New Options in the IECM Power Plant Simulation Model

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CO_2 Capture Technology Meeting
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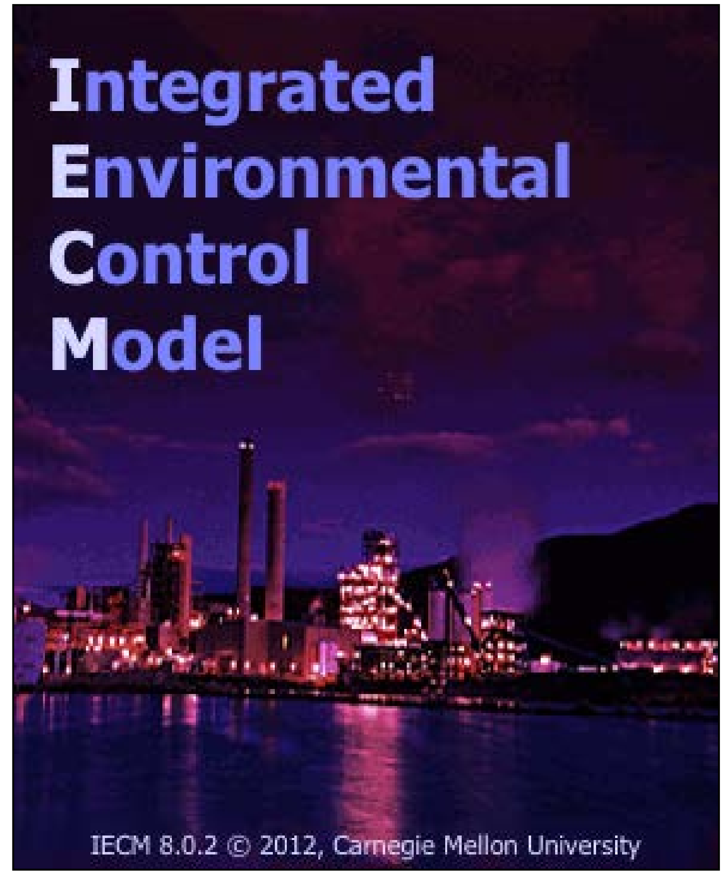
Outline of Talk

- 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
  - CO_2 capture and storage options (pre- and post-combustion, oxy-combustion; transport, storage)
- Free and publicly available at: **www.iecm-online.com**



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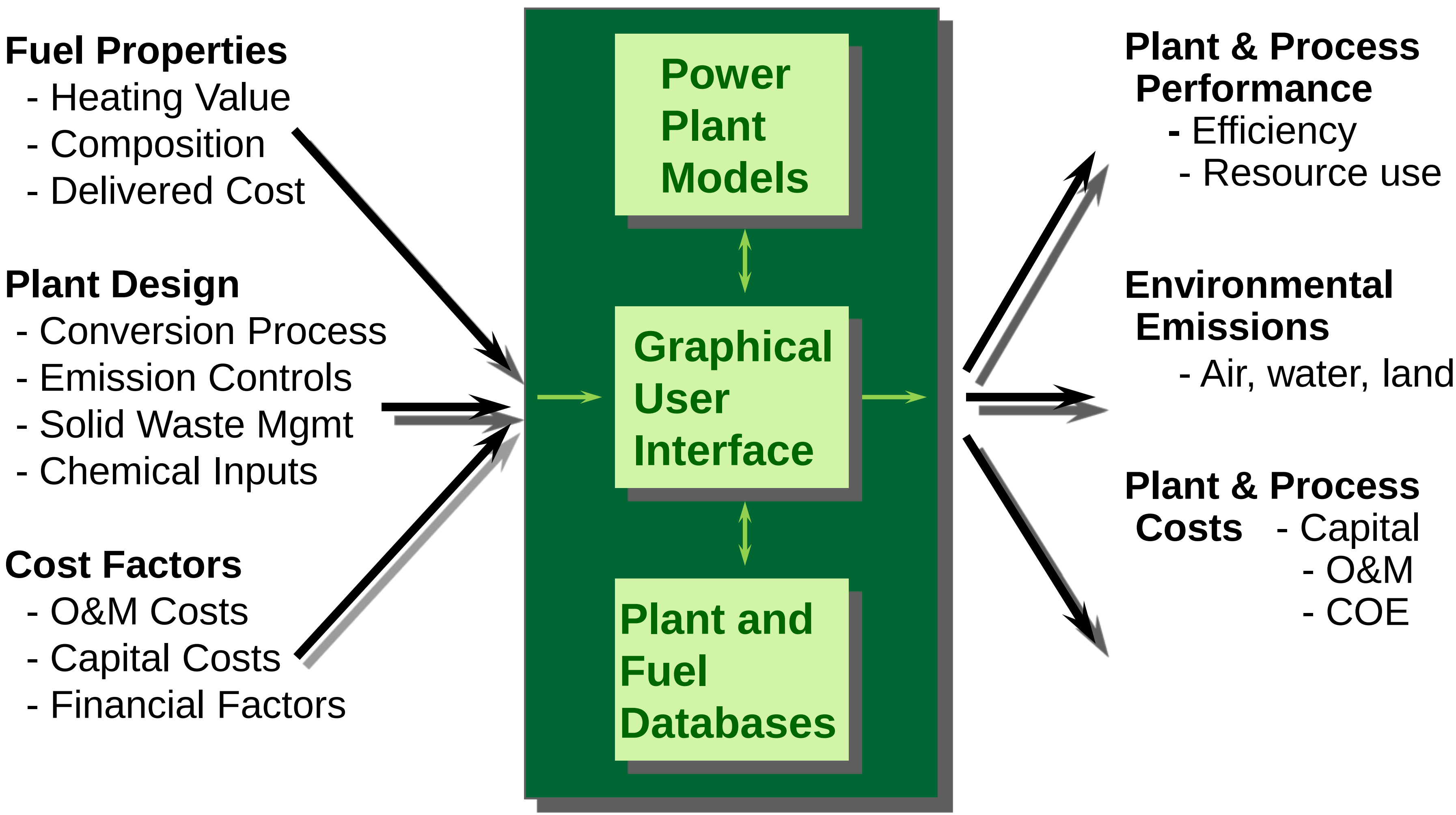
IECM Modeling Approach

- 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



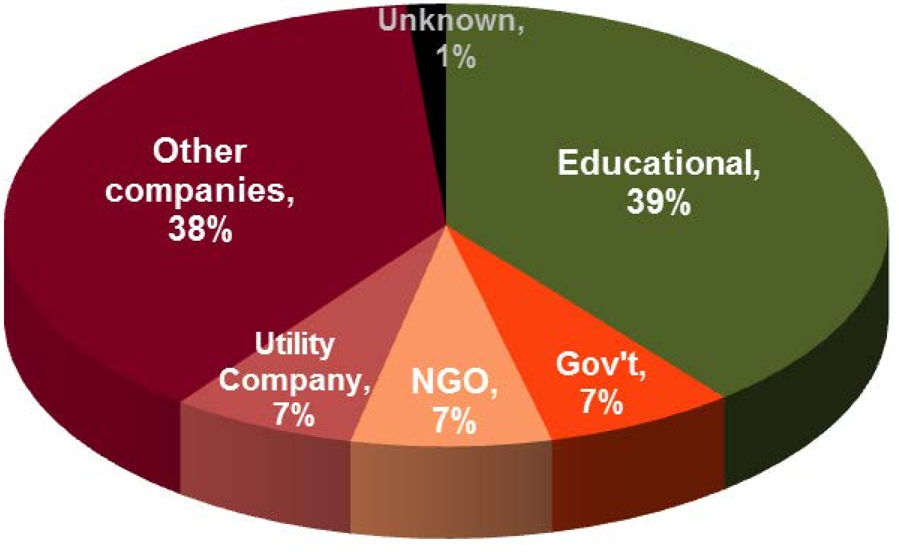
Inputs and results can be either deterministic or probabilistic

Technologies in IECM v.8.0.2

CO_2 Capture & Storage Systems*	Coal Combustion Plants		Gasification Plants (IGCC)	IGCC and NGCC Plants
Post-Combustion Capture Conv. Amine; Adv. amines (FG+); Chilled ammonia; Membrane systems; Aux. NG steam or power gen. (optional) Oxy-Combustion Capture Flue gas recycle; ASU; Chemical processing units Pre-Combustion Capture Water gas shift + Selexol Chemical looping CO_2 Compressor CO_2 Transport Pipelines (6 U.S. regions); Other (user-specified) CO_2 Storage Deep saline formation; Geol.Storage w/ EOR; Other (user-specified)	Boiler/Turbine Systems Subcritical; Supercritical; Ultra-supercritical Furnace Firing Tangential; Wall; Cyclone Furnace NOx Control LNB; SNCR; SNCR+LNB; Gas reburn Flue Gas NOx Removal Hot-side SCR Mercury Removal Carbon/sorbent injection	Particulate Removal Cold-side ESP; Fabric filter (Reverse air; Pulse jet) SO_2 Removal Wet limestone (Conv.; F. oxidation; Additives); Wet lime; Lime spray dry Solids Management Ash pond; Landfill; Co-mixing; useful byproducts Cooling and Wastewater Systems Once-thru cooling; Wet cooling tower; Dry cooling; Chemical treatment; Mech. treatment	Air Separation Unit Cryogenic Slurry Preparation & Coal Pretreatment Gasification Slurry-fed gasifier (GE-Q); Dry-fed gasifier (Shell) Syngas Cooling and Particulate Removal Mercury Removal Activated carbon H_2S Removal Selexol; Sulfinol Sulfur Recovery Claus plant; Beavon-Stretford unit	Gas Turbine GE 7FA; GE 7FB Heat Recovery Steam Generator Steam Turbine Boiler Feedwater System Process Condensate Treatment Cooling Water System Once-through; Wet cooling tower; Dry cooling Aux. Equipment

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

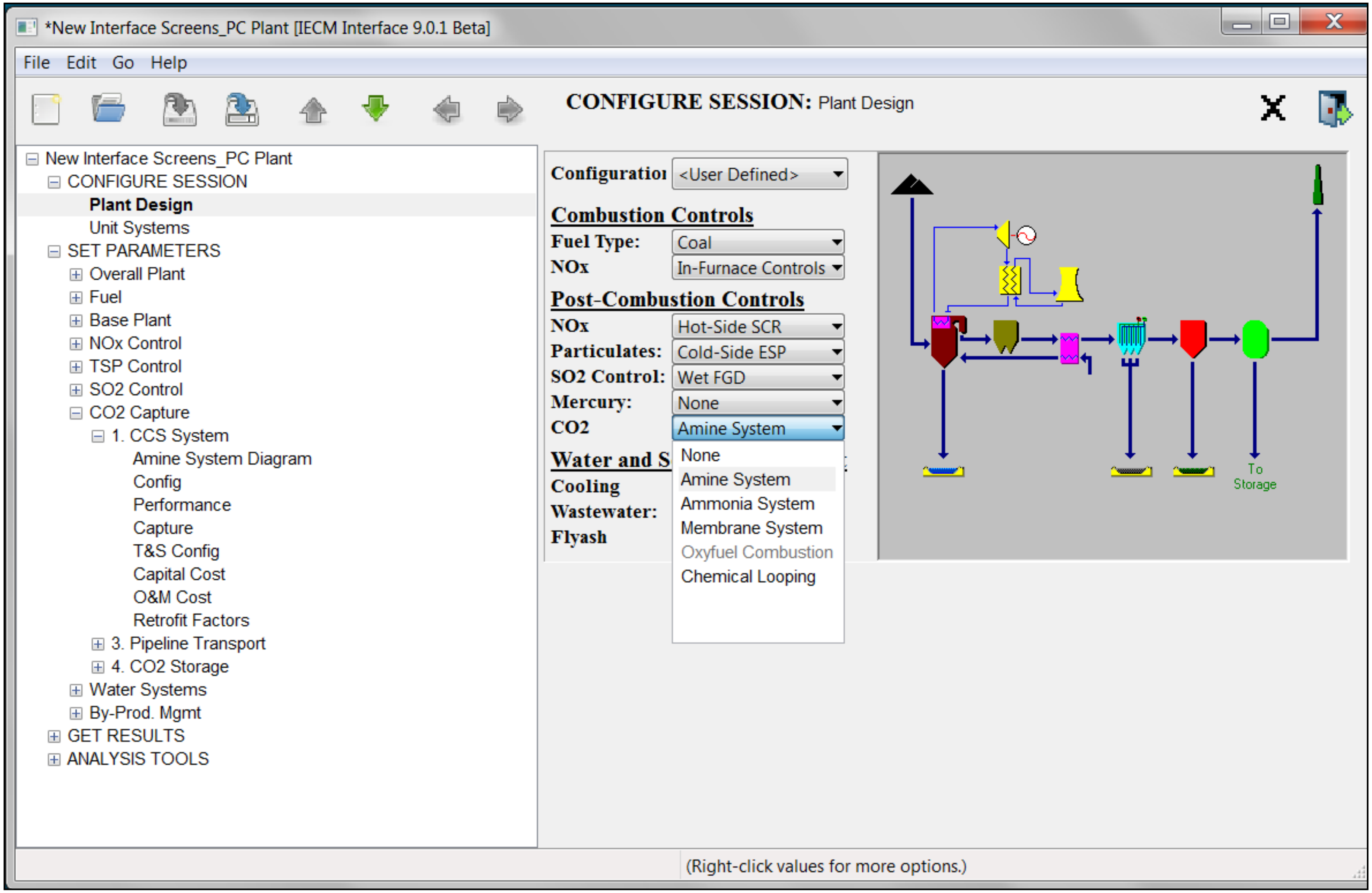
Recent Developments

New IECM Options and Features
(v.9.0 beta)

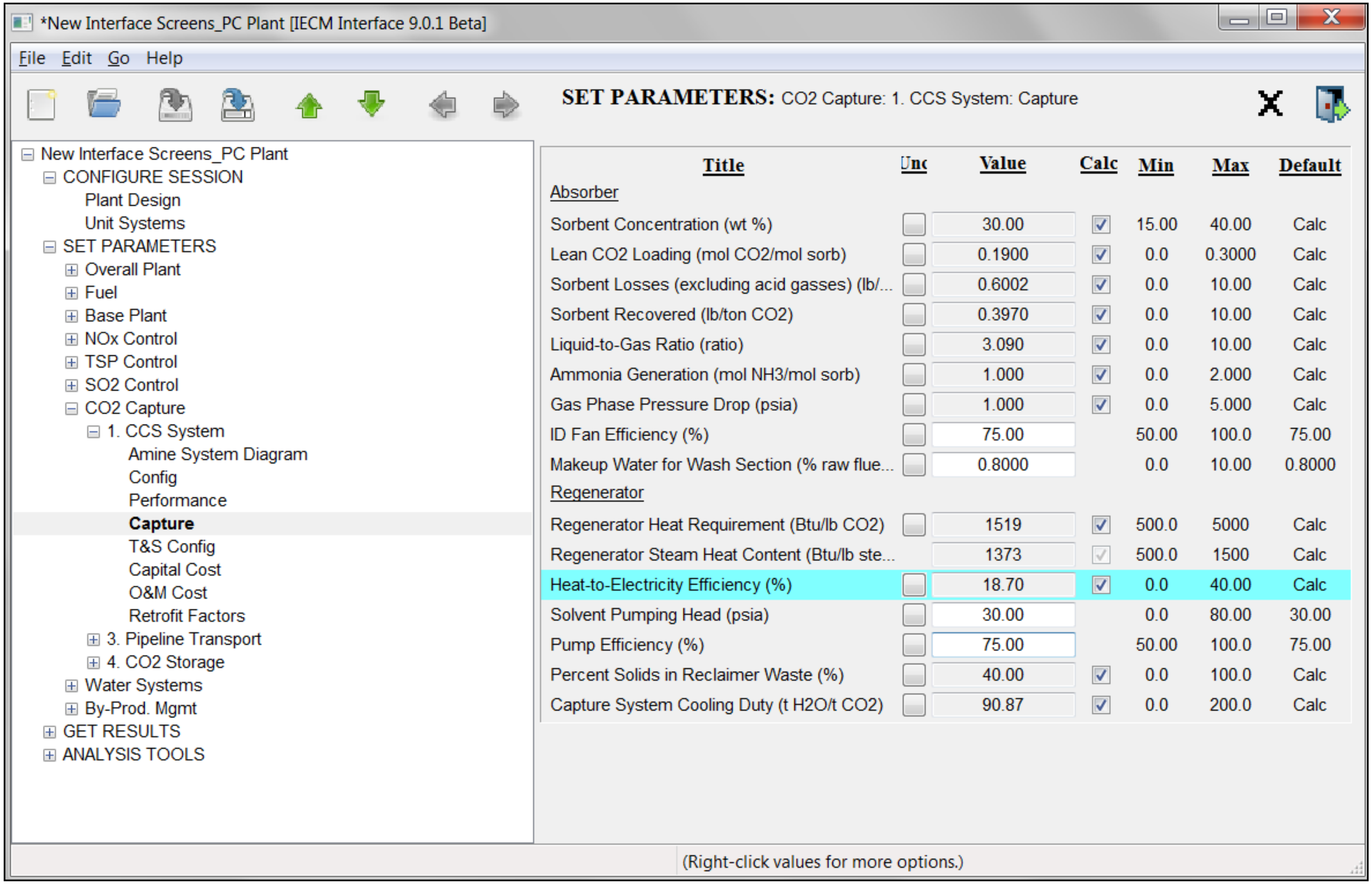
NEW SOFTWARE FEATURES

- 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

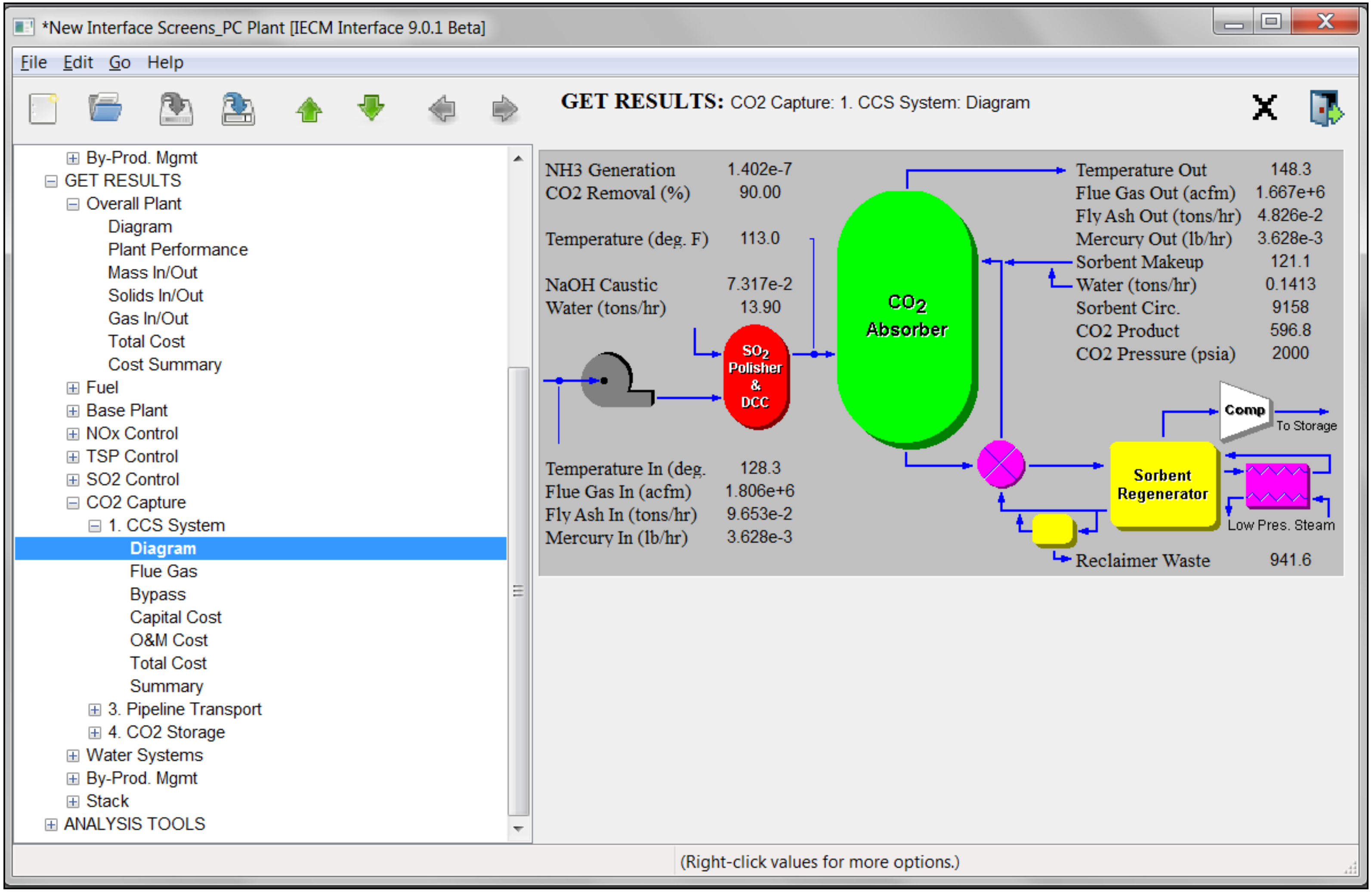
New Interface: Configure Session



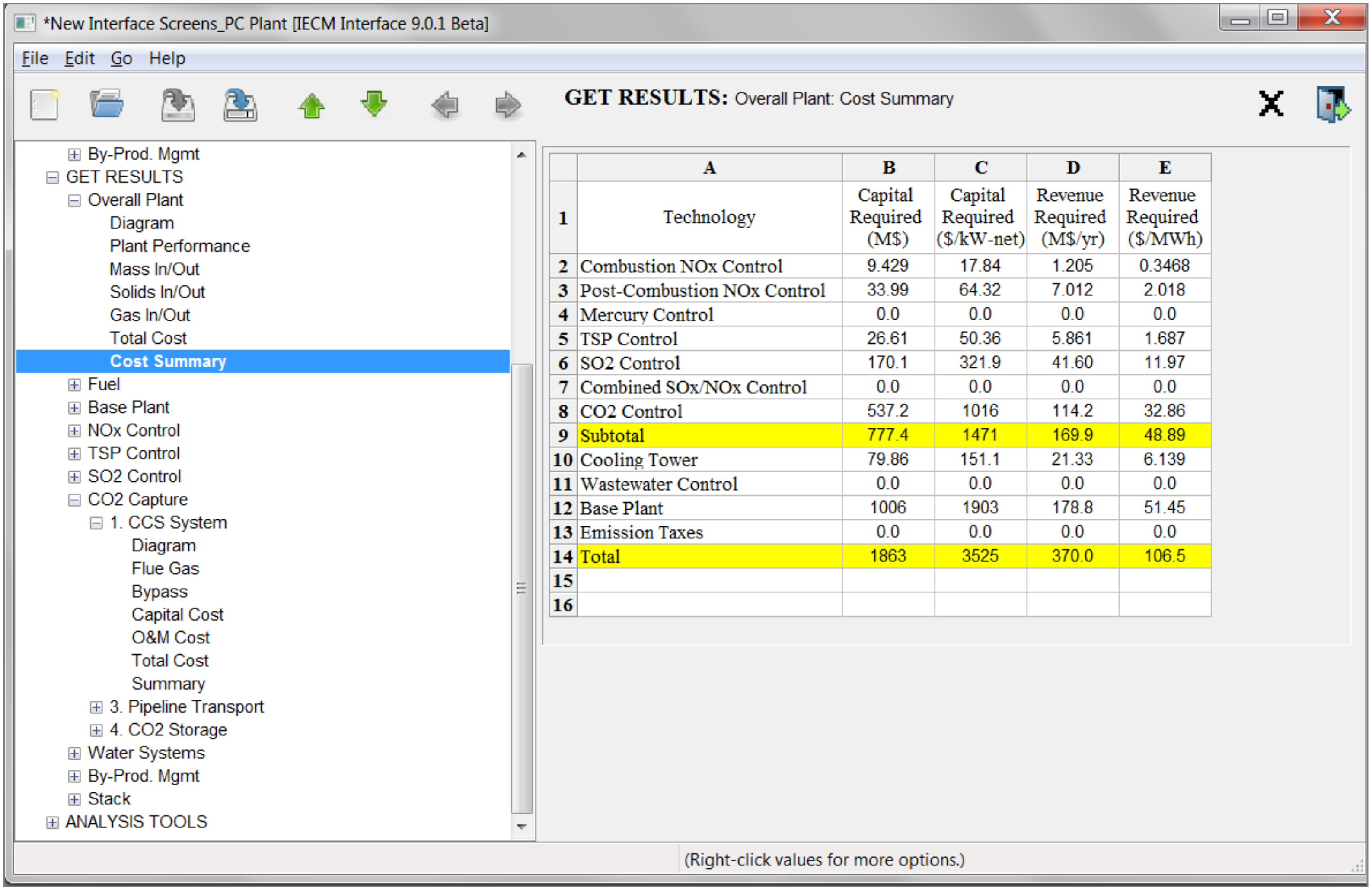
New Interface: Set Parameters



New Interface: Get Results *(diagram)*

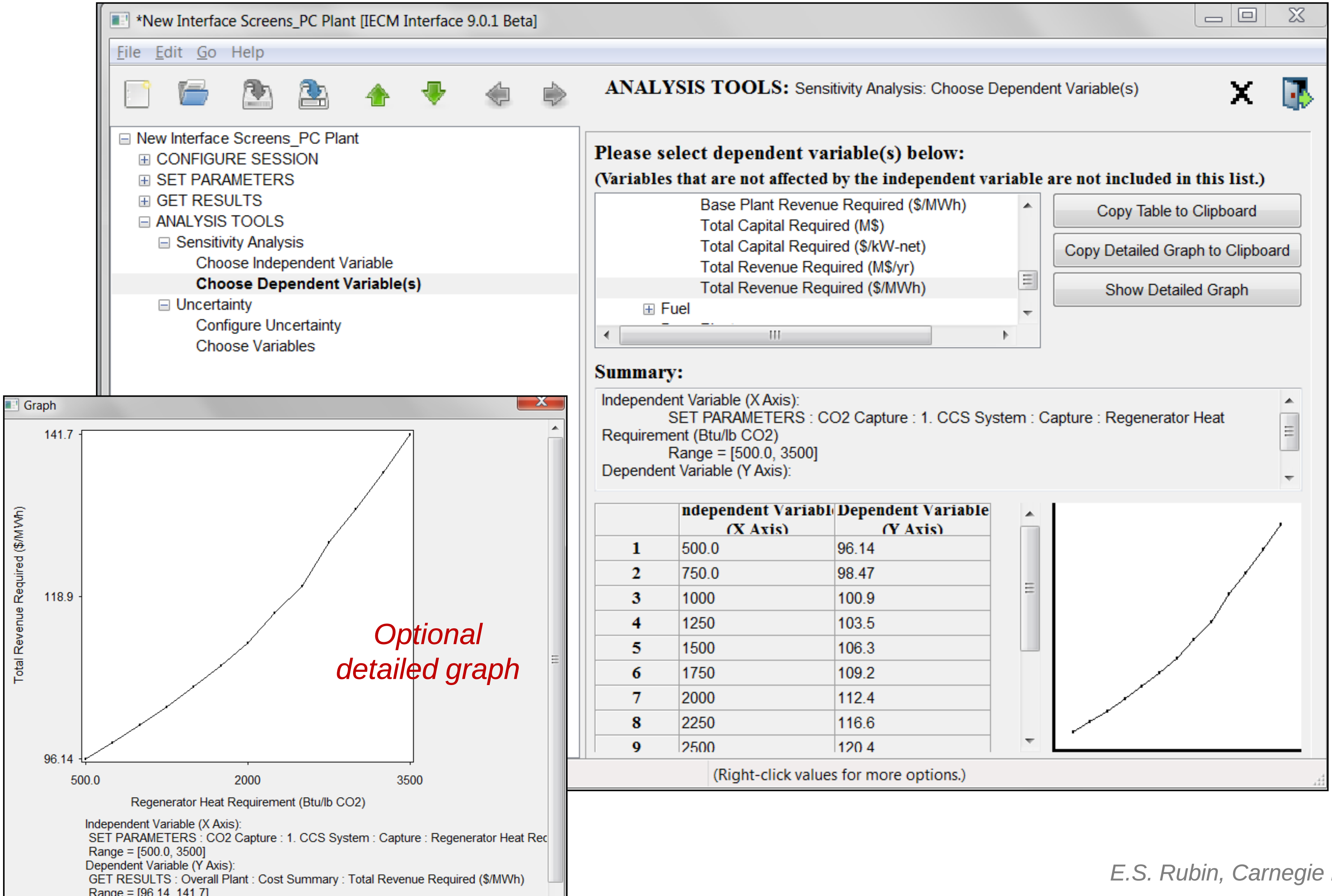


New Interface: Get Results *(table)*



	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					

New Interface: Analysis Tools *(sensitivity)*



New IECM Options and Features (v.9.0 beta)

NEW TECHNOLOGY OPTIONS

For PC Plants:

- Calcium looping system model for post-combustion CO_2 capture
- Enhanced oxy-combustion system performance and cost models

For IGCC Plants:

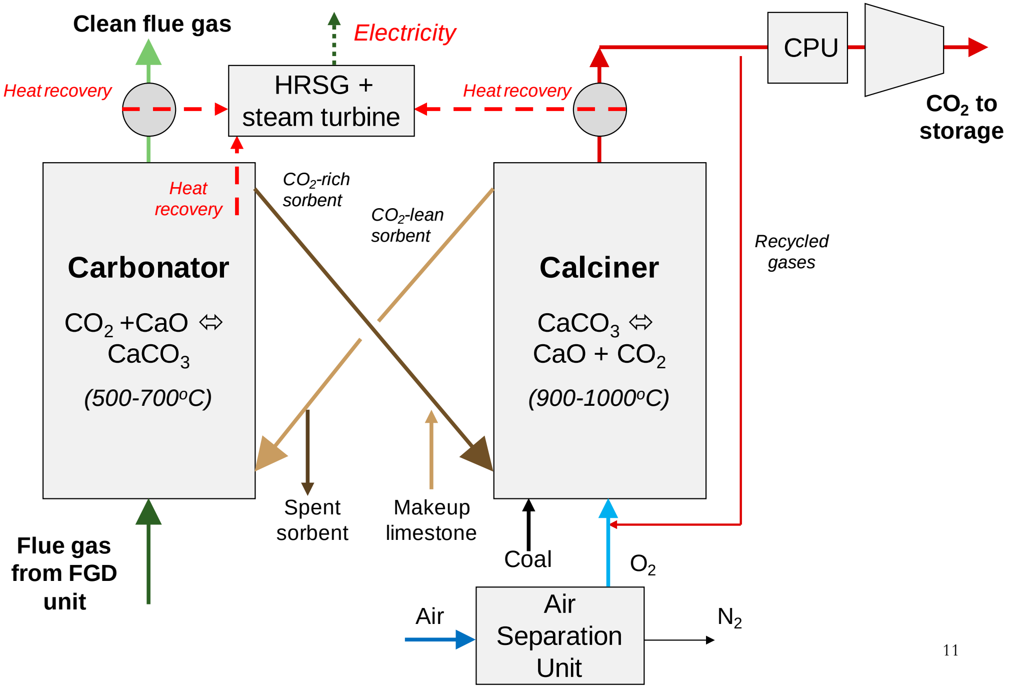
- Updated chemical looping system cost model for pre-combustion capture
- Ability to specify custom fuels and syngas composition for IGCC plants
- Updated direct capital cost default values for IGCC plants

For All Plant Types:

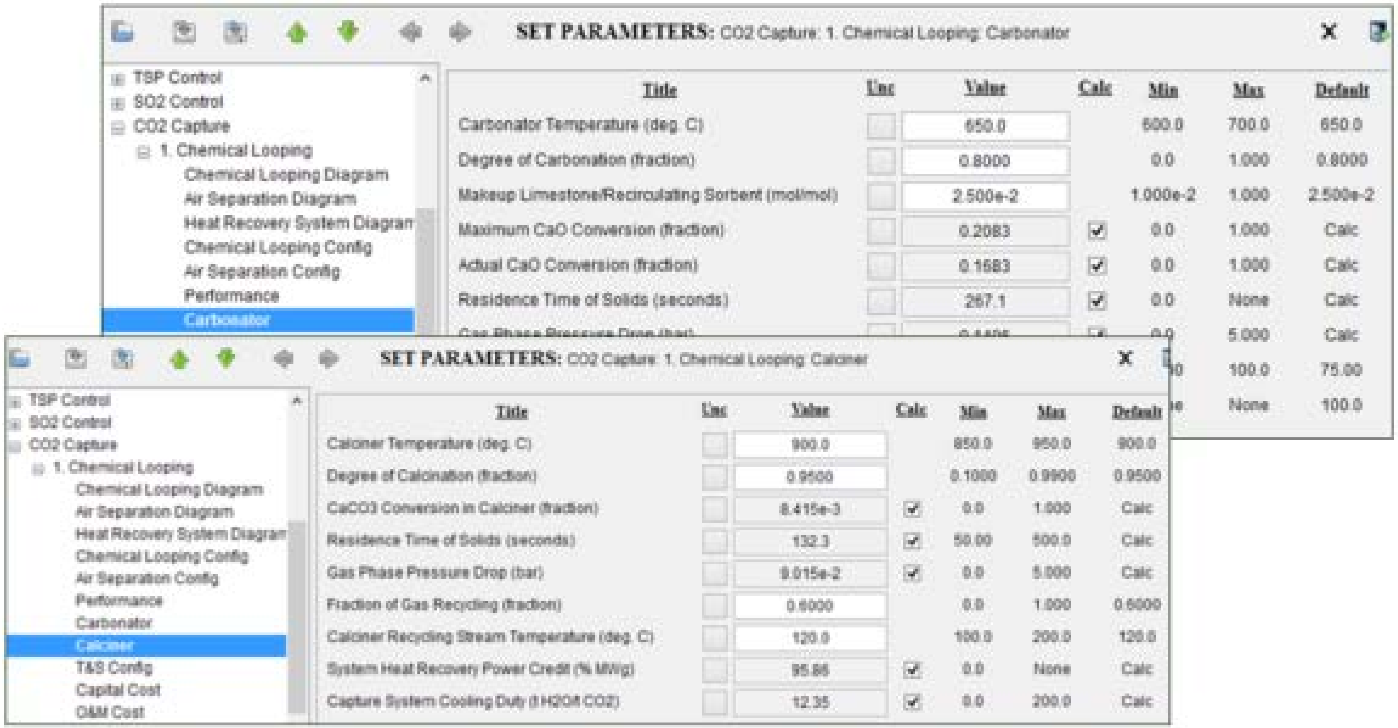
- Updated process and project contingency cost factor default values (based on current level of maturity and cost estimating basis)
- Site-specific CO_2 storage cost model and geological reservoir database

Post-Combustion CaL Process Model

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



Post-Combustion CaL Process Model



Post-Combustion CaL Process Model

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

- TSP Control
- SO2 Control
- CO2 Capture
  - 1. Chemical Looping
    - Chemical Looping Diagram
    - Air Separation Diagram
    - Heat Recovery System Diagram
    - Chemical Looping Config
    - Air Separation Config
    - Performance
    - **Carbonator**

Title	Unc	Value	Calc	Min	Max	Default
Carbonator Temperature (deg. C)		650.0		600.0	700.0	650.0
Degree of Carbonation (fraction)		0.8000		0.0	1.000	0.8000
Makeup Limestone/Recirculating Sorbent (mol/mol)		2.500e-2		1.000e-2	1.000	2.500e-2
Maximum CaO Conversion (fraction)		0.2083	✓	0.0	1.000	Calc
Actual CaO Conversion (fraction)		0.1683	✓	0.0	1.000	Calc
Residence Time of Solids (seconds)		267.1	✓	0.0	None	Calc
Gas Phase Pressure Drop (bar)		0.1406	✓	0.0	5.000	Calc
				00	100.0	75.00
				ne	None	100.0

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

- TSP Control
- SO2 Control
- CO2 Capture
  - 1. Chemical Looping
    - Chemical Looping Diagram
    - Air Separation Diagram
    - Heat Recovery System Diagram
    - Chemical Looping Config
    - Air Separation Config
    - Performance
    - Carbonator
    - **Calciner**

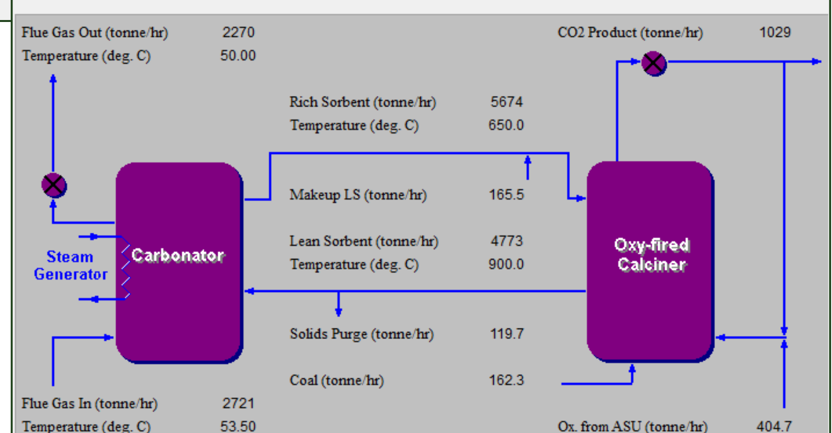
Title	Unc	Value	Calc	Min	Max	Default
Calciner Temperature (deg. C)		900.0		850.0	950.0	900.0
Degree of Calcination (fraction)		0.9500		0.1000	0.9900	0.9500
CaCO3 Conversion in Calciner (fraction)		8.415e-3	✓	0.0	1.000	Calc
Residence Time of Solids (seconds)		132.3	✓	50.00	500.0	Calc
Gas Phase Pressure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

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

	A	B
1	CO2 Capture Process Area Costs	Capital Cost ($/kW-net)
2	Carbonator	501.1
3	Calciner	279.9
4	ASU	233.8
5	Blowers	6.317
6	CO2 Product Compressor	105.8
7	CO2 Cryogenic Purification Unit	236.7
8	Heat Recovery Steam Generator	152.1
9	Coal Handling Equipment for ASU	76.45
10	Solids Handling Equipment	114.7
11	Steam Turbine for Power Generation	273.4
12	Process Facilities Capital	1980
13		
14		
15		
16		

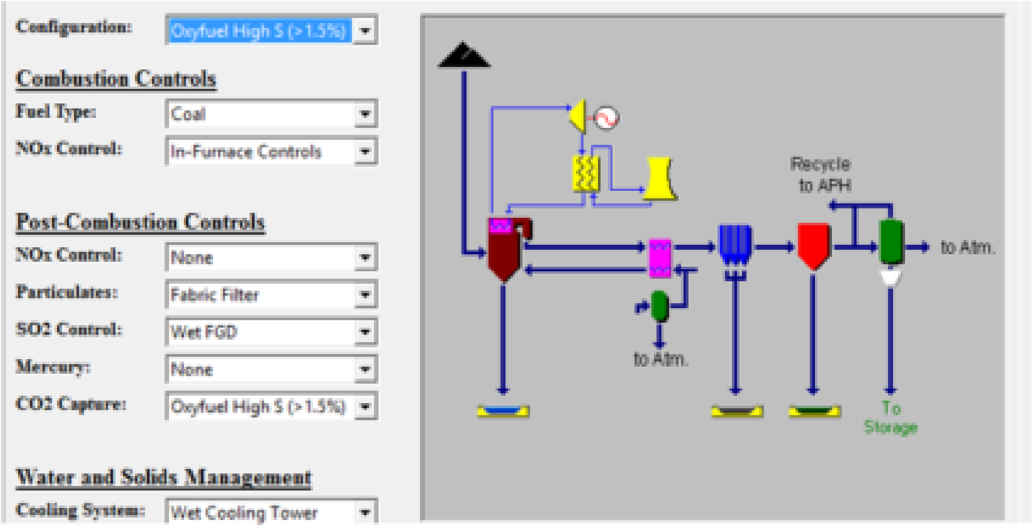
	A	B
1	CO2 Capture Plant Costs	Capital Cost ($/kW-net)
2	Process Facilities Capital	1980
3	General Facilities Capital	198.0
4	Engineering & Home Office Fees	138.7
5	Process Contingency Cost	438.3
6	Project Contingency Cost	516.7
7	Interest Charges (AFUDC)	237.5
8	Royalty Fees	9.904
9	Preproduction (Startup) Cost	83.74
10	Inventory (Working) Capital	16.36
11	Total Capital Requirement (TCR)	3619
12		
13		
14		
15		
16	Effective TCR	3619

GET RESULTS: CO2 Capture: 1. Chemical Looping: Chemical Looping Diagram



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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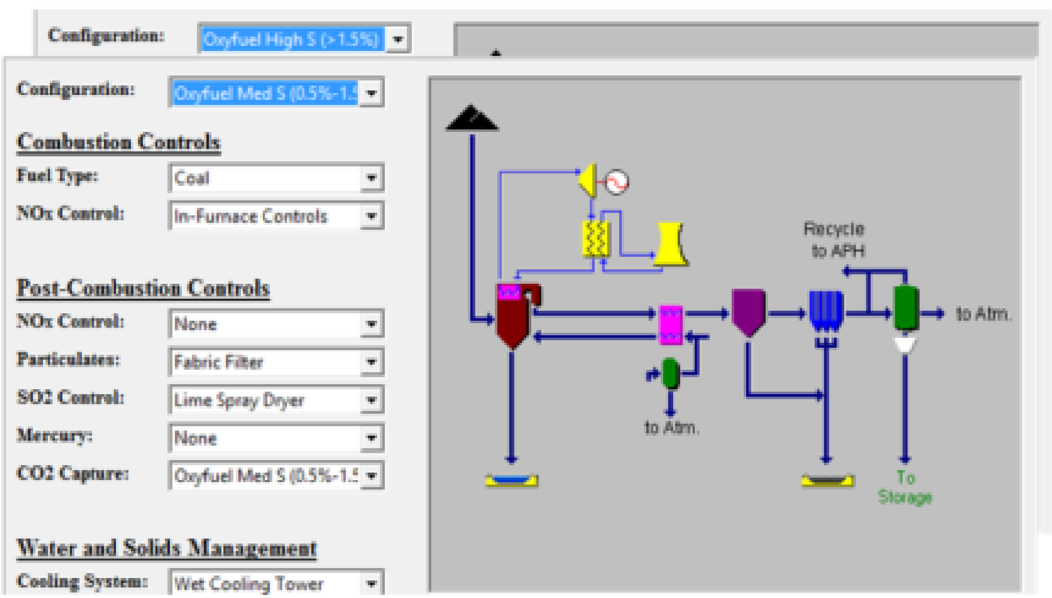

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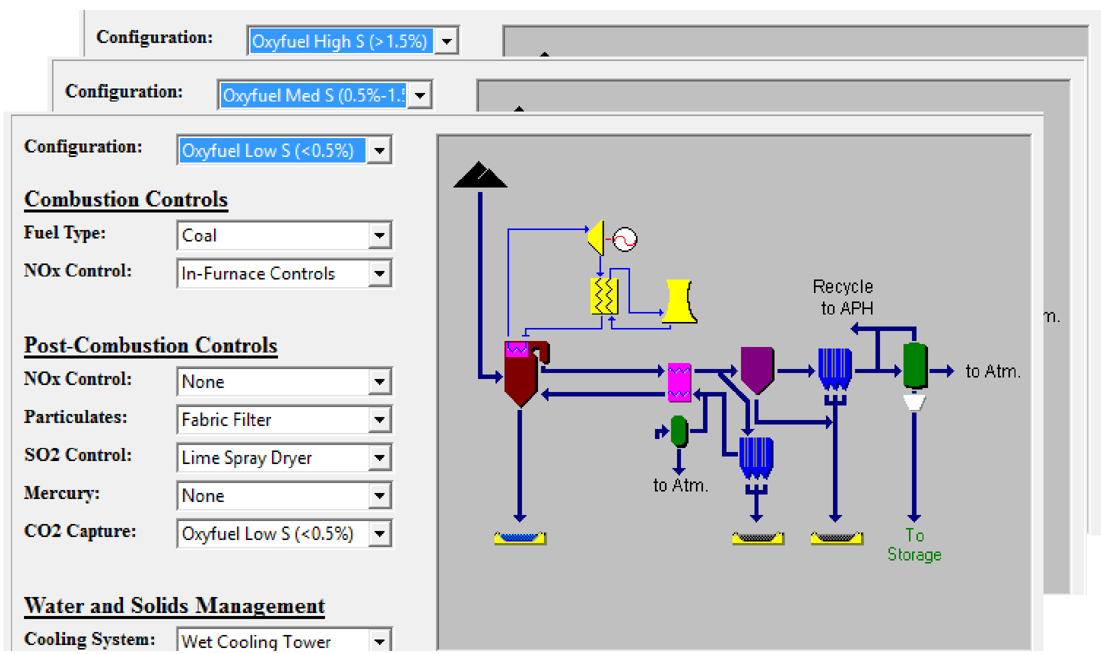
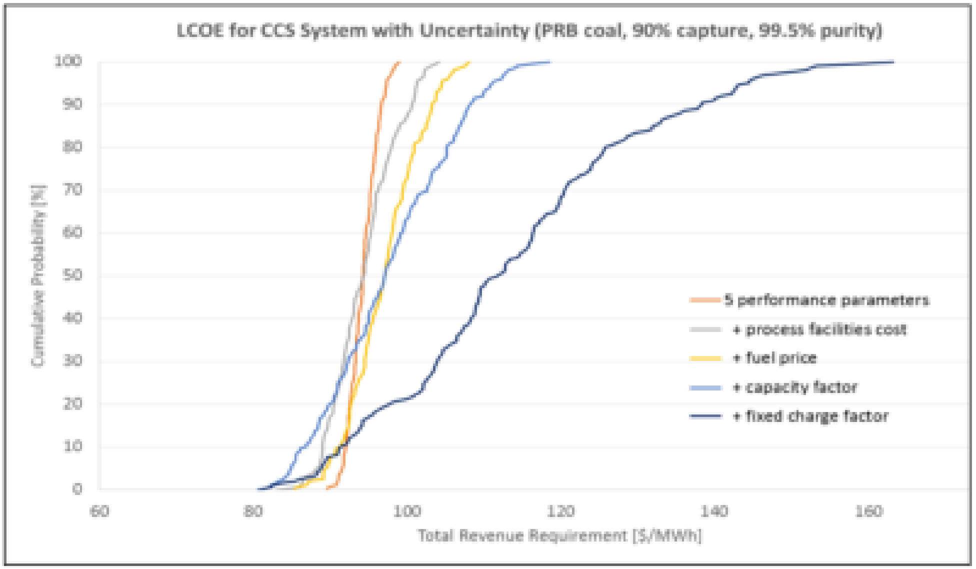


Oxy-Combustion Process Model:
Examples of uncertainty analysis, LCOE



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

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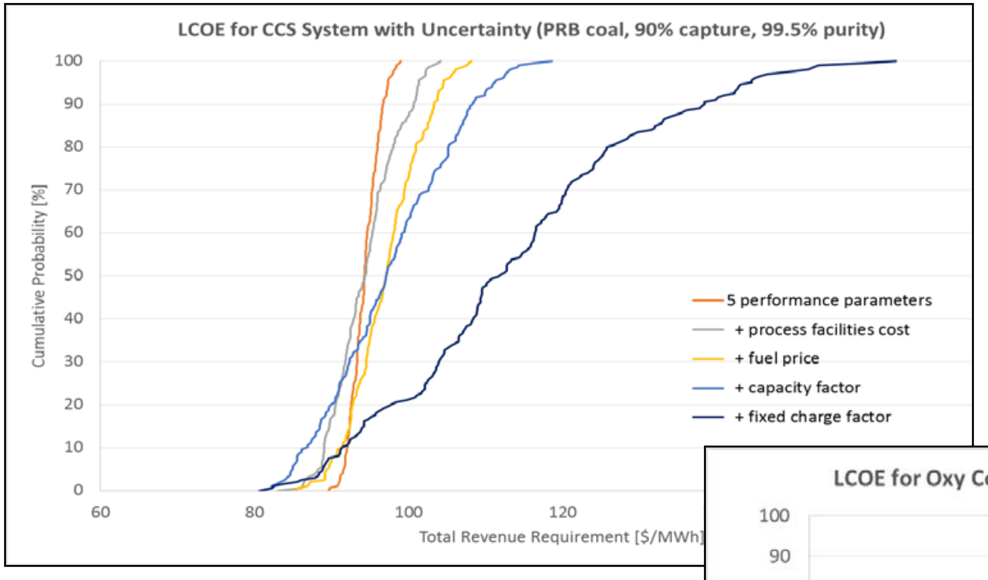
Examples of uncertainty analysis, LCOE



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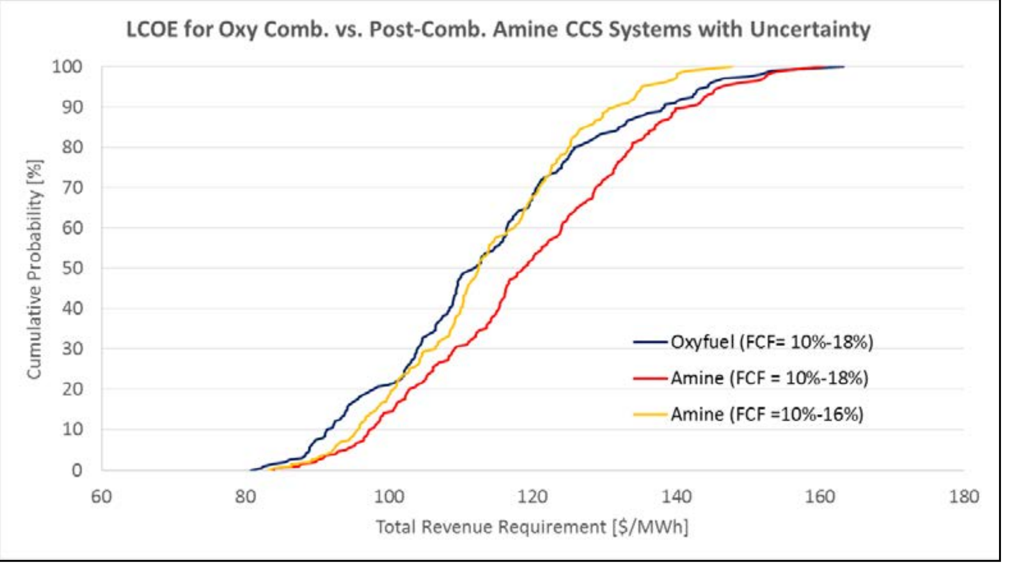
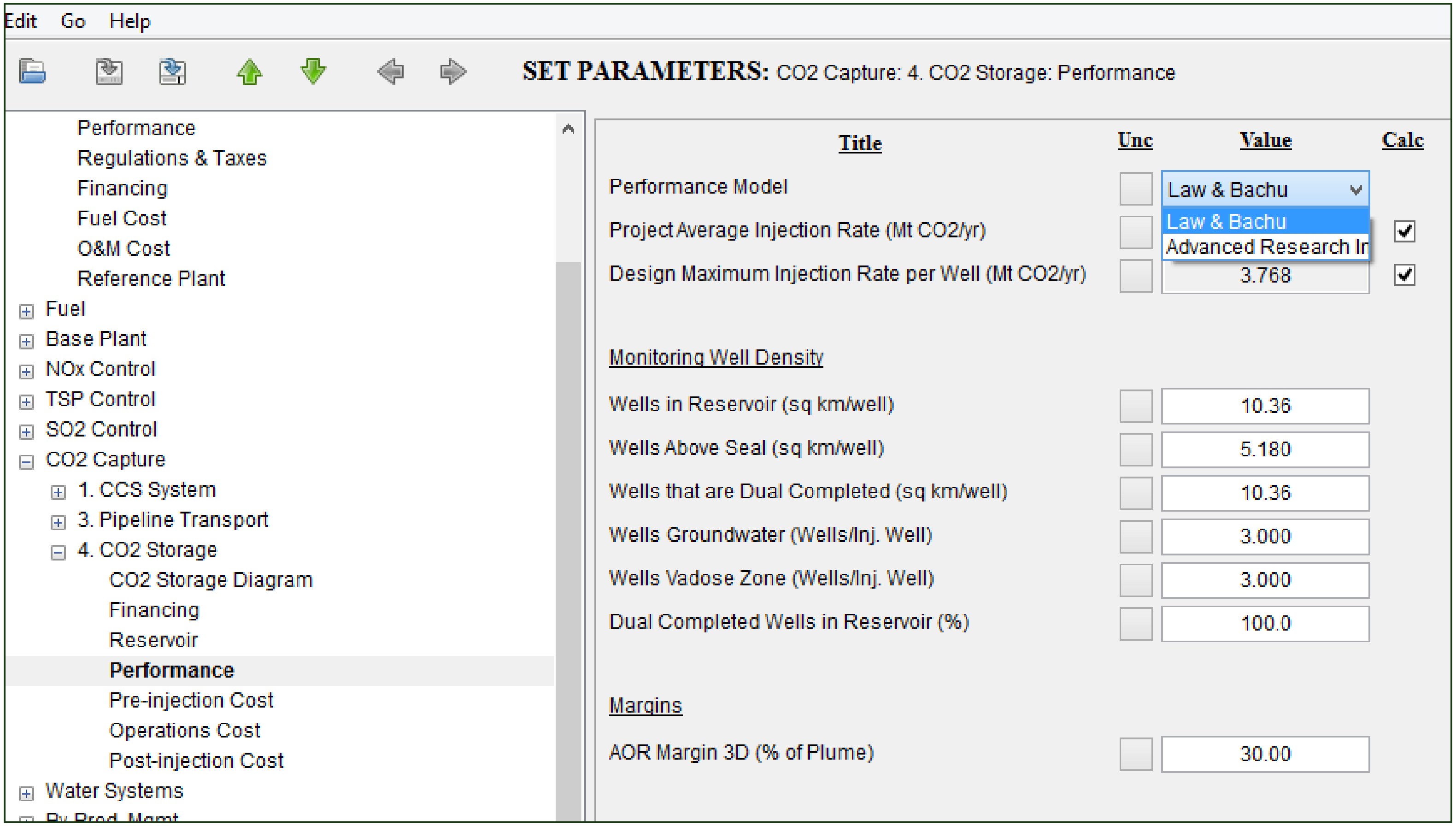


Comparative analysis of oxy- vs. post-combustion CCS for two uncertainty ranges of FCF for amine-based system

CO_2 Storage Cost Model

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



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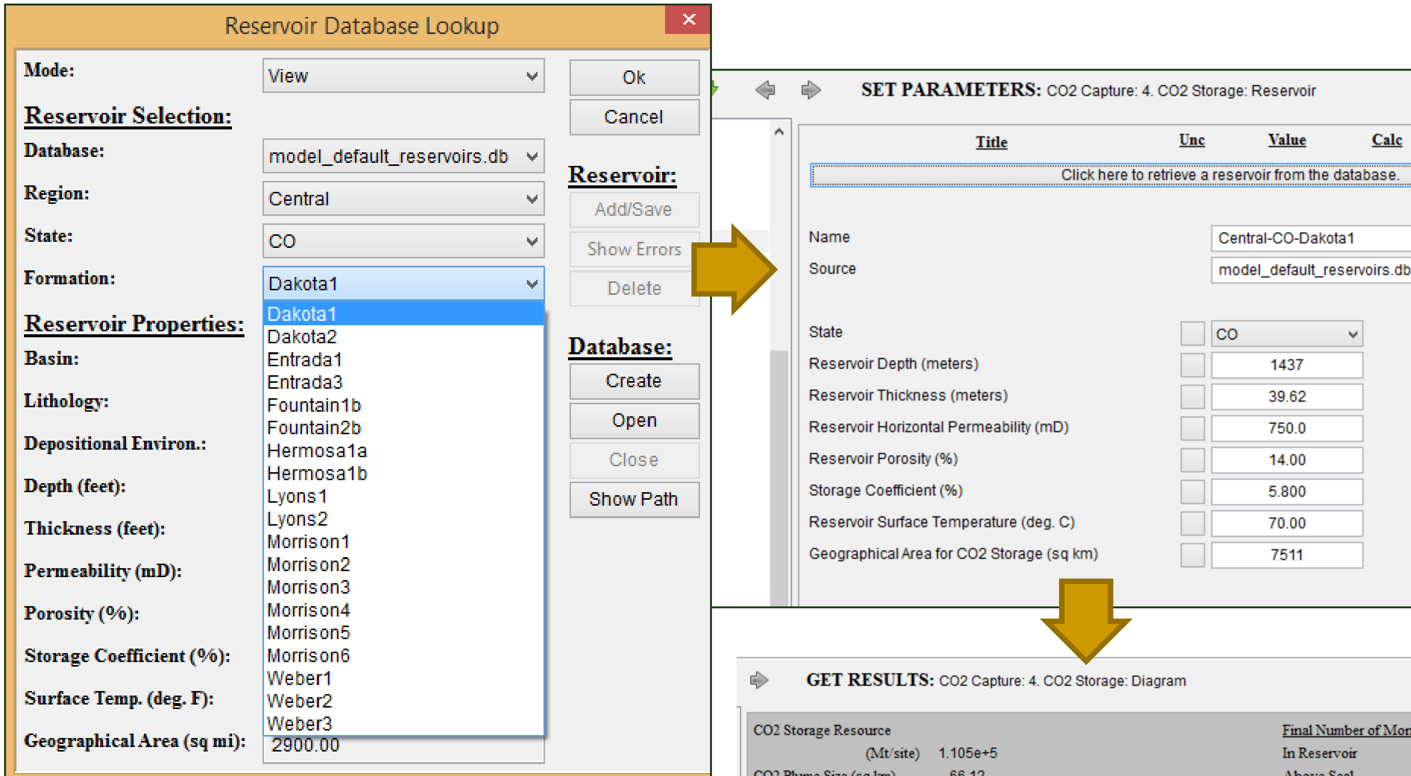

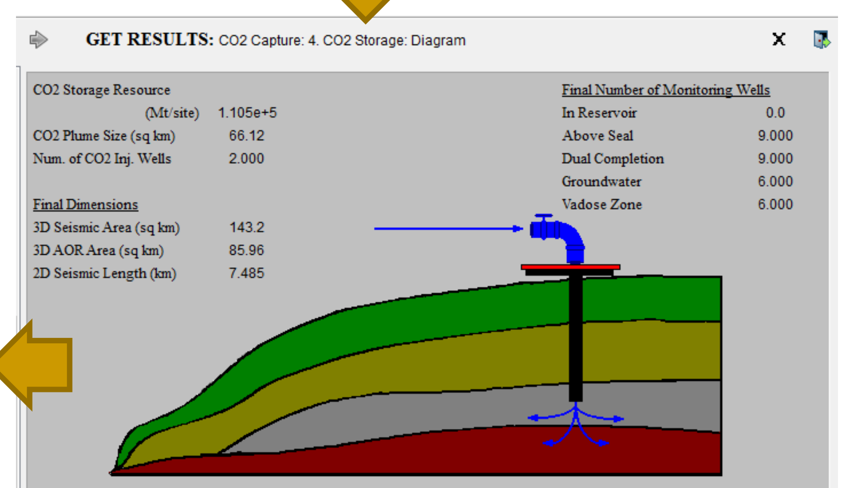

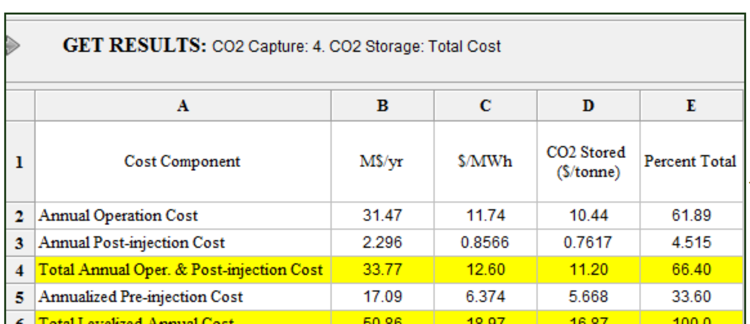

GET RESULTS: CO2 Capture: 4. CO2 Storage: Total Cost

	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

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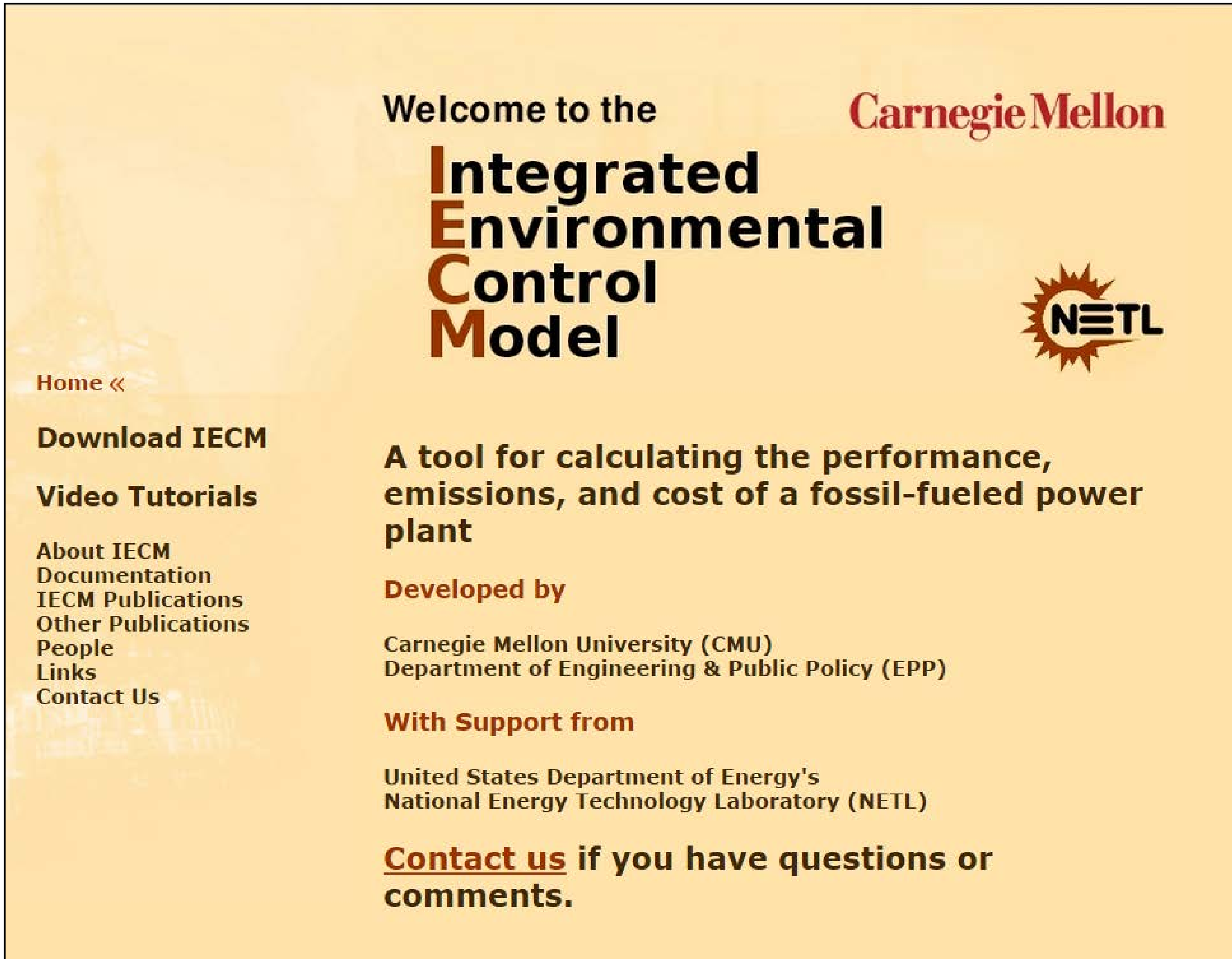
Future Developments

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

Visit: www.iecm-online.com



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Thank You

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