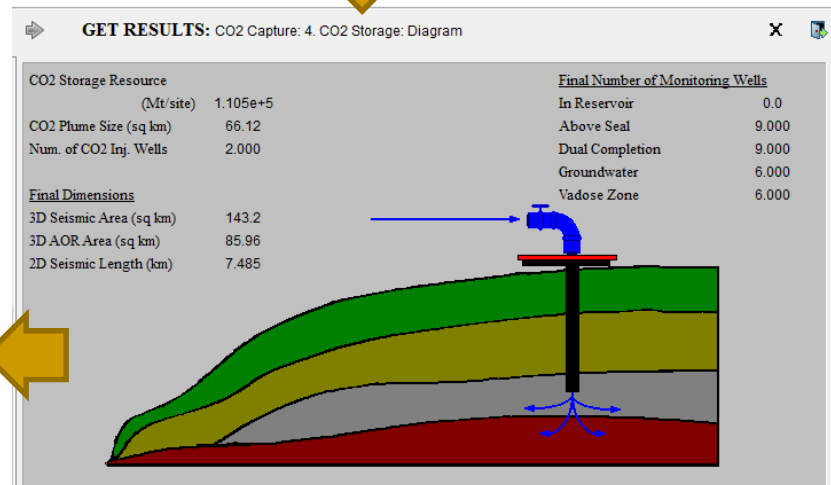
Surface Temp. (deg. F): 2900.00

Geographical Area (sq mi): 2900.00

Buttons: Ok, Cancel, Add/Save, Show Errors, Delete, Create, Open, Close, Show Path

SET PARAMETERS: CO2 Capture: 4. CO2 Storage: Reservoir

Title	Unc	Value	Calc
Click here to retrieve a reservoir from the database.			
Name		Central-CO-Dakota1	
Source		model_default_reservoirs.db	
State	<input type="checkbox"/>	CO	
Reservoir Depth (meters)	<input type="checkbox"/>	1437	
Reservoir Thickness (meters)	<input type="checkbox"/>	39.62	
Reservoir Horizontal Permeability (mD)	<input type="checkbox"/>	750.0	
Reservoir Porosity (%)	<input type="checkbox"/>	14.00	
Storage Coefficient (%)	<input type="checkbox"/>	5.800	
Reservoir Surface Temperature (deg. C)	<input type="checkbox"/>	70.00	
Geographical Area for CO2 Storage (sq km)	<input type="checkbox"/>	7511	



GET RESULTS: CO2 Capture: 4. CO2 Storage: Total Cost

	A	B	C	D	E
1	Cost Component	M\$/yr	\$/MWh	CO2 Stored (\$/tonne)	Percent Total
2	Annual Operation Cost	31.47	11.74	10.44	61.89
3	Annual Post-injection Cost	2.296	0.8566	0.7617	4.515
4	Total Annual Oper. & Post-injection Cost	33.77	12.60	11.20	66.40
5	Annualized Pre-injection Cost	17.09	6.374	5.668	33.60
6	Total Levelized Annual Cost	50.86	18.97	16.87	100.0

Future Developments


New Process Models Nearing Completion

- Advanced membranes system (post-combustion)
- Ionic liquid systems (pre- and post-combustion)
- Metal organic framework systems (post-combustion)
- Carbon-based sorbent systems (post-combustion)
- Other solid sorbent systems (post-combustion)
- Enhanced water-gas shift reactor (pre-combustion)
- Hybrid water cooling systems (wet/dry)
- Life cycle analysis capability

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Integrated Environmental Control Model



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A tool for calculating the performance, emissions, and cost of a fossil-fueled power plant

Developed by

Carnegie Mellon University (CMU)
Department of Engineering & Public Policy (EPP)

With Support from

United States Department of Energy's
National Energy Technology Laboratory (NETL)

Contact us if you have questions or comments.

Thank You

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