A New Virtual Engineering Tool for Modeling Advanced Power Plants with Near-Zero Emissions

Edward S. Rubin
Department of Engineering and Public Policy
Carnegie Mellon University
Pittsburgh, Pennsylvania

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Project Objectives

- Develop and demonstrate a modeling framework that allows technology component models to be assembled into an advanced power plant design whose performance, emissions and cost can be simulated and modified in a 3-D virtual engineering environment
- Develop and demonstrate the capability to utilize and link a hierarchy of component models of different levels of complexity suitable for different applications ranging from preliminary design to detailed plant design

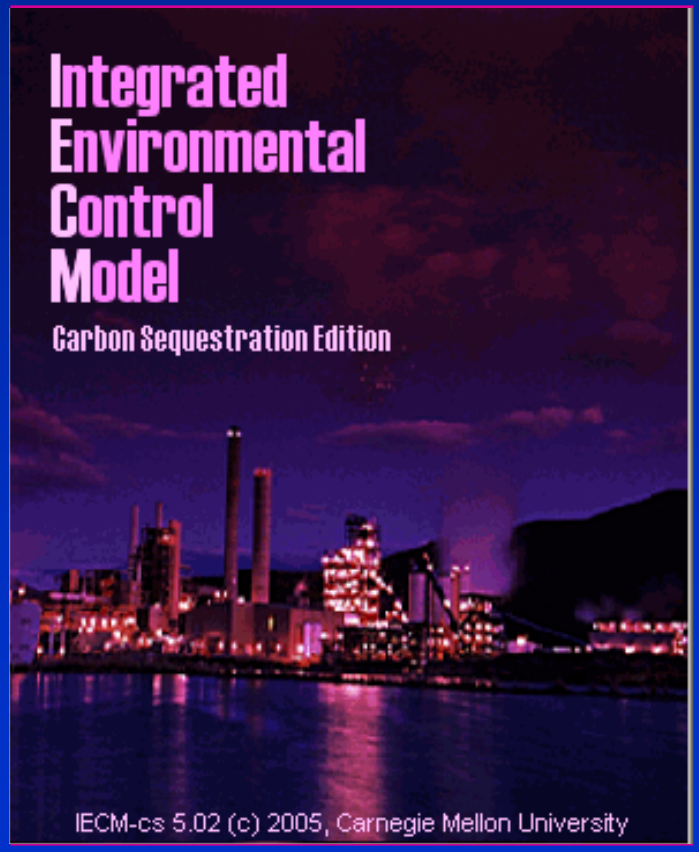
Approach

- Utilize the VE-Suite virtual engineering environment developed by ISU to link, simulate and visualize user-defined models of advanced power systems
- Utilize the Integrated Environmental Control Model (IECM) developed by CMU to provide initial simulations of complete power plants employing combustion- or gasification-based designs with near-zero emissions
- Later, utilize other models in place of IECM components to demonstrate an integrated modeling hierarchy

The IECM

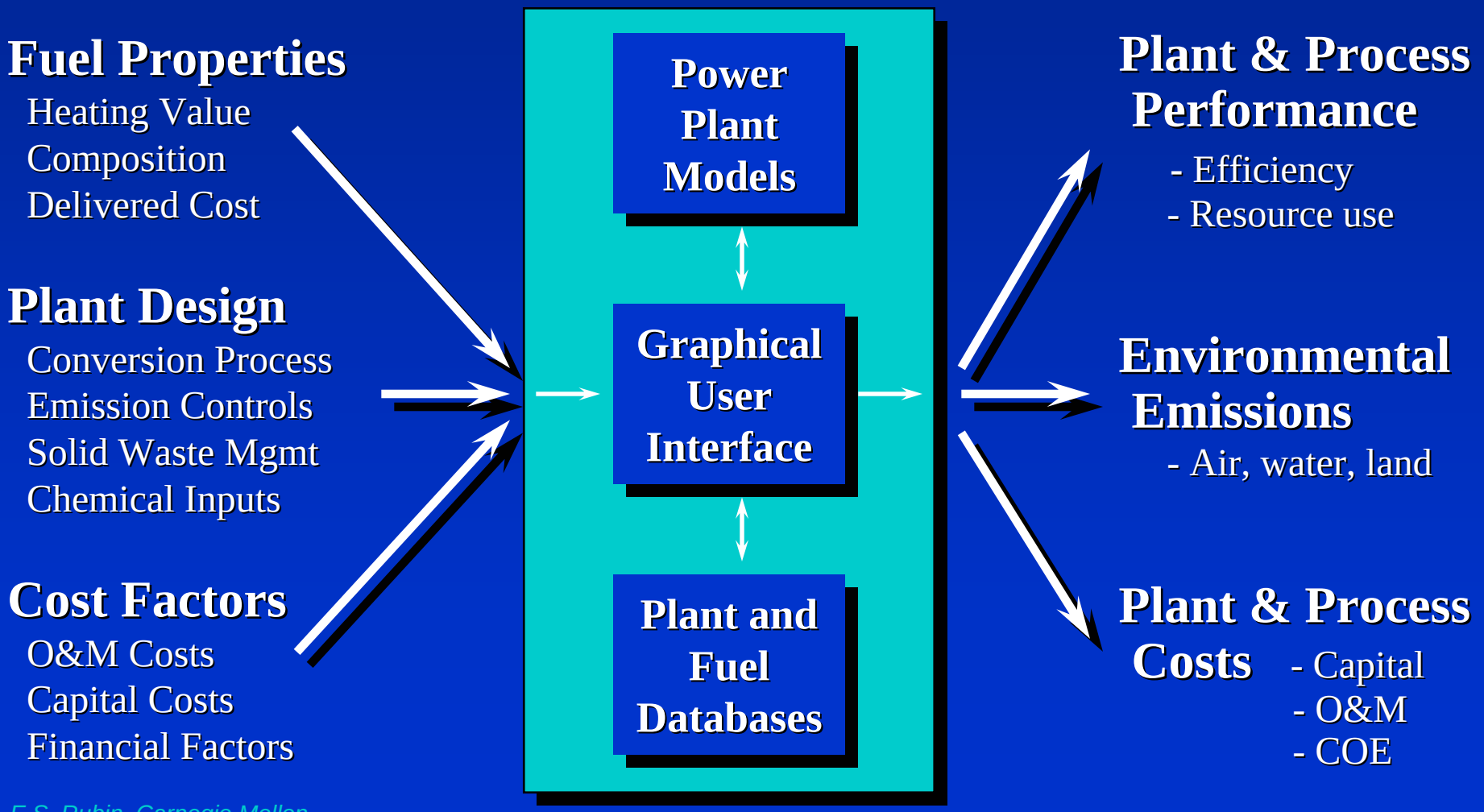
The IECM

- A desktop computer model developed for DOE/NETL
- Provides preliminary design estimates of performance, emissions, costs and uncertainties:
  - PC, NGCC and IGCC plants
  - Emission control systems
  - CO_2 capture and storage options (pre- and post-combustion, oxy-combustion, transport, storage)
- Hundreds of users worldwide



IECM Software Package

(Free at: www.iecm-online.com)



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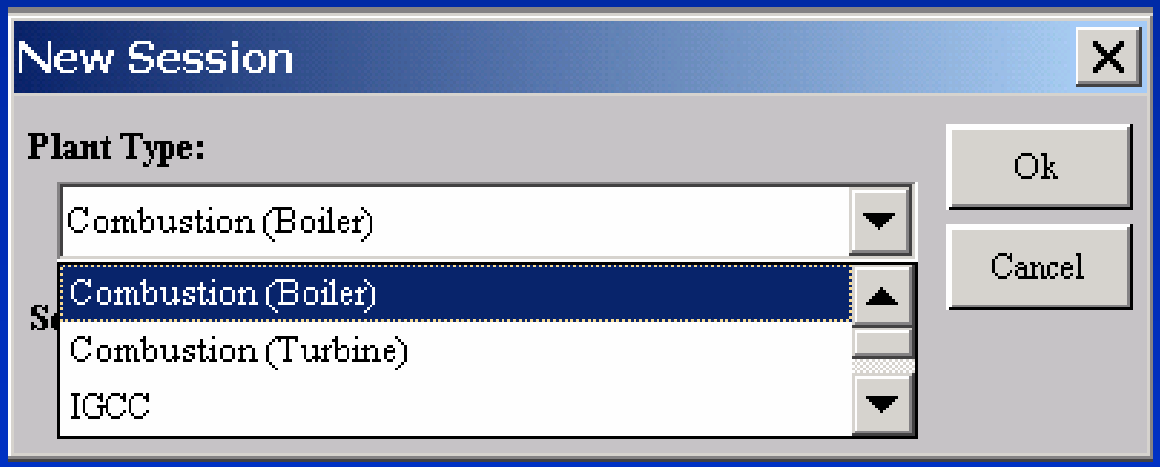
Advanced Power Systems with CO_2 Capture and Storage (CCS)

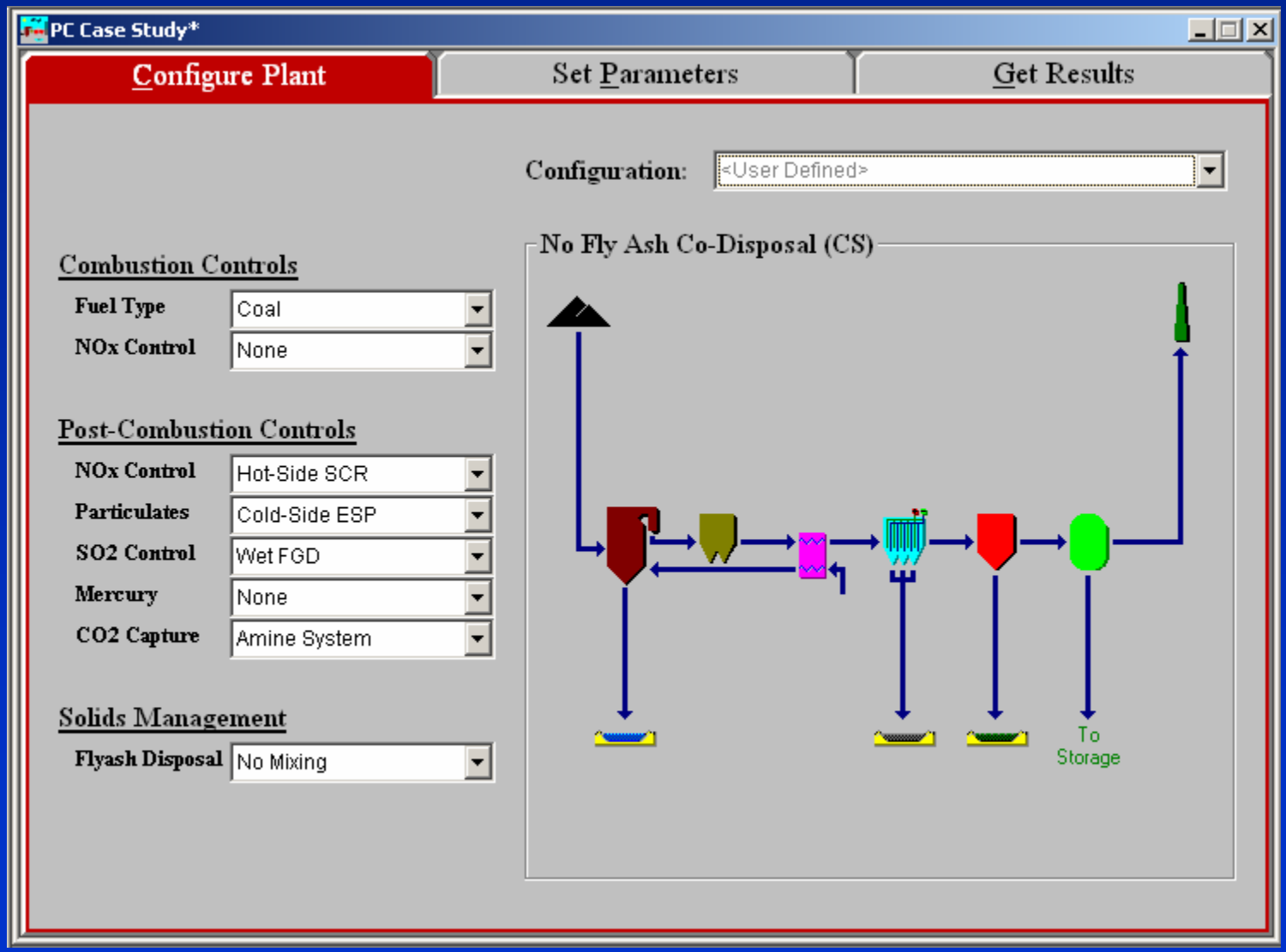
- PC plant with post-combustion capture
- PC plant with oxyfuel combustion
- NGCC plant with post-combustion capture
- IGCC plant with pre-combustion capture

A Quick Tour of the IECM

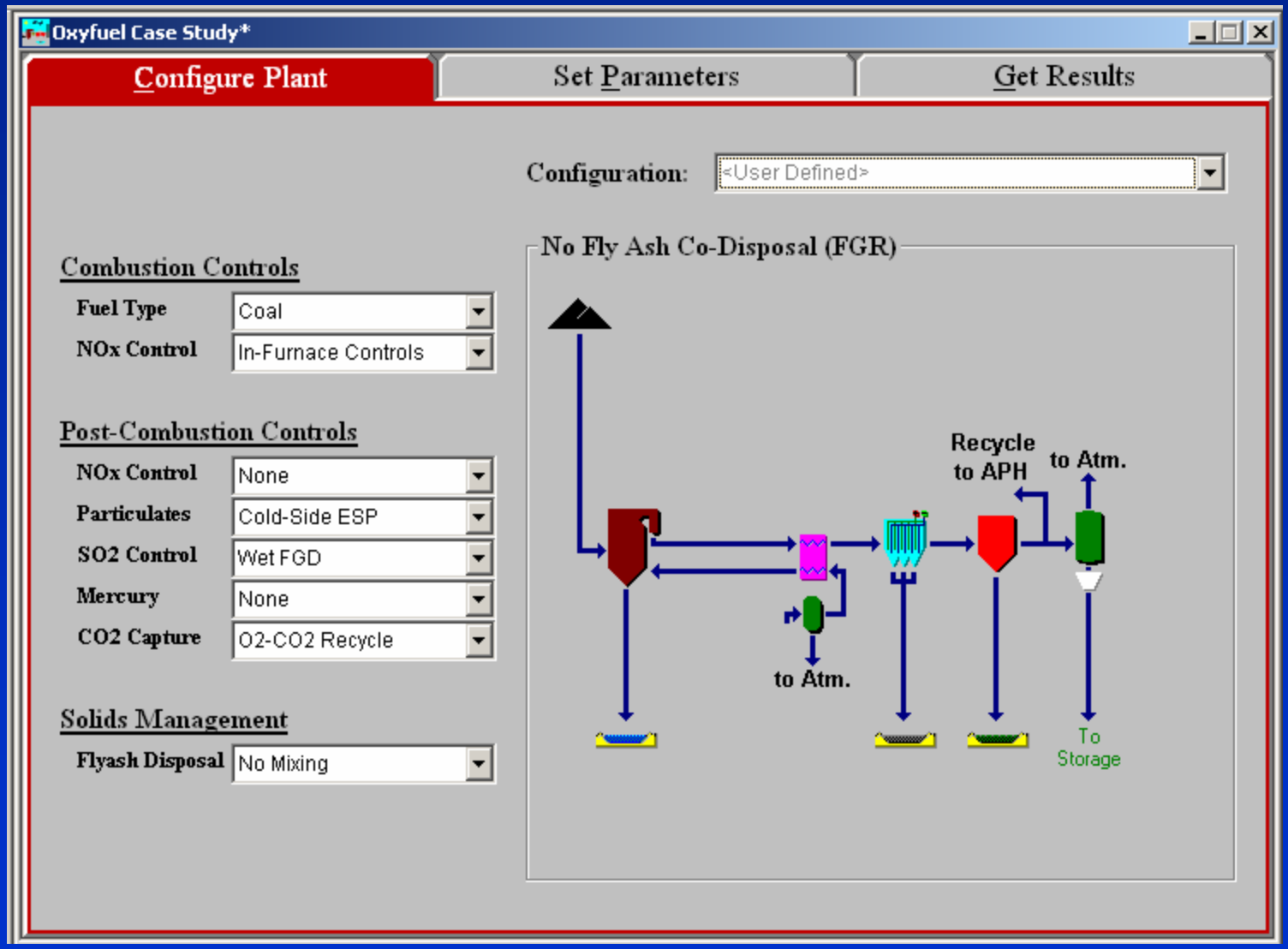
Select Plant Type



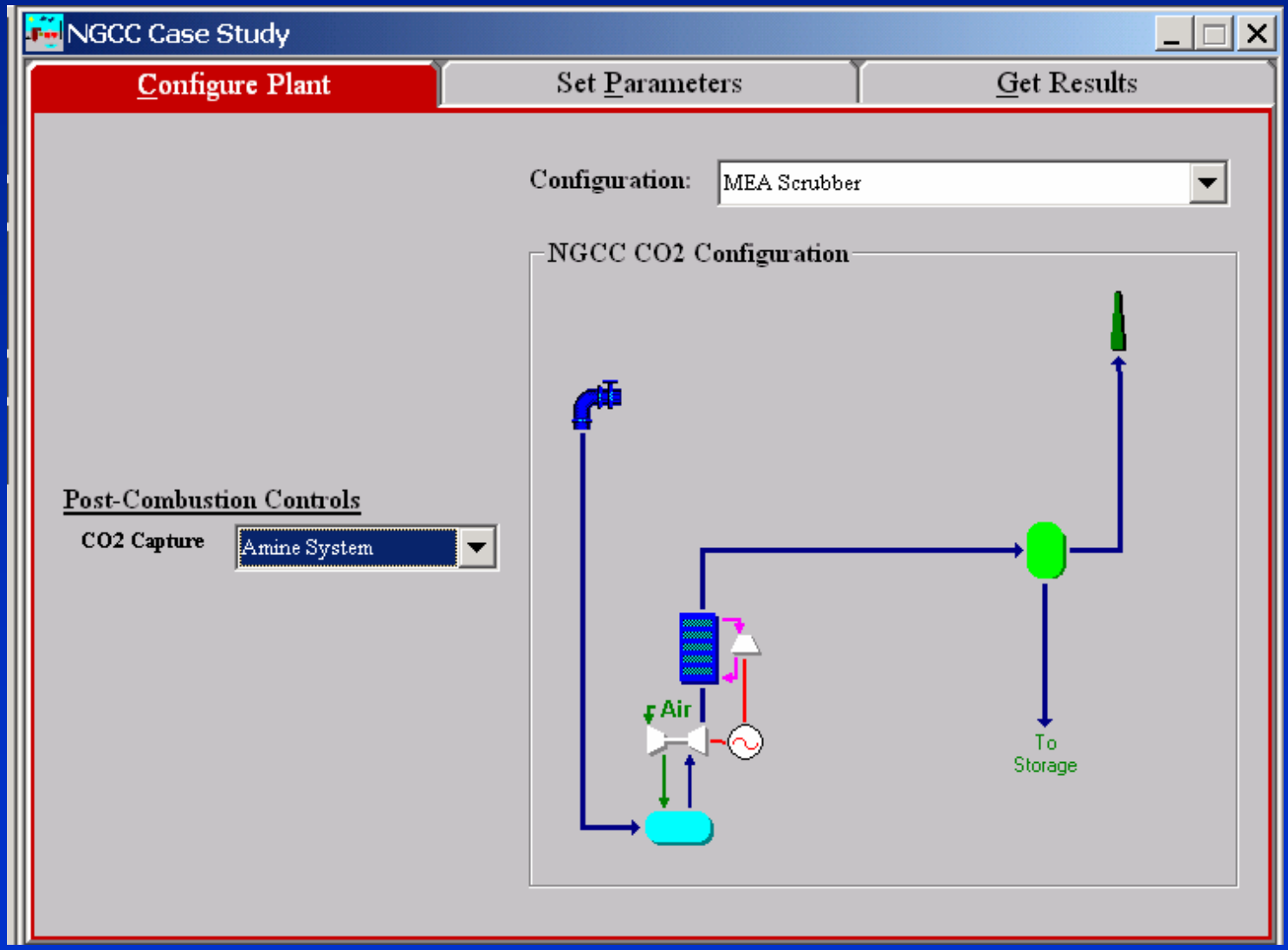
PC Plant with CCS



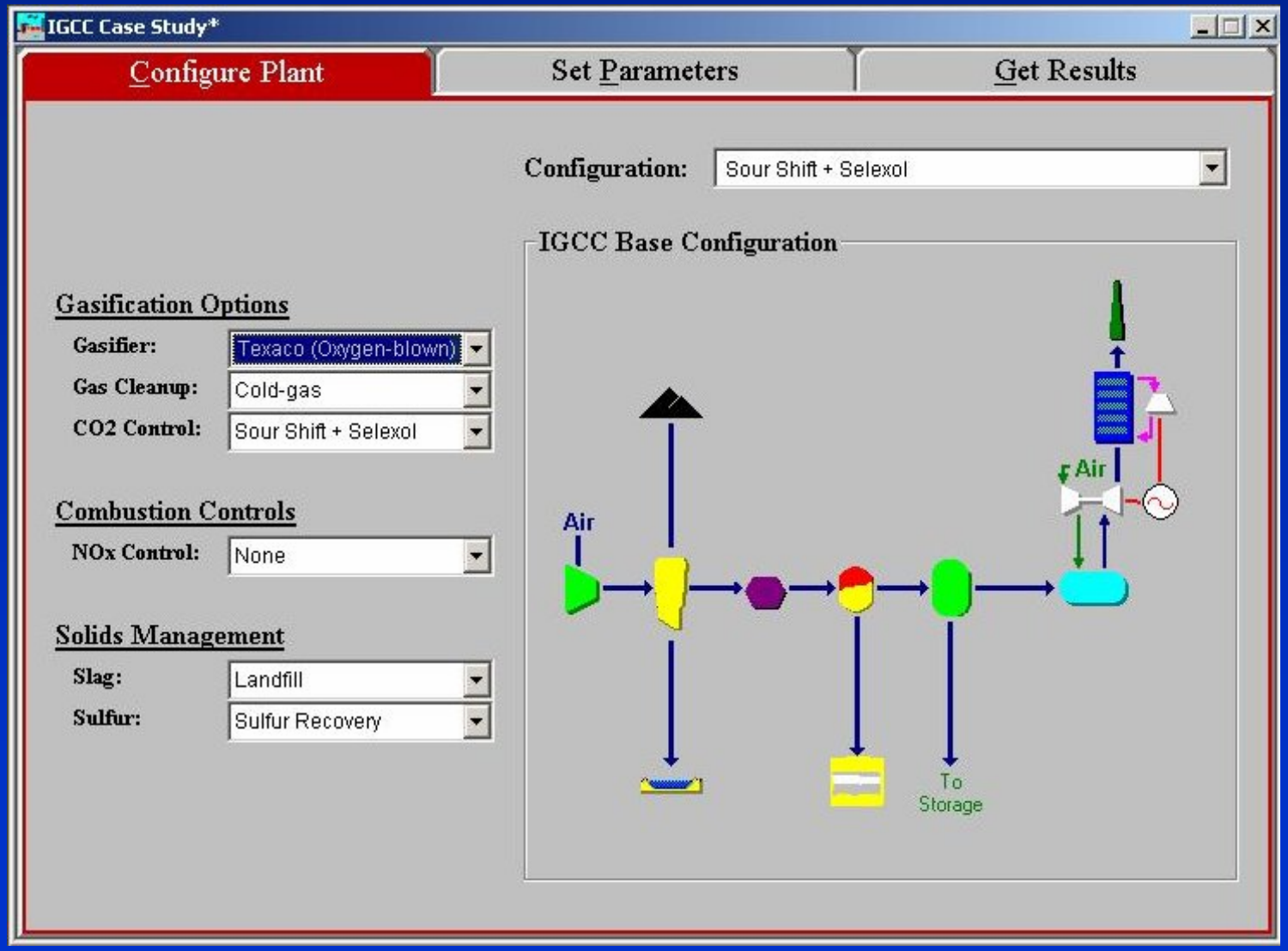
Oxyfuel Plant with CCS



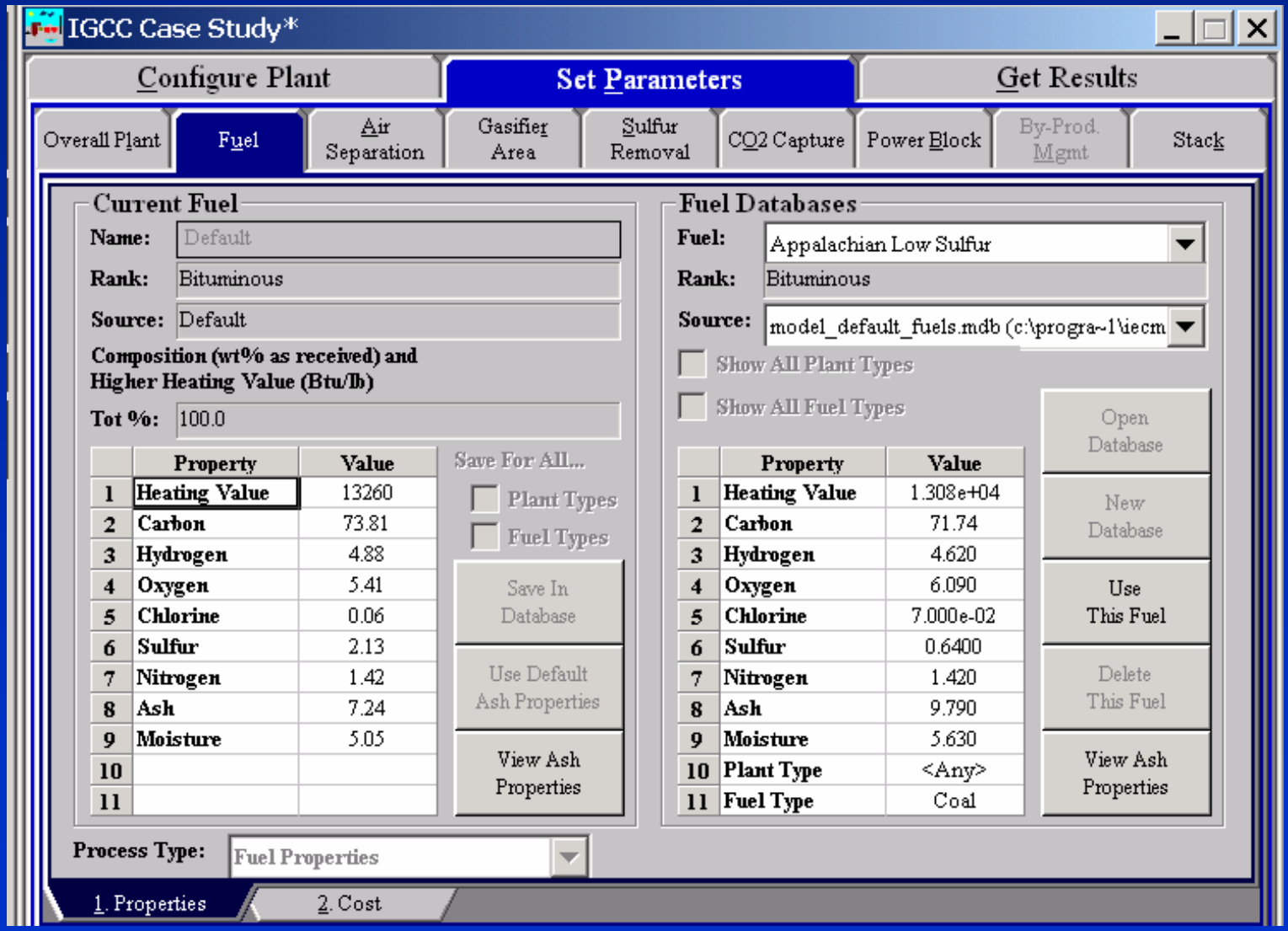
NGCC Plant with CCS



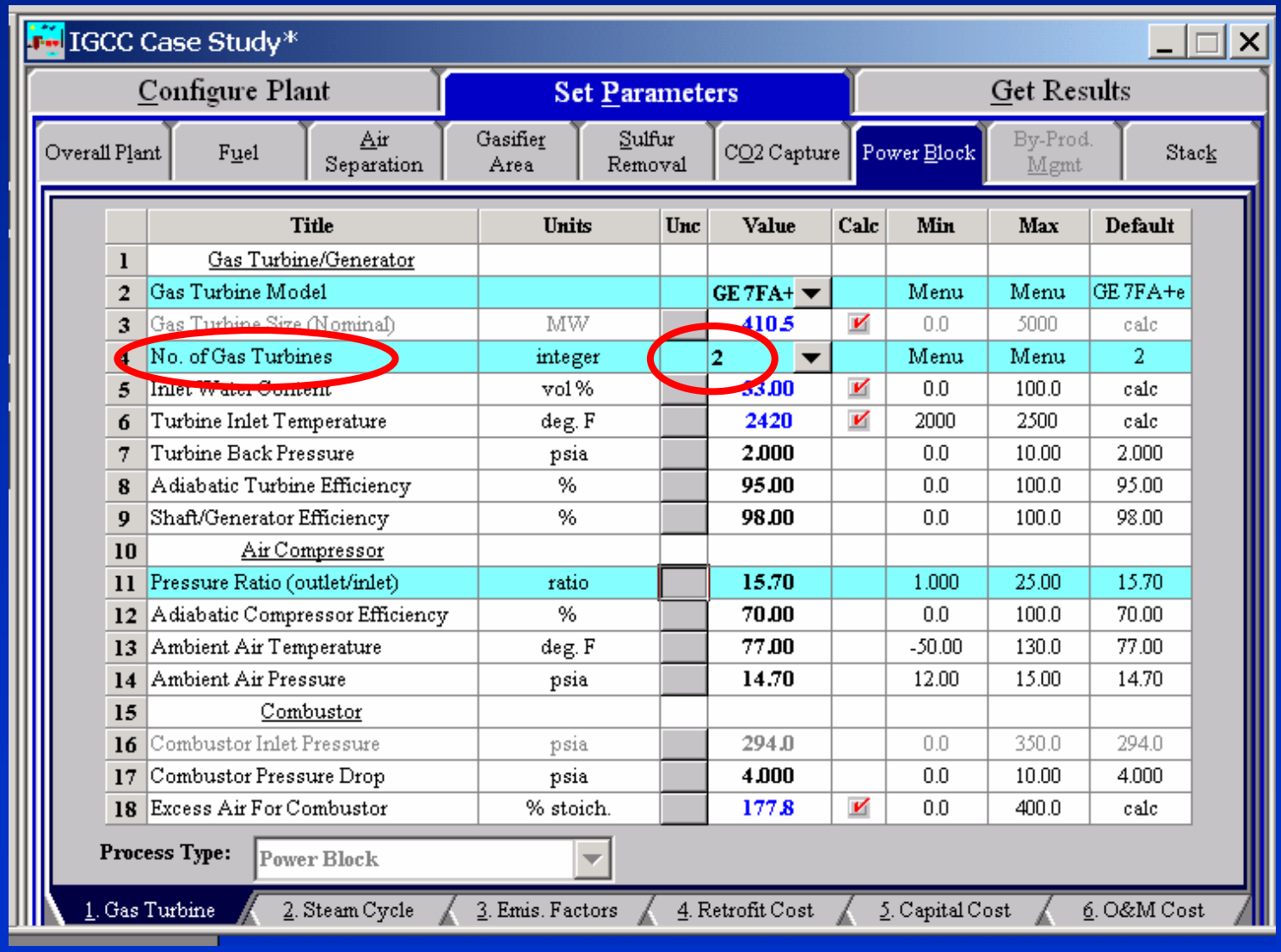
IGCC Plant with CCS



Specify Fuel Properties

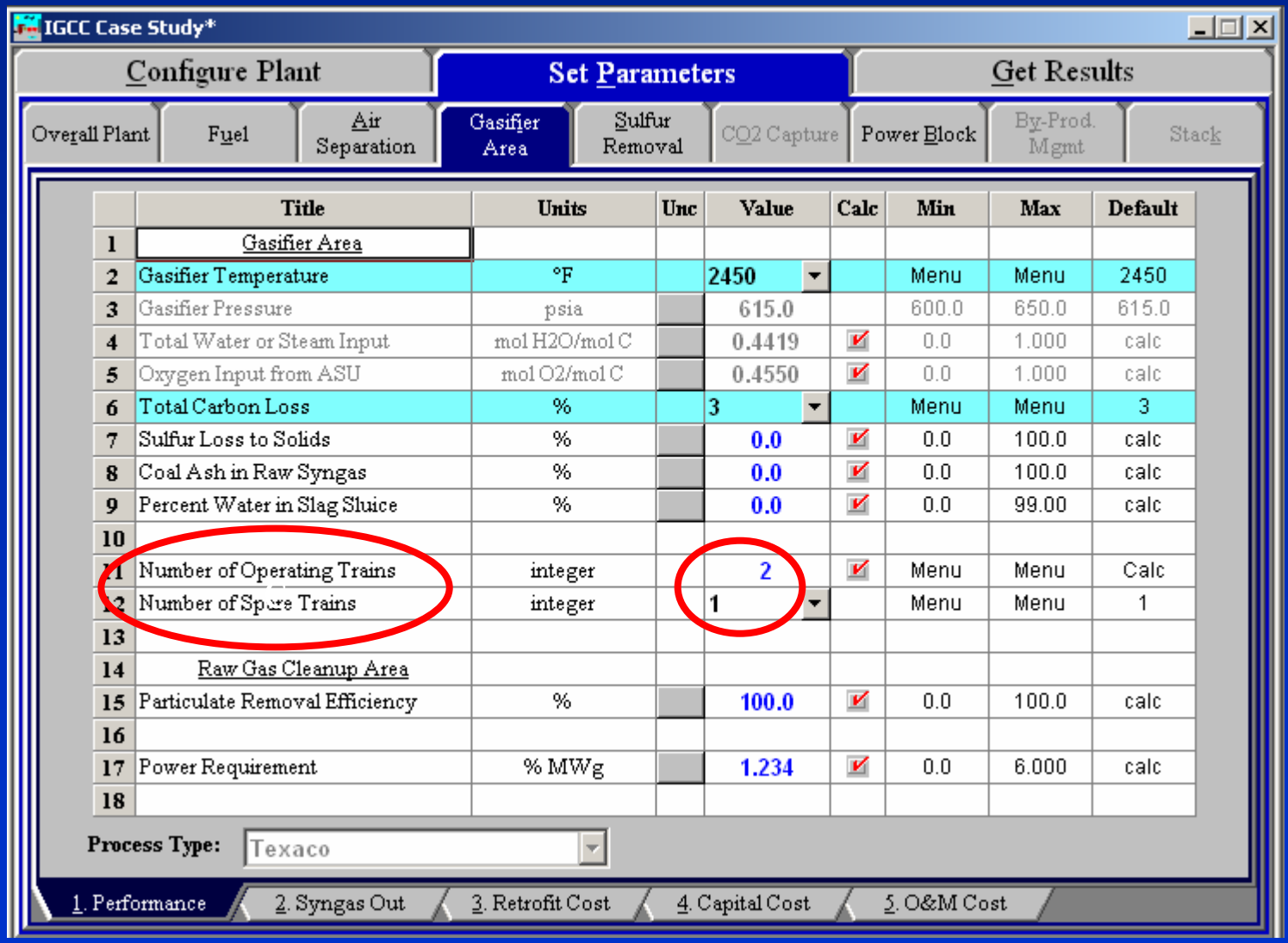


Set Power Block Parameters



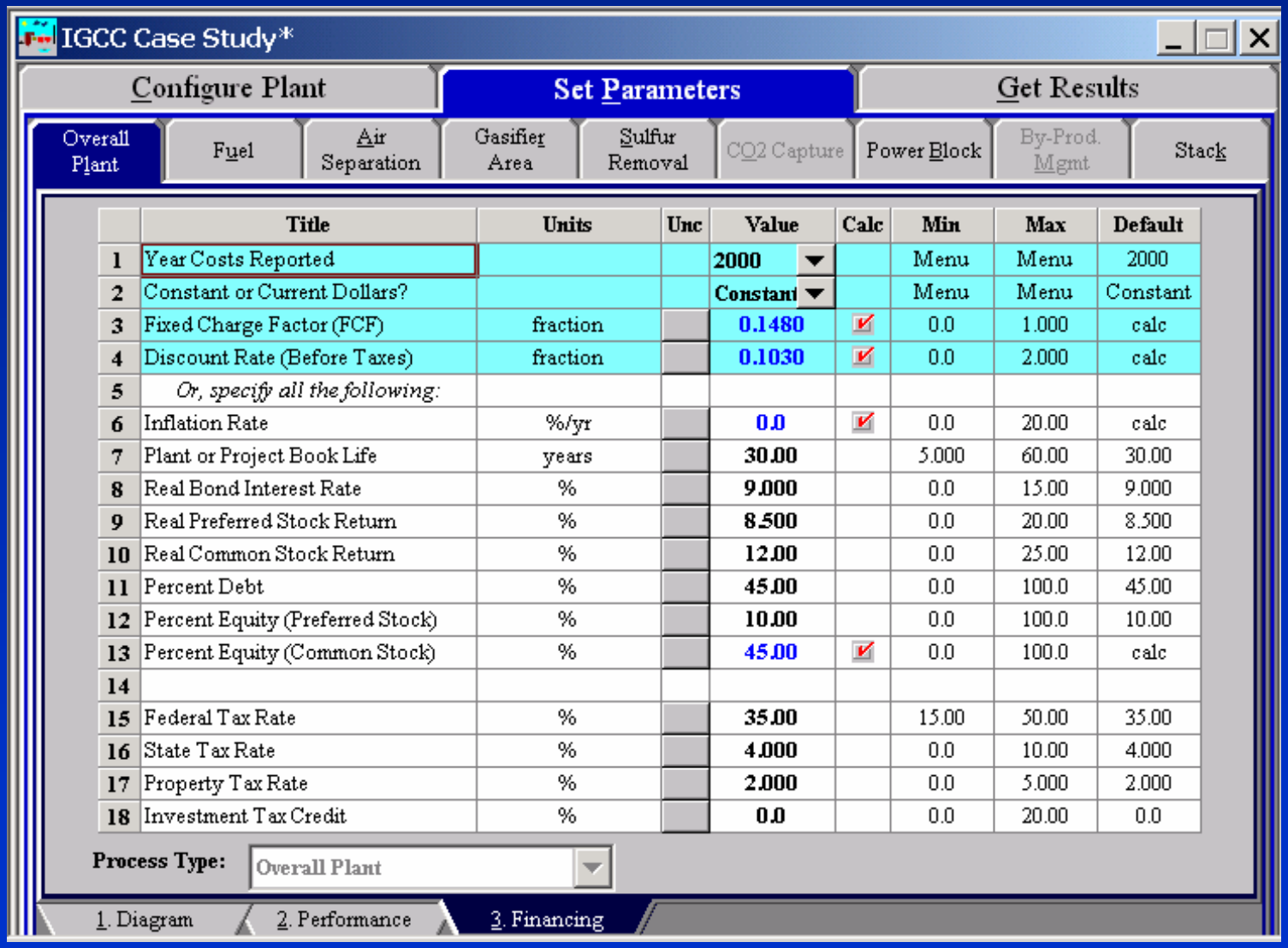
	Title	Units	Unc	Value	Calc	Min	Max	Default
1	Gas Turbine/Generator							
2	Gas Turbine Model			GE 7FA+		Menu	Menu	GE 7FA+e
3	Gas Turbine Size (Nominal)	MW		410.5	☑	0.0	5000	calc
4	No. of Gas Turbines	integer		2		Menu	Menu	2
5	Inlet Water Content	vol %		3.00	☑	0.0	100.0	calc
6	Turbine Inlet Temperature	deg. F		2420	☑	2000	2500	calc
7	Turbine Back Pressure	psia		2.000		0.0	10.00	2.000
8	Adiabatic Turbine Efficiency	%		95.00		0.0	100.0	95.00
9	Shaft/Generator Efficiency	%		98.00		0.0	100.0	98.00
10	Air Compressor							
11	Pressure Ratio (outlet/inlet)	ratio		15.70		1.000	25.00	15.70
12	Adiabatic Compressor Efficiency	%		70.00		0.0	100.0	70.00
13	Ambient Air Temperature	deg. F		77.00		-50.00	130.0	77.00
14	Ambient Air Pressure	psia		14.70		12.00	15.00	14.70
15	Combustor							
16	Combustor Inlet Pressure	psia		294.0		0.0	350.0	294.0
17	Combustor Pressure Drop	psia		4.000		0.0	10.00	4.000
18	Excess Air For Combustor	% stoich.		177.8	☑	0.0	400.0	calc

Specify Gasifier Parameters



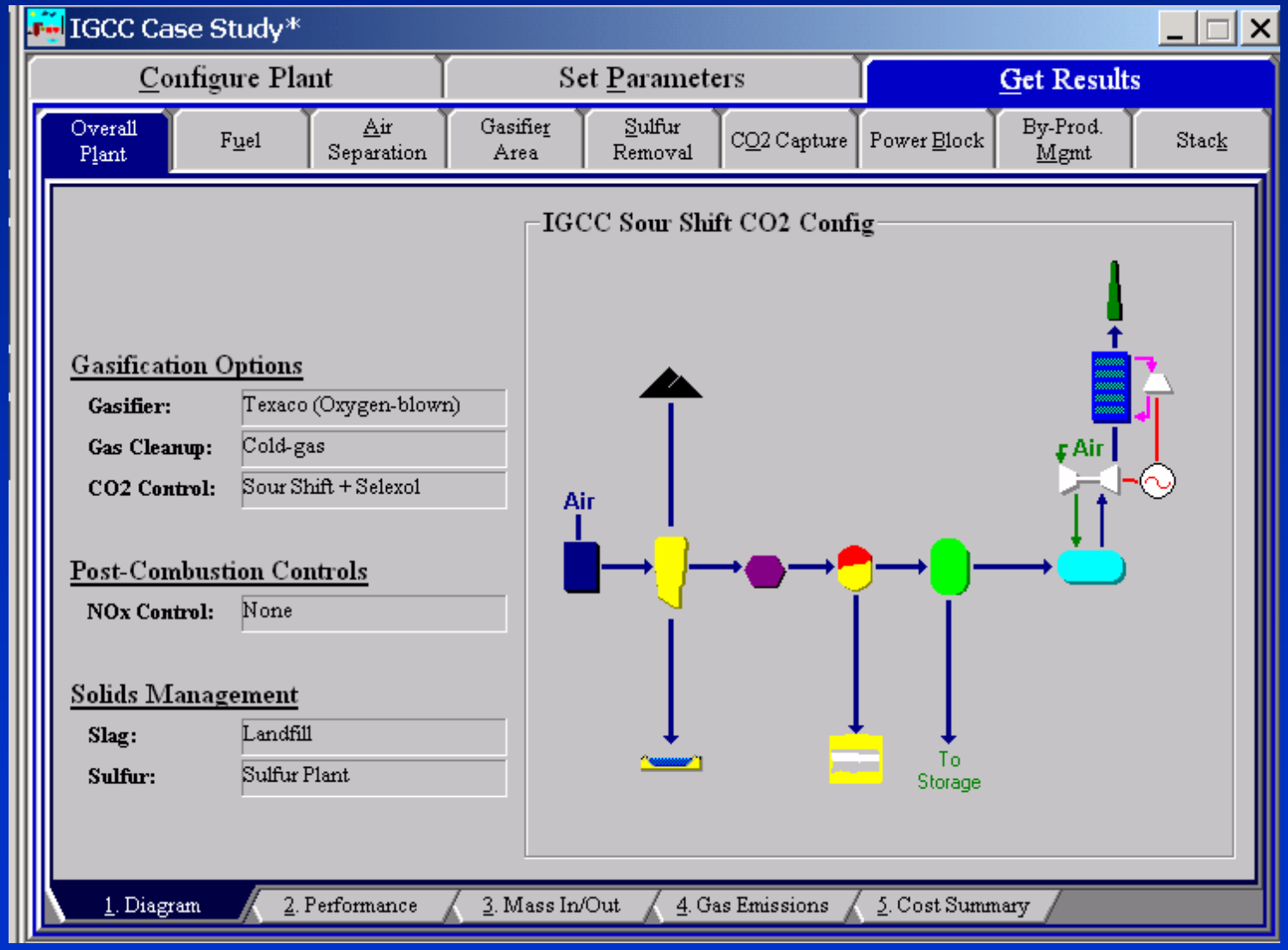
	Title	Units	Unc	Value	Calc	Min	Max	Default
1	Gasifier Area							
2	Gasifier Temperature	°F		2450		Menu	Menu	2450
3	Gasifier Pressure	psia		615.0		600.0	650.0	615.0
4	Total Water or Steam Input	mol H2O/mol C		0.4419	☑	0.0	1.000	calc
5	Oxygen Input from ASU	mol O2/mol C		0.4550	☑	0.0	1.000	calc
6	Total Carbon Loss	%		3		Menu	Menu	3
7	Sulfur Loss to Solids	%		0.0	☑	0.0	100.0	calc
8	Coal Ash in Raw Syngas	%		0.0	☑	0.0	100.0	calc
9	Percent Water in Slag Sluice	%		0.0	☑	0.0	99.00	calc
10								
11	Number of Operating Trains	integer		2	☑	Menu	Menu	Calc
12	Number of Spare Trains	integer		1		Menu	Menu	1
13								
14	Raw Gas Cleanup Area							
15	Particulate Removal Efficiency	%		100.0	☑	0.0	100.0	calc
16								
17	Power Requirement	% MWg		1.234	☑	0.0	6.000	calc
18								

Set Financial Parameters

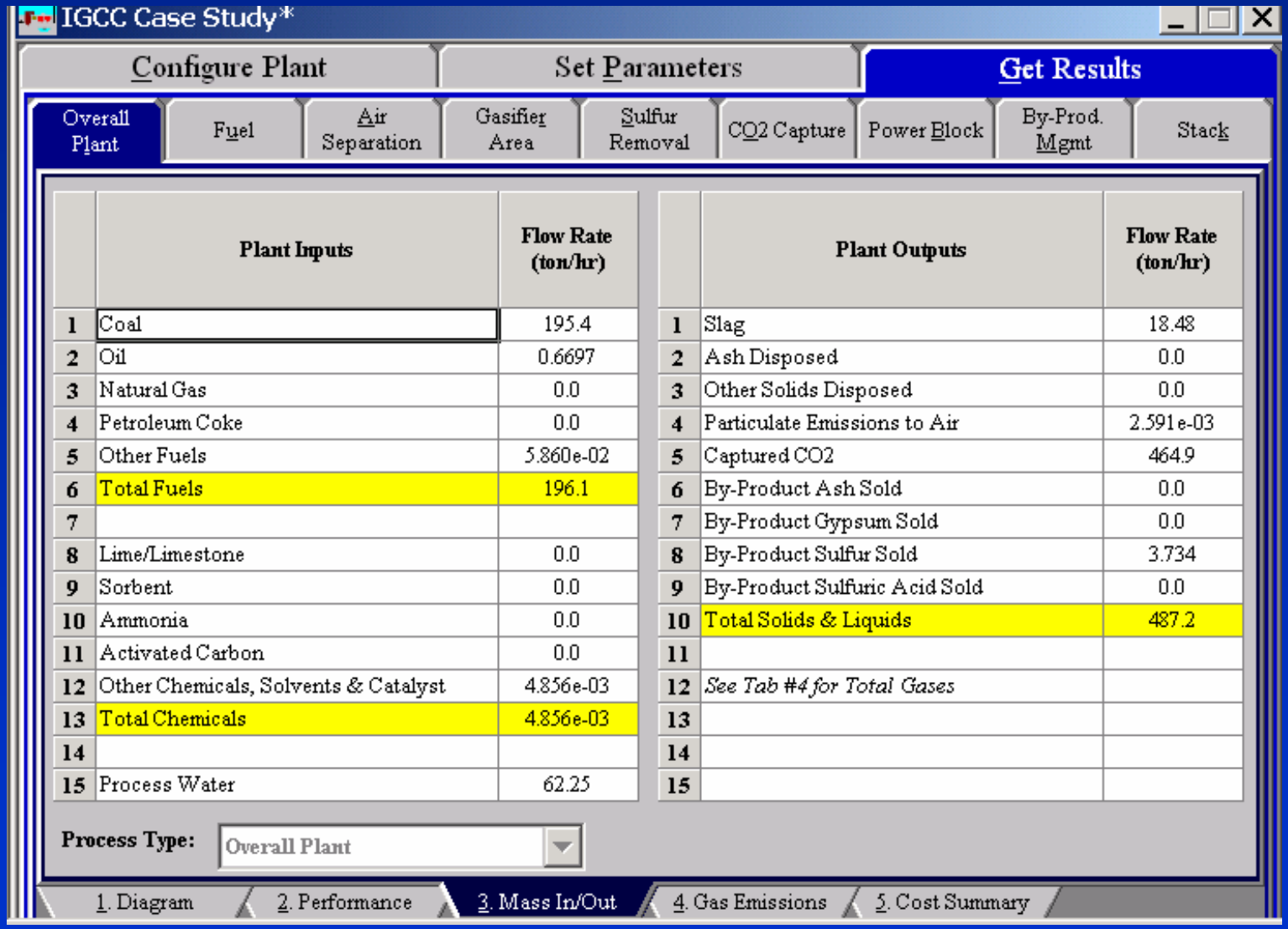


	Title	Units	Unc	Value	Calc	Min	Max	Default
1	Year Costs Reported			2000		Menu	Menu	2000
2	Constant or Current Dollars?			Constant		Menu	Menu	Constant
3	Fixed Charge Factor (FCF)	fraction		0.1480	☑	0.0	1.000	calc
4	Discount Rate (Before Taxes)	fraction		0.1030	☑	0.0	2.000	calc
5	*Or, specify all the following:*							
6	Inflation Rate	%/yr		0.0	☑	0.0	20.00	calc
7	Plant or Project Book Life	years		30.00		5.000	60.00	30.00
8	Real Bond Interest Rate	%		9.000		0.0	15.00	9.000
9	Real Preferred Stock Return	%		8.500		0.0	20.00	8.500
10	Real Common Stock Return	%		12.00		0.0	25.00	12.00
11	Percent Debt	%		45.00		0.0	100.0	45.00
12	Percent Equity (Preferred Stock)	%		10.00		0.0	100.0	10.00
13	Percent Equity (Common Stock)	%		45.00	☑	0.0	100.0	calc
14								
15	Federal Tax Rate	%		35.00		15.00	50.00	35.00
16	State Tax Rate	%		4.000		0.0	10.00	4.000
17	Property Tax Rate	%		2.000		0.0	5.000	2.000
18	Investment Tax Credit	%		0.0		0.0	20.00	0.0

Get Results for Overall Plant



Results for Plant Mass Flows



	Plant Inputs	Flow Rate (ton/hr)
1	Coal	195.4
2	Oil	0.6697
3	Natural Gas	0.0
4	Petroleum Coke	0.0
5	Other Fuels	5.860e-02
6	Total Fuels	196.1
7		
8	Lime/Limestone	0.0
9	Sorbent	0.0
10	Ammonia	0.0
11	Activated Carbon	0.0
12	Other Chemicals, Solvents & Catalyst	4.856e-03
13	Total Chemicals	4.856e-03
14		
15	Process Water	62.25

	Plant Outputs	Flow Rate (ton/hr)
1	Slag	18.48
2	Ash Disposed	0.0
3	Other Solids Disposed	0.0
4	Particulate Emissions to Air	2.591e-03
5	Captured CO2	464.9
6	By-Product Ash Sold	0.0
7	By-Product Gypsum Sold	0.0
8	By-Product Sulfur Sold	3.734
9	By-Product Sulfuric Acid Sold	0.0
10	Total Solids & Liquids	487.2
11		
12	*See Tab #4 for Total Gases*	
13		
14		
15		

Results for Plant Costs

IGCC Case Study*

Configure Plant | Set Parameters | Get Results

Overall Plant | Fuel | Air Separation | Gasifier Area | Sulfur Removal | CO2 Capture | Power Block | By-Prod. Mgmt | Stack

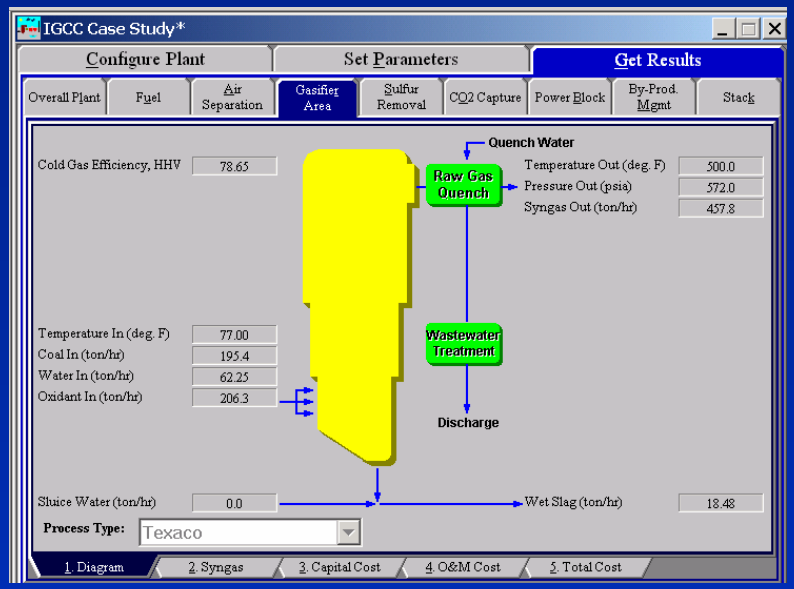
	Technology	Capital Required (M$)	Capital Required ($/kW-net)	Revenue Required (M$/yr)	Revenue Required ($/MWh)
1	Air Separation Unit	160.2	326.1	46.47	14.39
2	Gasifier Area	242.8	494.1	87.76	27.17
3	Particulate Control	0.0	0.0	0.0	0.0
4	Sulfur Control	54.38	110.7	12.23	3.788
5	Mercury Control	0.0	0.0	0.0	0.0
6	CO2 Capture	143.9	292.8	57.34	17.75
7	Power Block	300.4	611.4	21.95	6.795
8	Post-Combustion NOx Control	0.0	0.0	0.0	0.0
9	Subtotal	901.6	1835	225.8	69.89
10	Emission Taxes	0.0	0.0	0.0	0.0
11	Total	901.6	1835	225.8	69.89
12					
13					
14					
15					

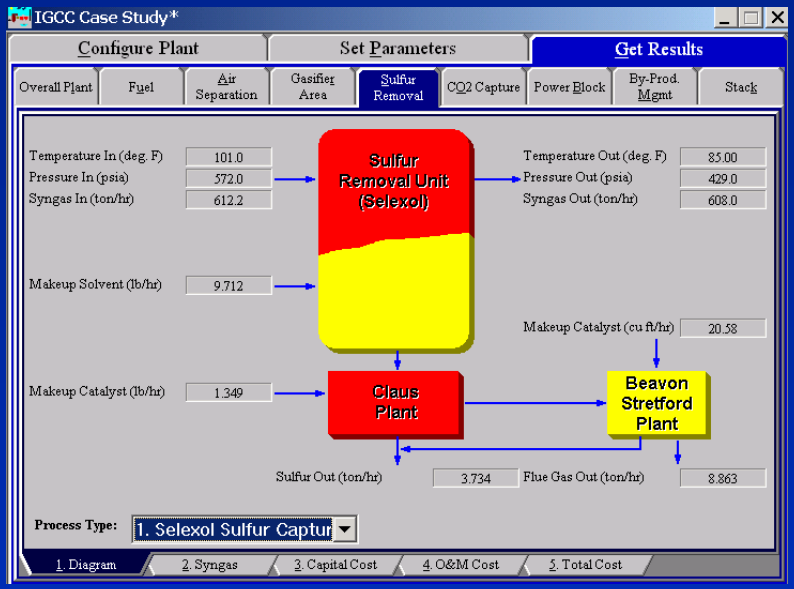
Process Type: Overall Plant

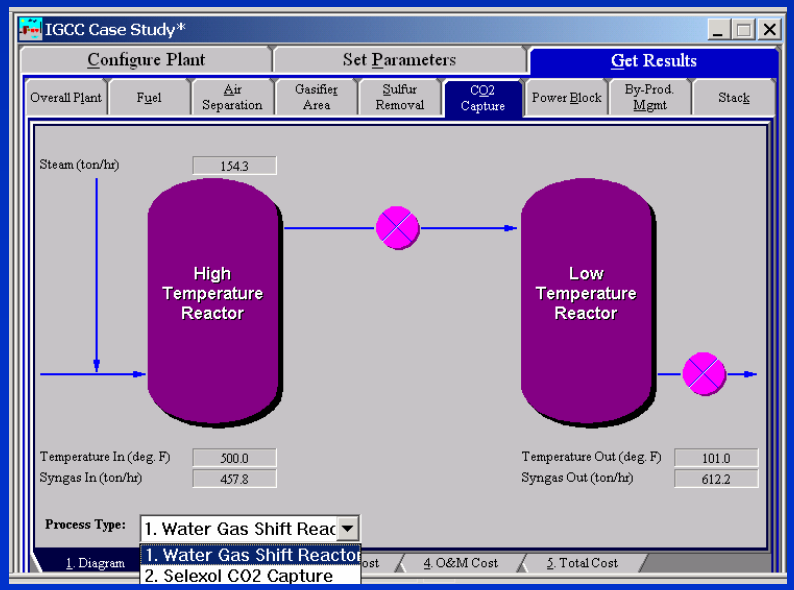
Costs are in Constant 2002 dollars.

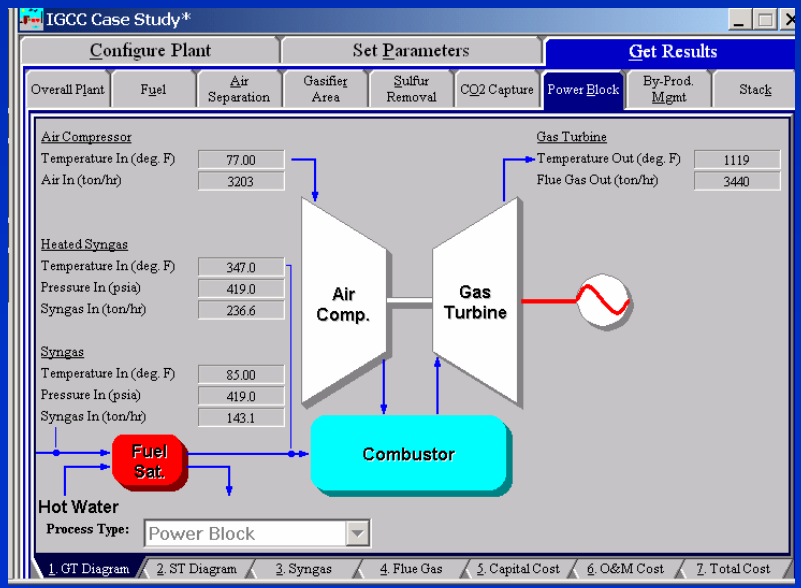
1. Diagram | 2. Performance | 3. Mass In/Out | 4. Gas Emissions | 5. Total Cost | 6. Cost Summary

Results for Specific Components







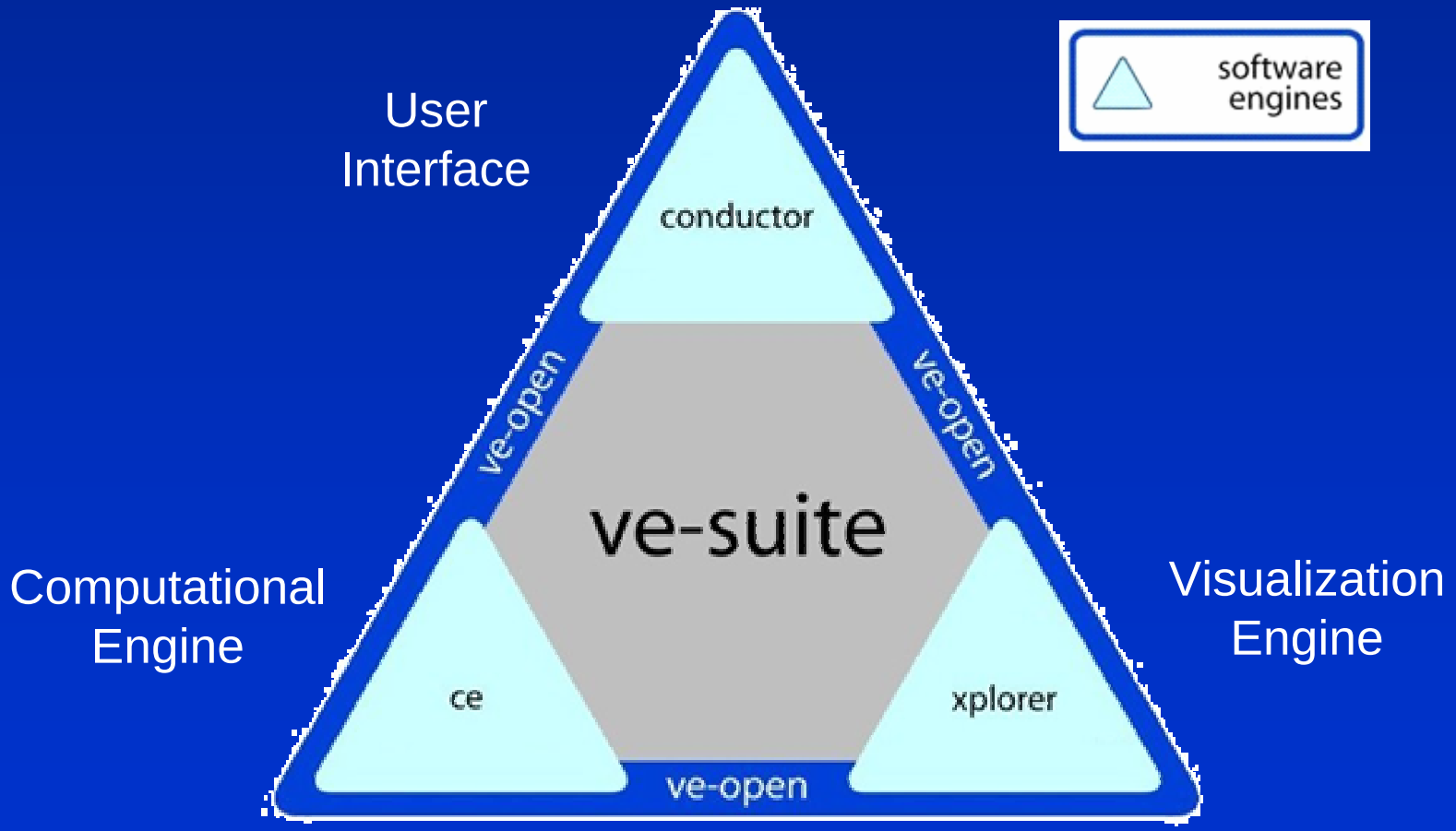


VE-Suite

The VE-Suite Environment
(http://vesuite.org)

- Key Features
  - Comprehensive graphics capabilities
  - Supports a hierarchy of component models
  - Extensibility for component models
  - Platform independence
  - Distributed computing
  - Multiple disciplines
- Software Packages
  - VRJuggler
  - Kitware's Visualization ToolKit (VTK)
  - Open Scene Graph
  - CORBA compliant libraries (ACE/TAO)
  - wxWidgets

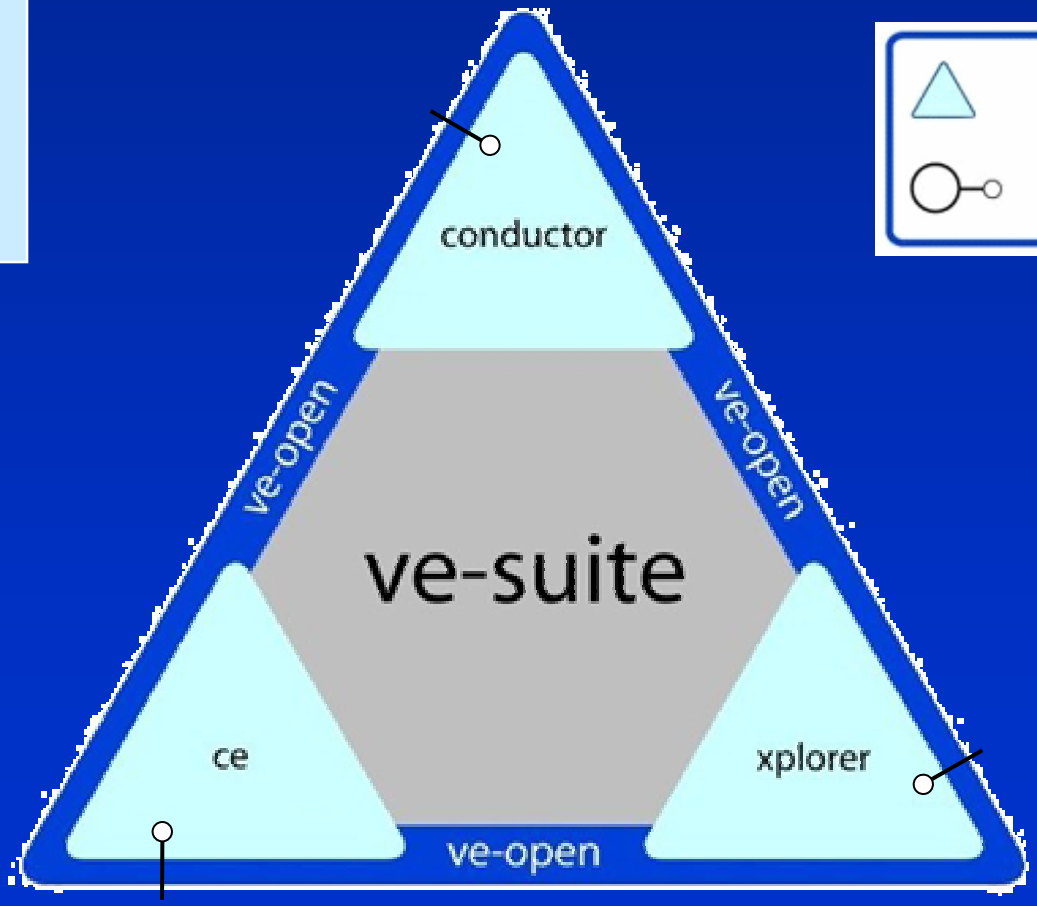
The VE-Suite Framework

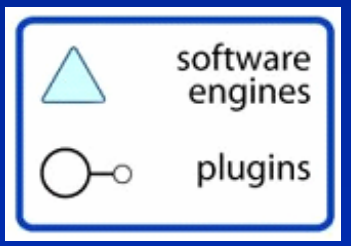


Connecting Models to VE-Suite

Model "A"

Computation Code | Graphic Objects | User Interface





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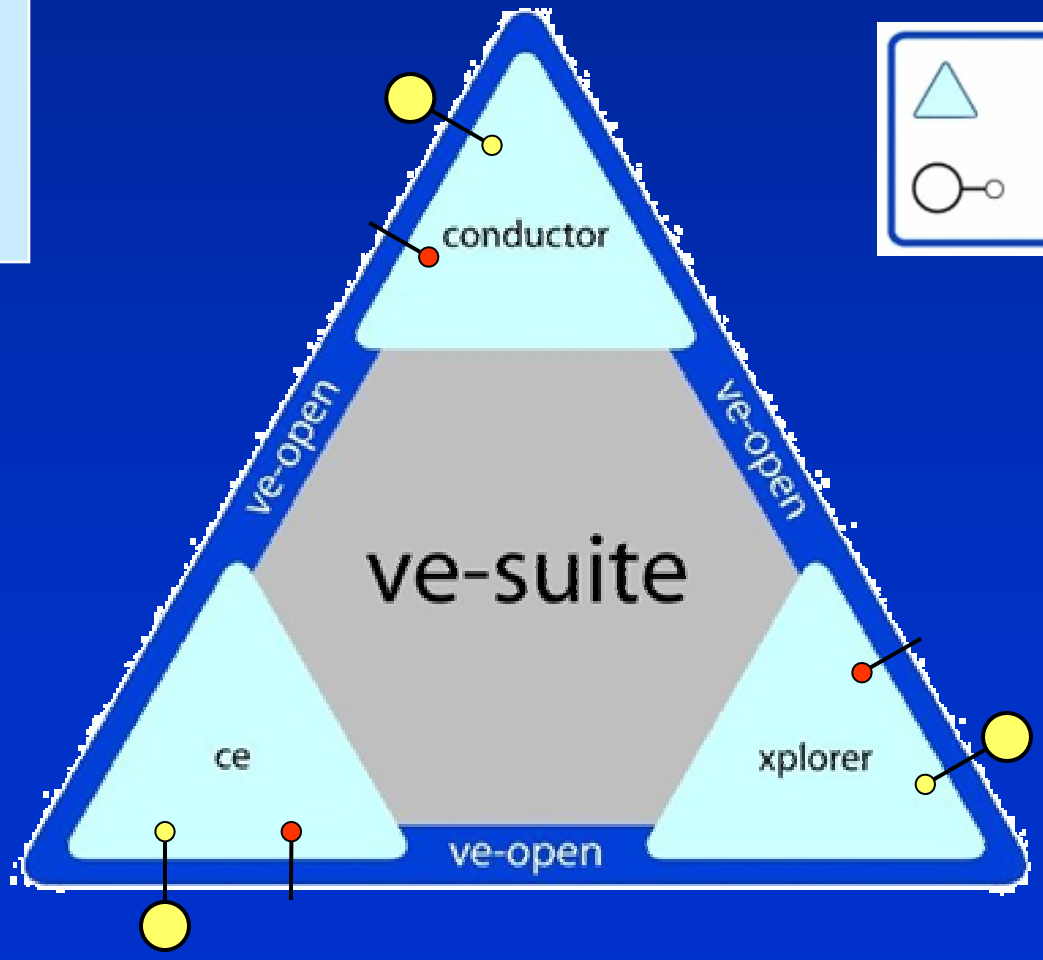
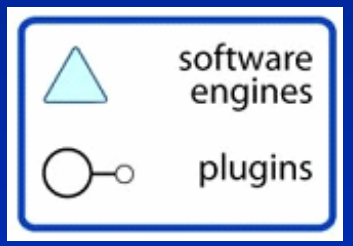
Connecting Models to VE-Suite

Model "B"

Computation Code | Graphic Objects | User Interface





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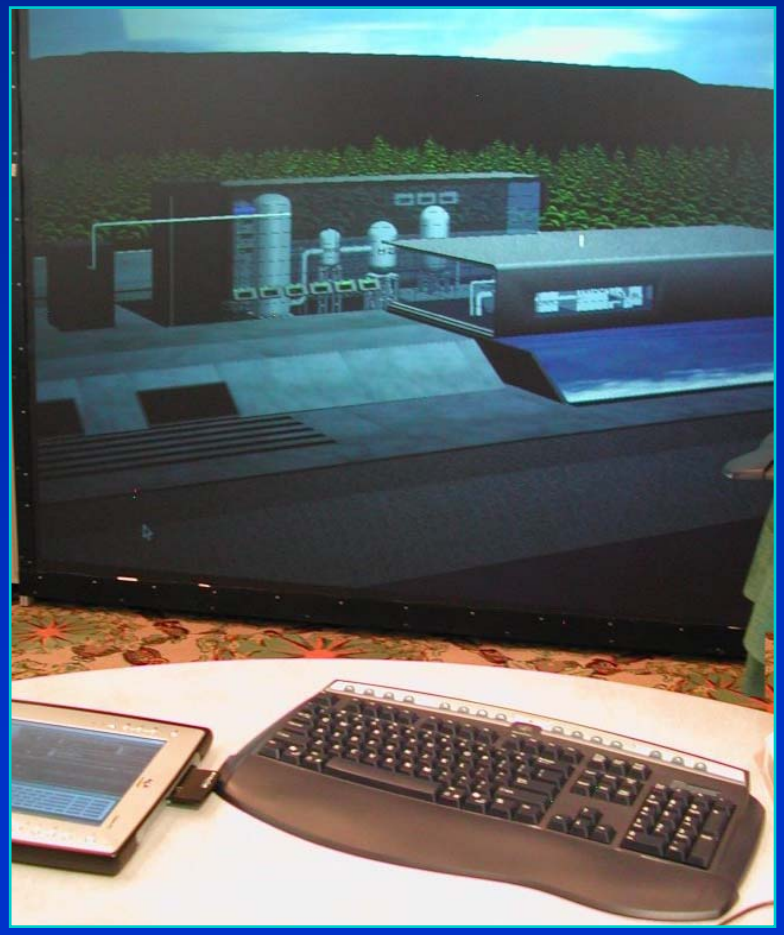
Recent Developments

Linking IECM to VE-Suite

- Cooperative effort between CMU and ISU
- Approximately 35 IECM component model plug-ins as options for configuring complete power plants
- IECM re-coded using standardized interface protocols
- All engineering and cost calculations are done in IECM; current 3-D visualizations are illustrative
- VE-Suite reports all inputs and outputs; all quantitative results in VE-Suite are “live”

Physical Setup

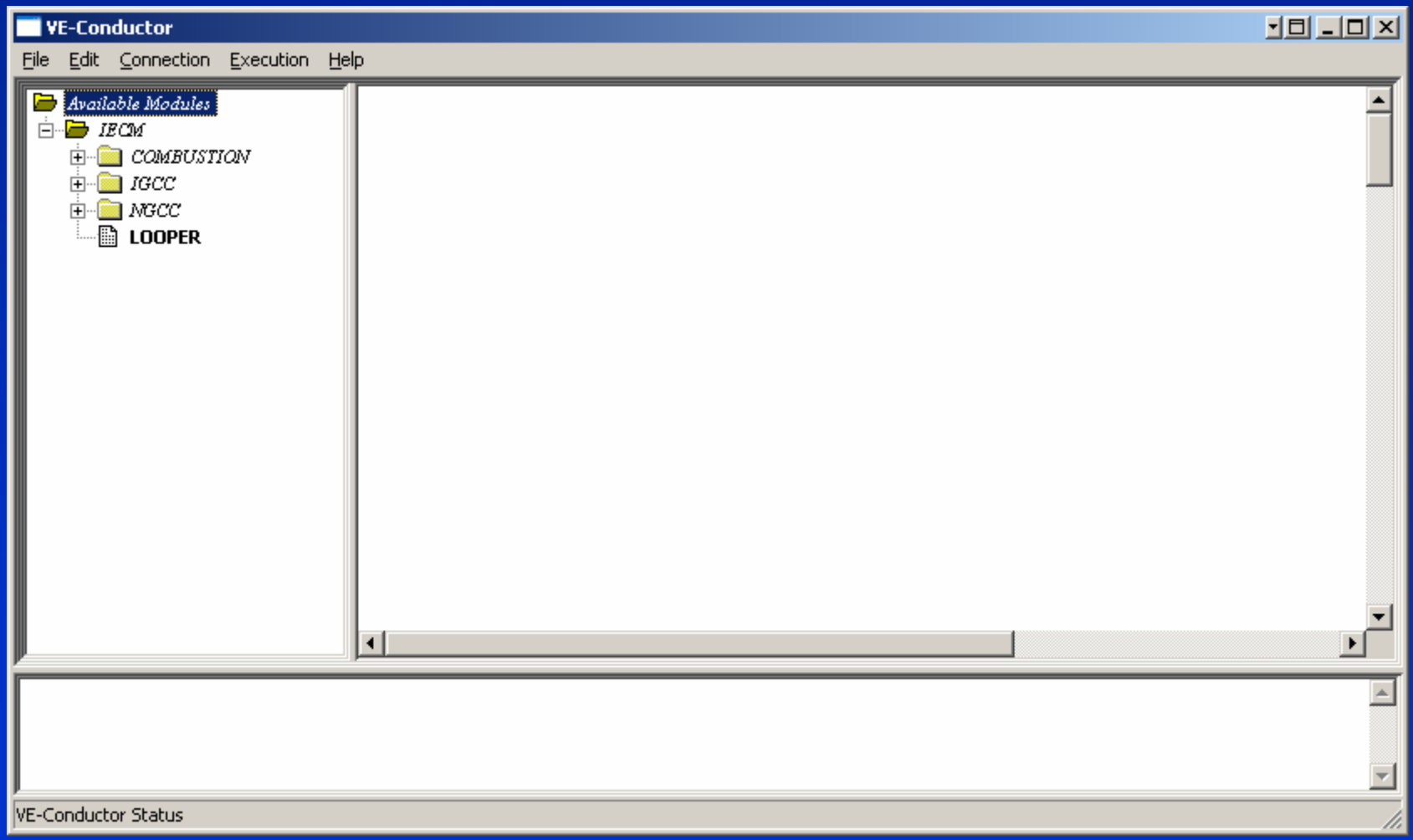


3-D wall
or monitor
display

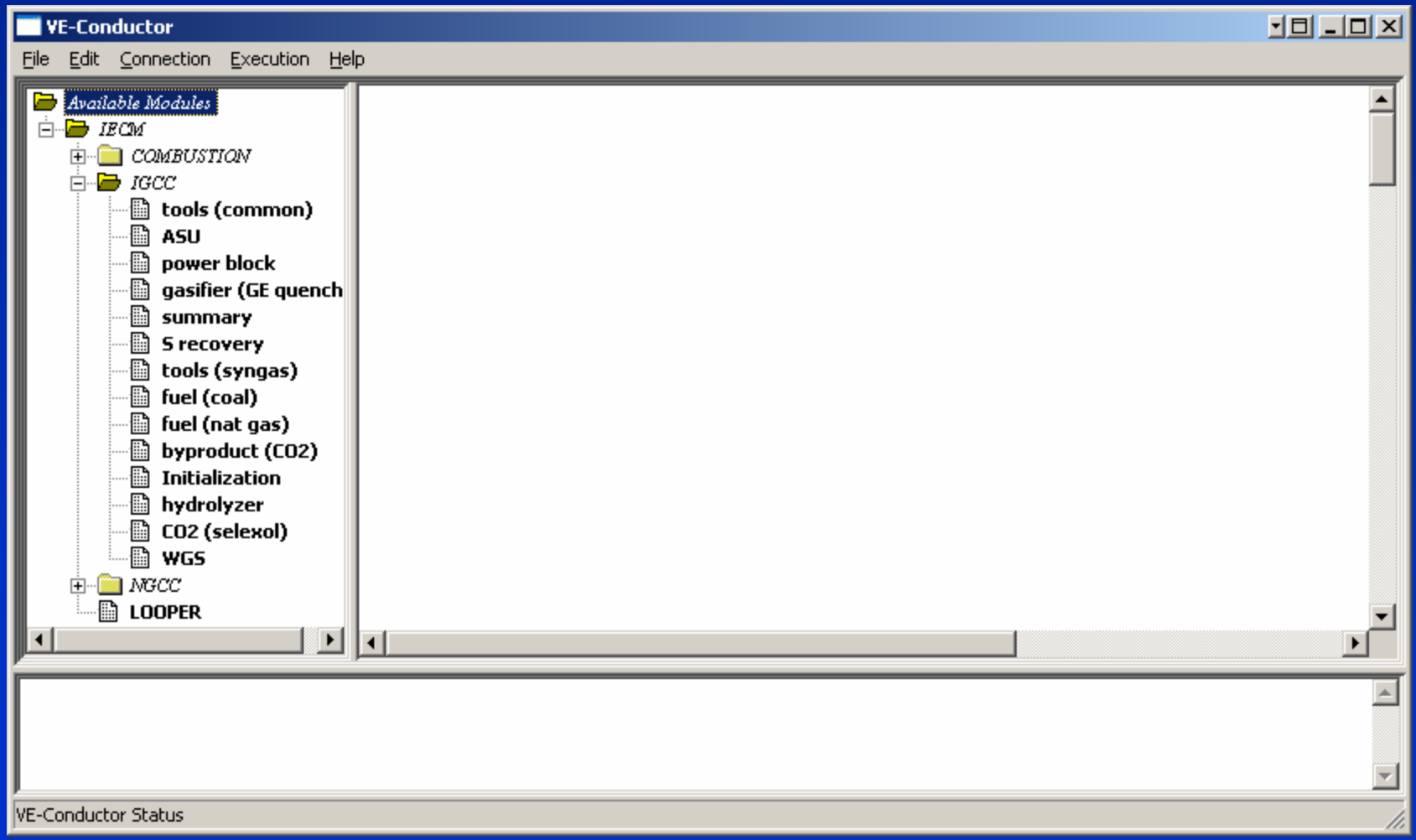
2-D interface
& keyboard
controls

Illustrative Applications to Advanced Power Systems

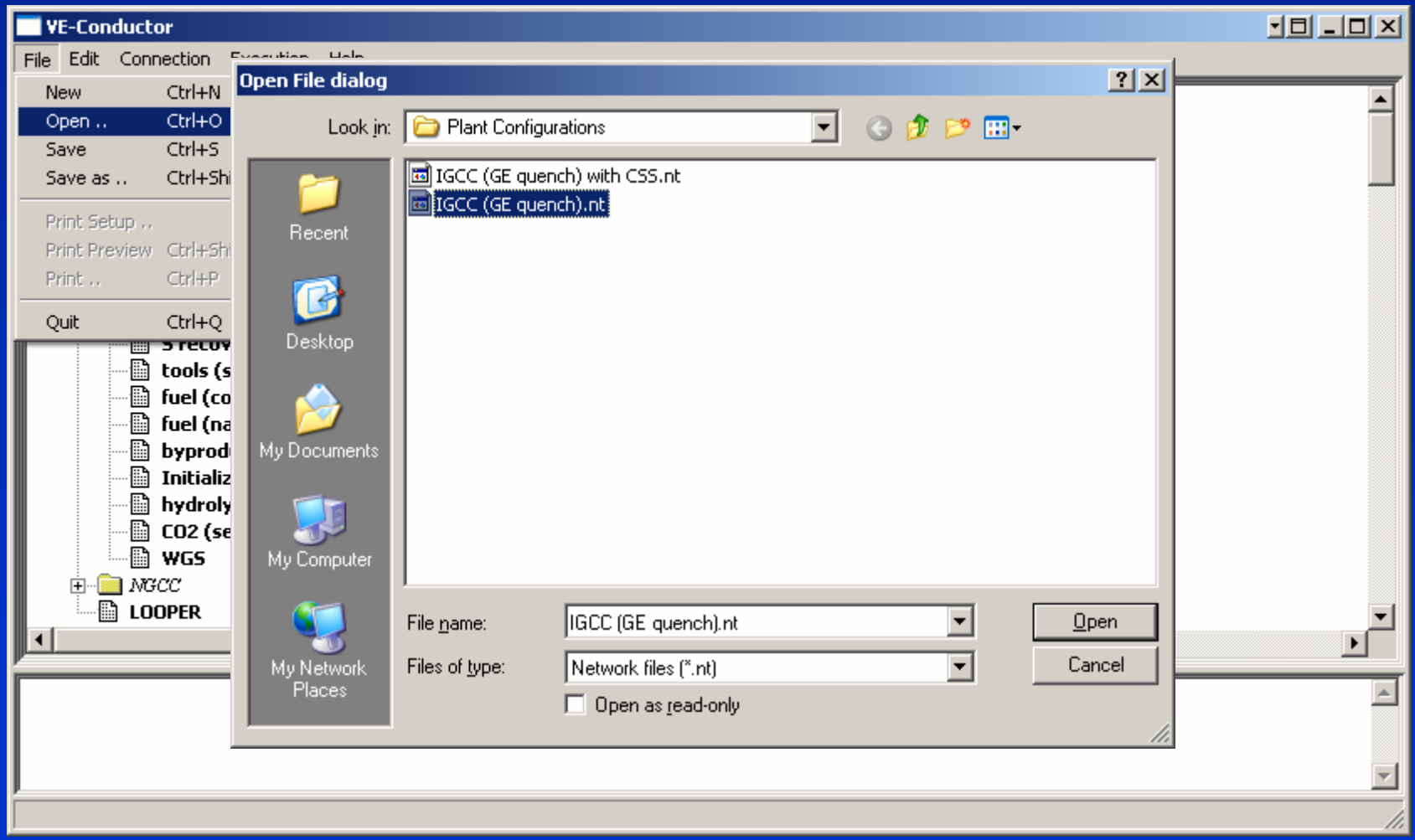
All IECM Plant Types are Now Available in VE-Suite



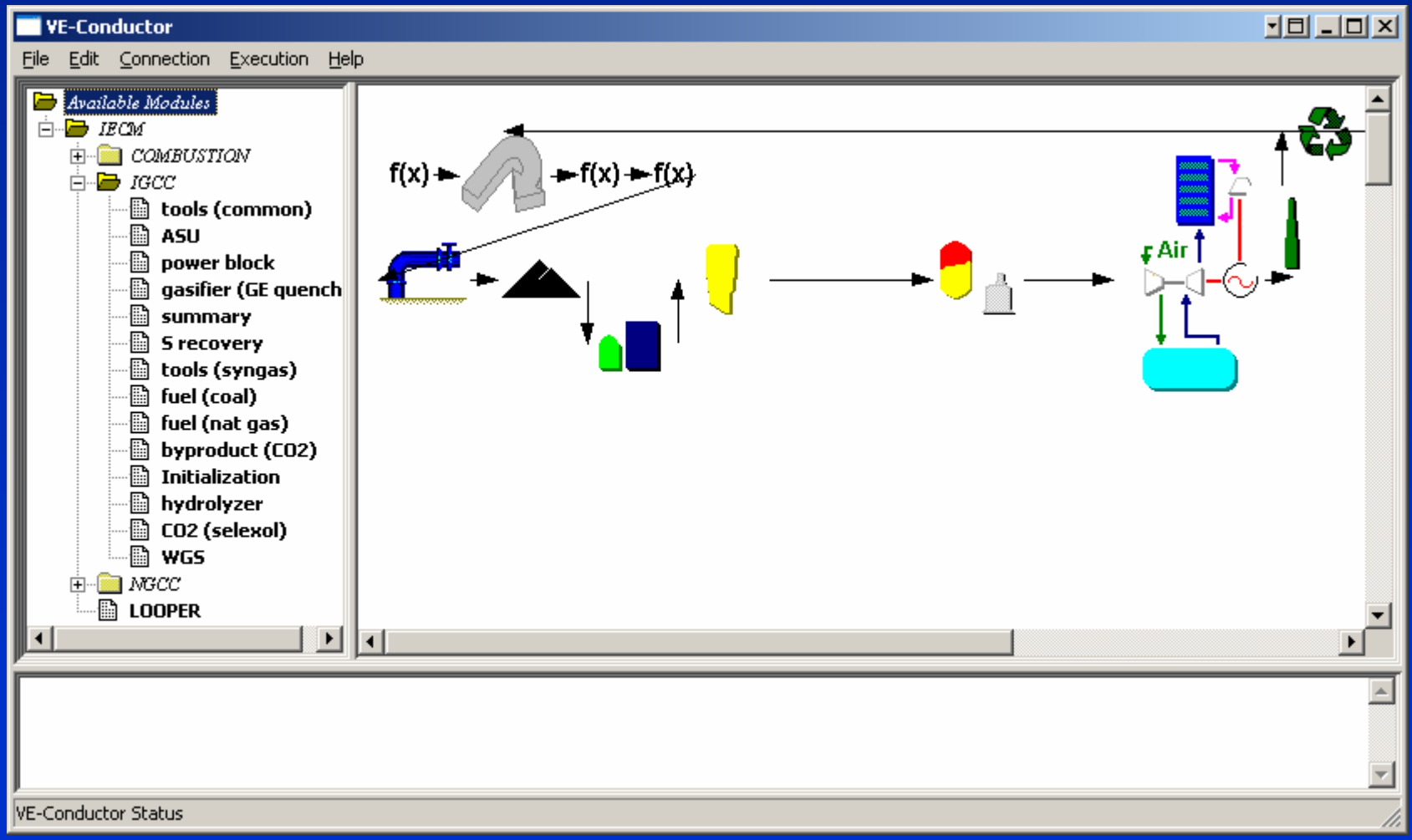
View Available IGCC Components



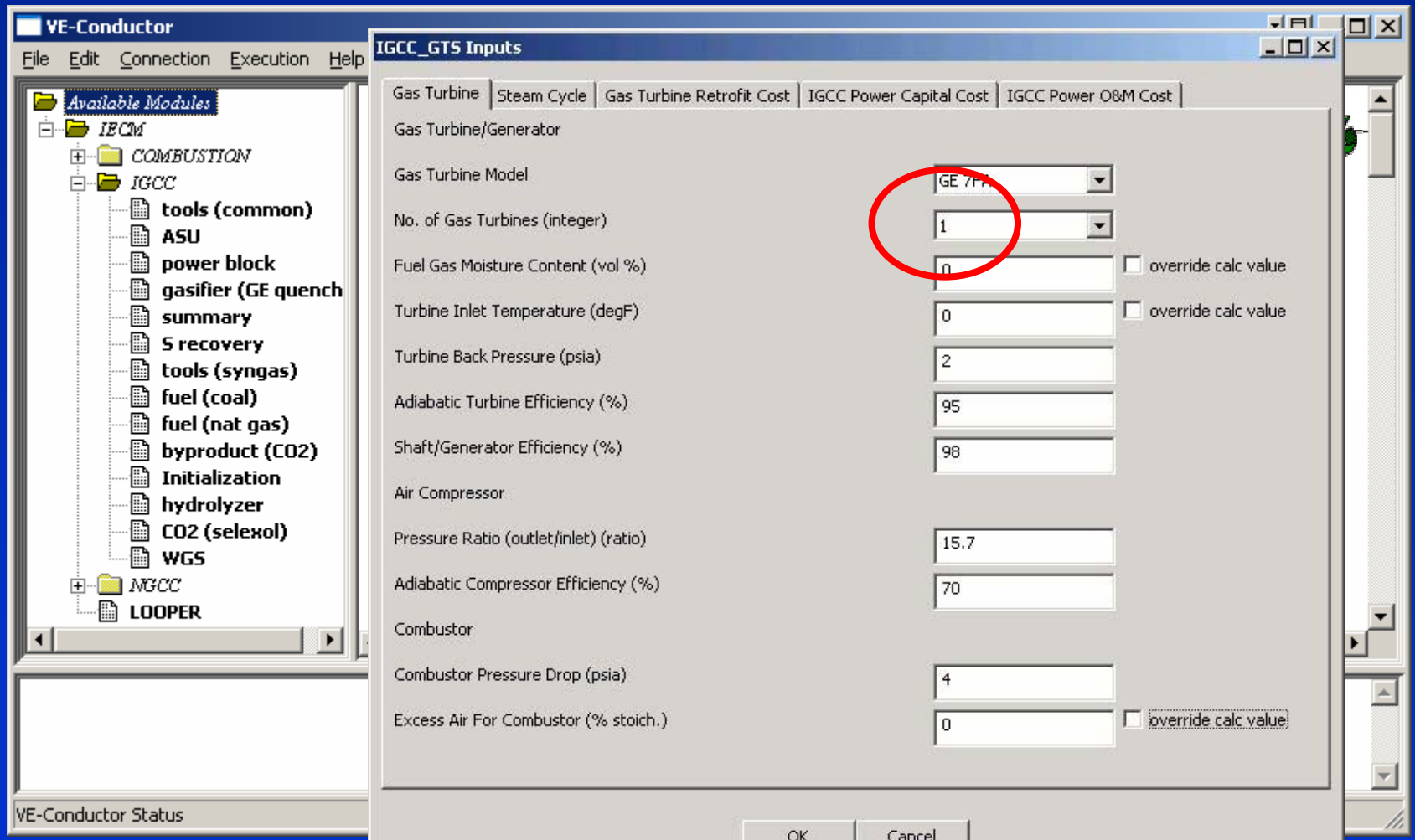
Select a Pre-Configured IGCC Flowsheet



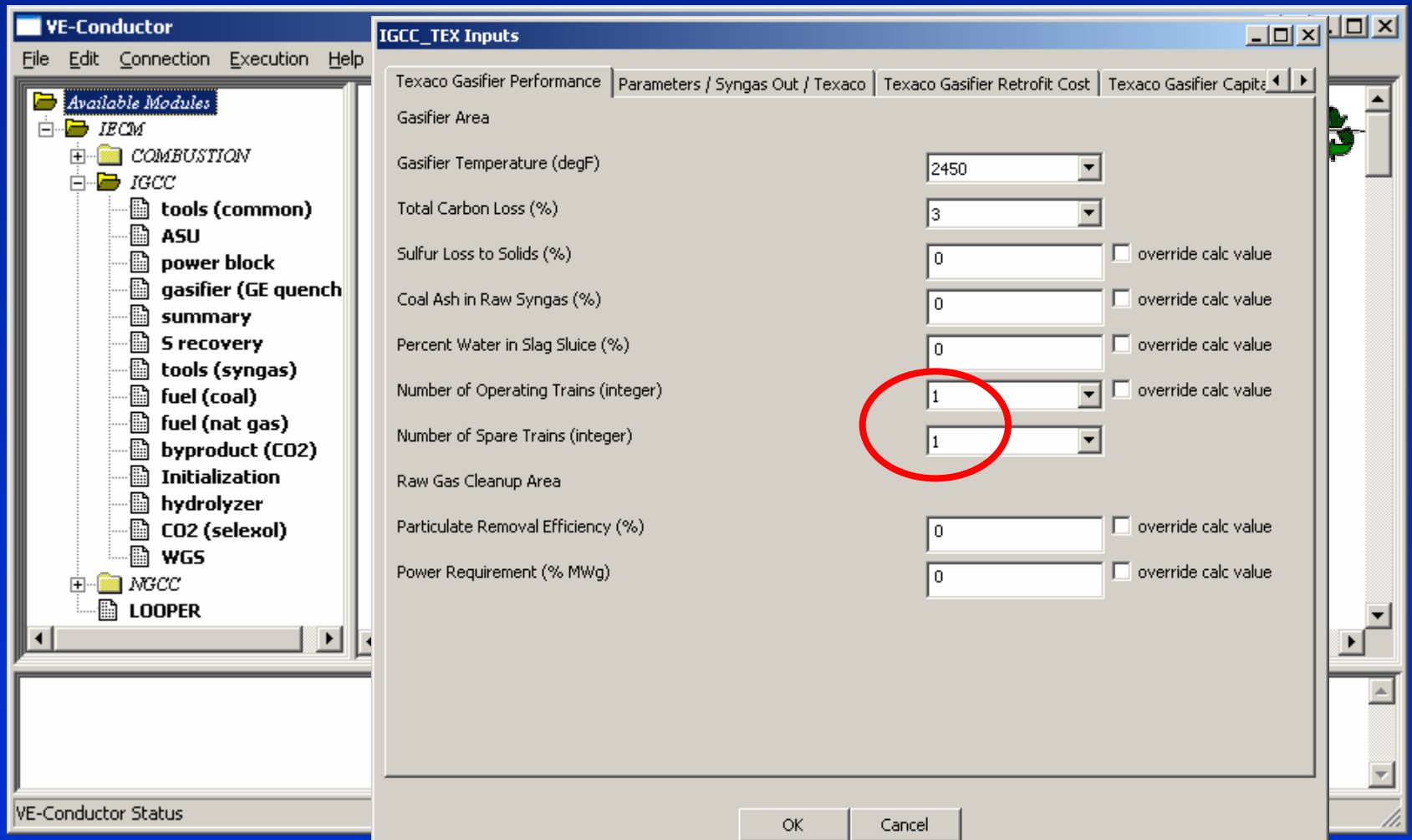
Selected IGCC Flowsheet



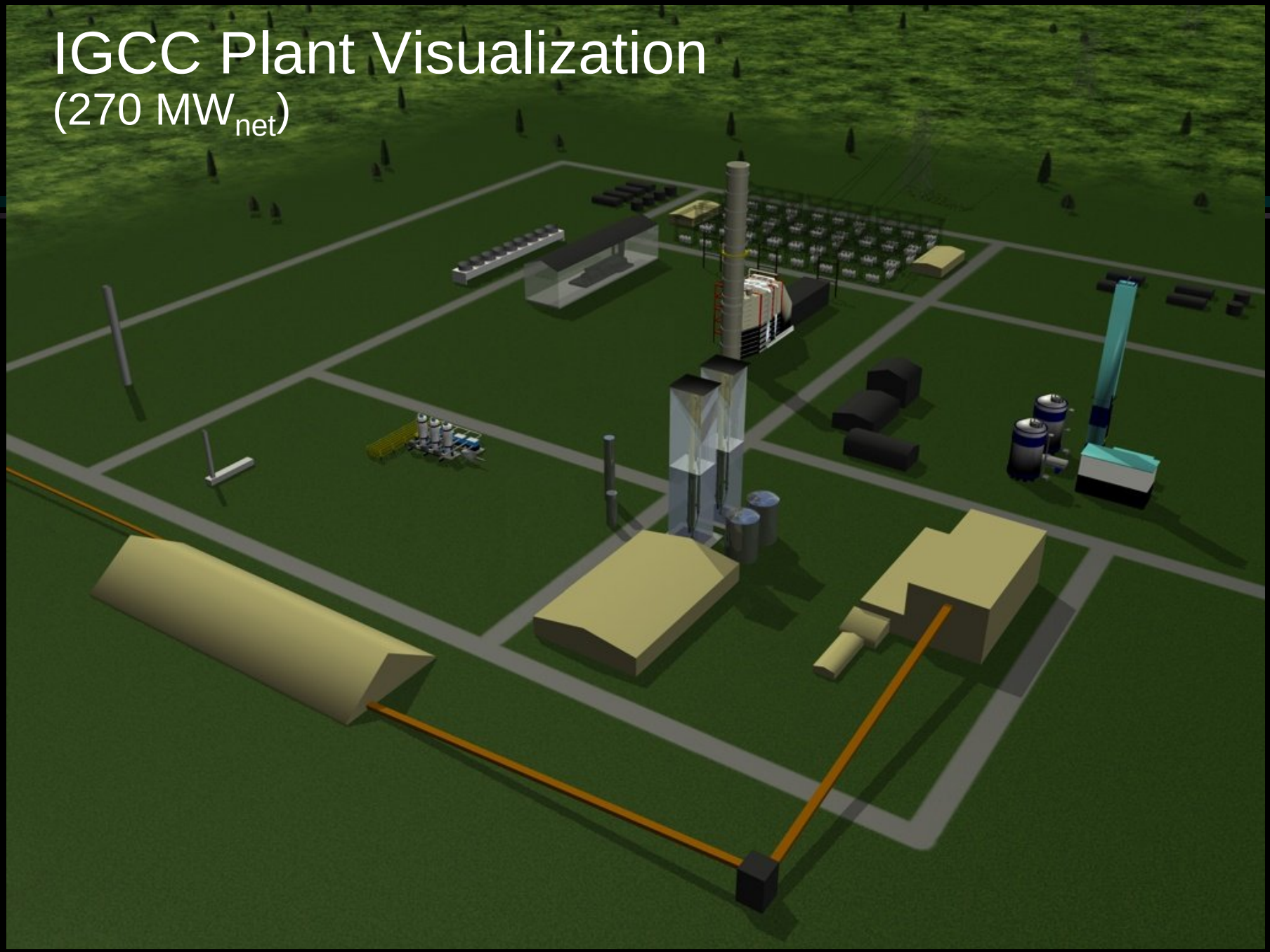
Power Block Performance Inputs



Gasifier Performance Inputs



IGCC Plant Visualization
(270 MW_{net})



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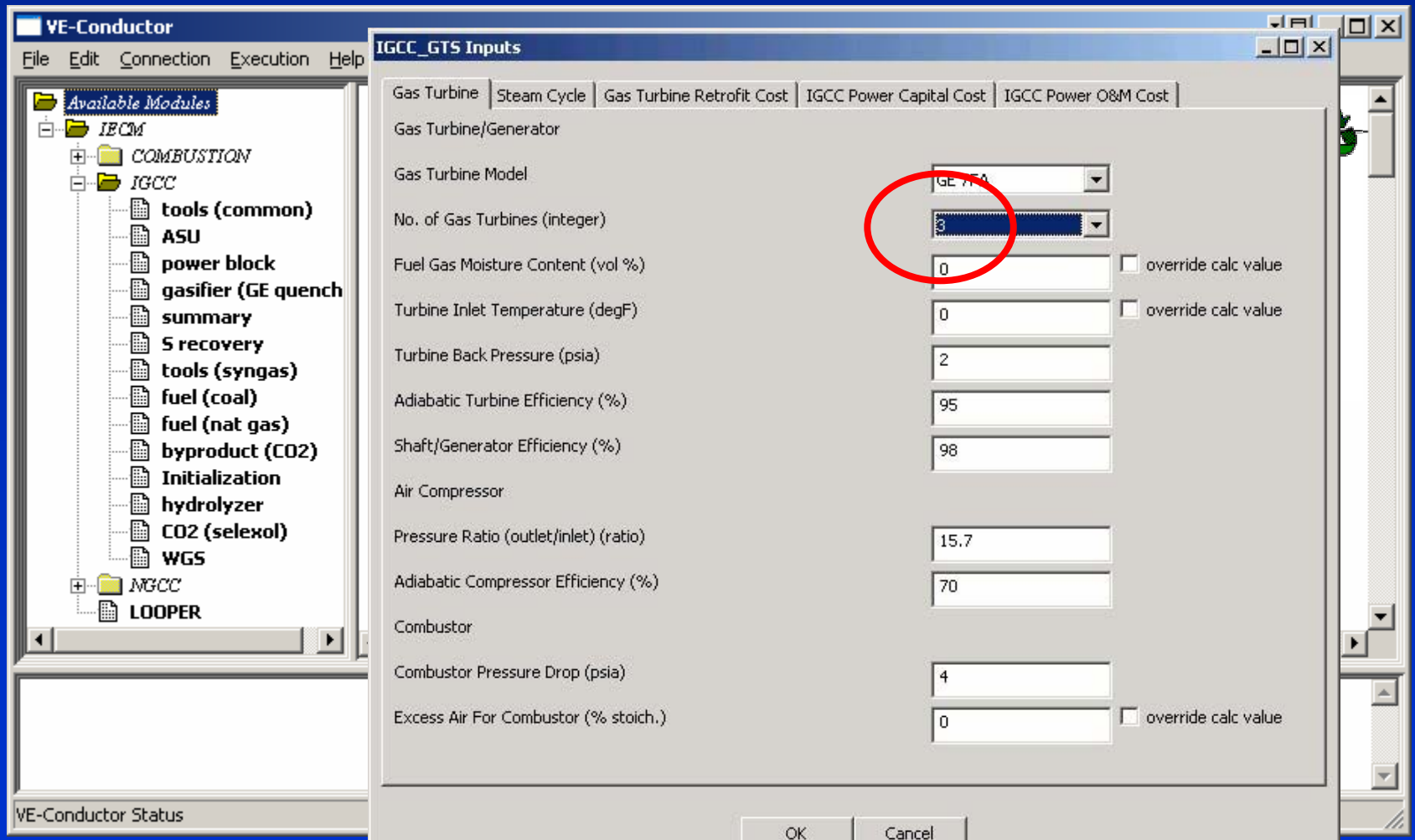
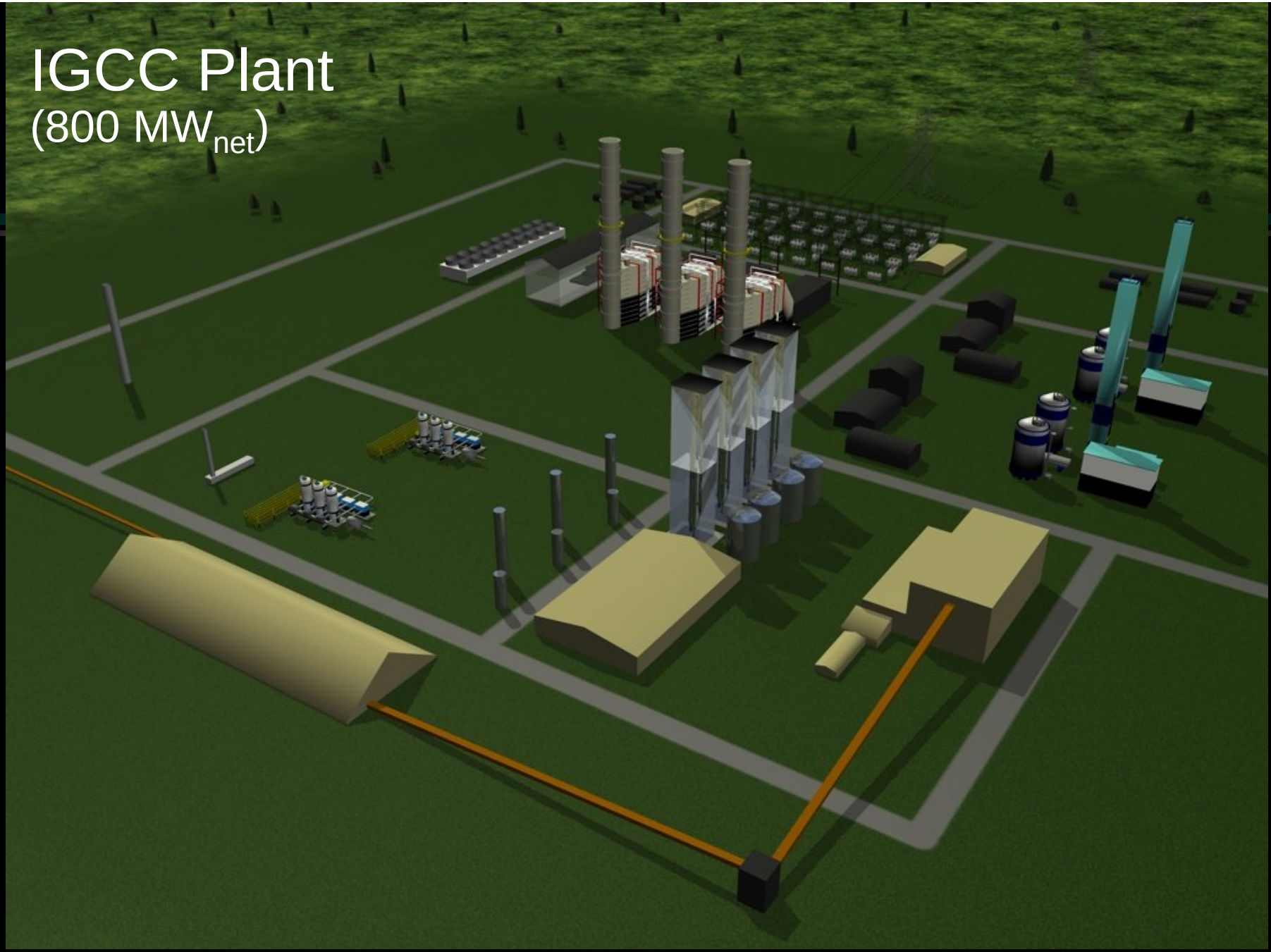
Increase Plant Size



IGCC Plant
(800 MW_{net})



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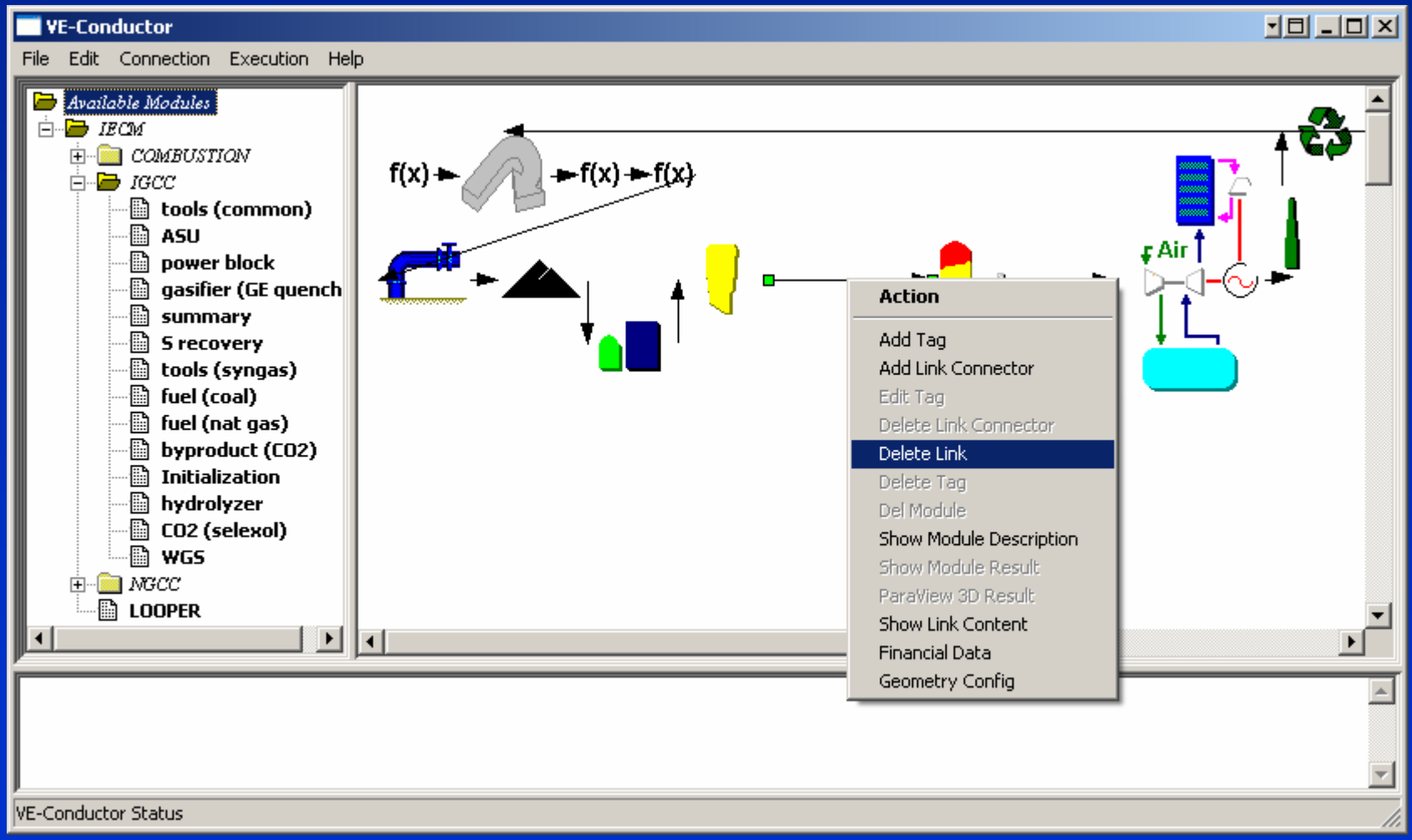
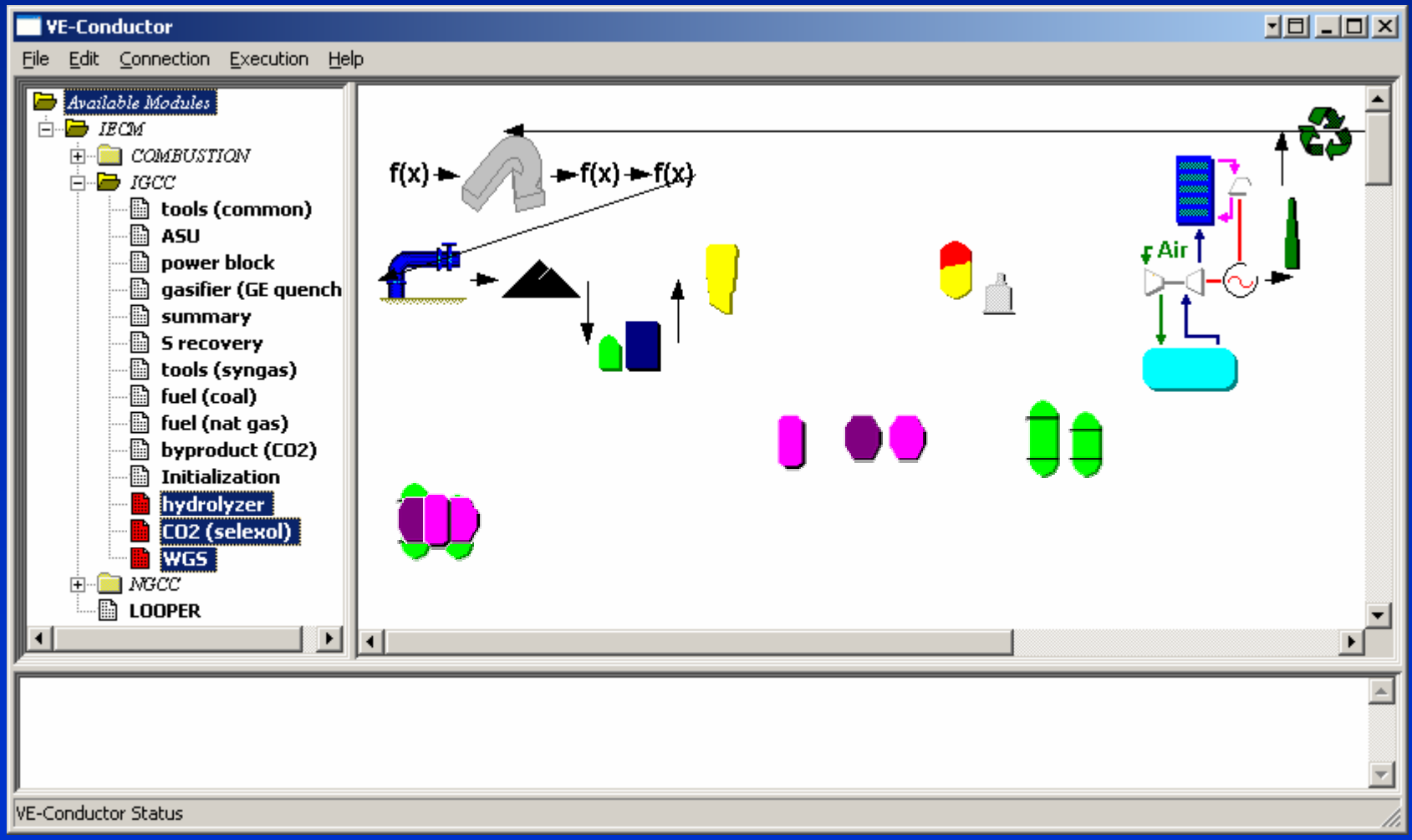
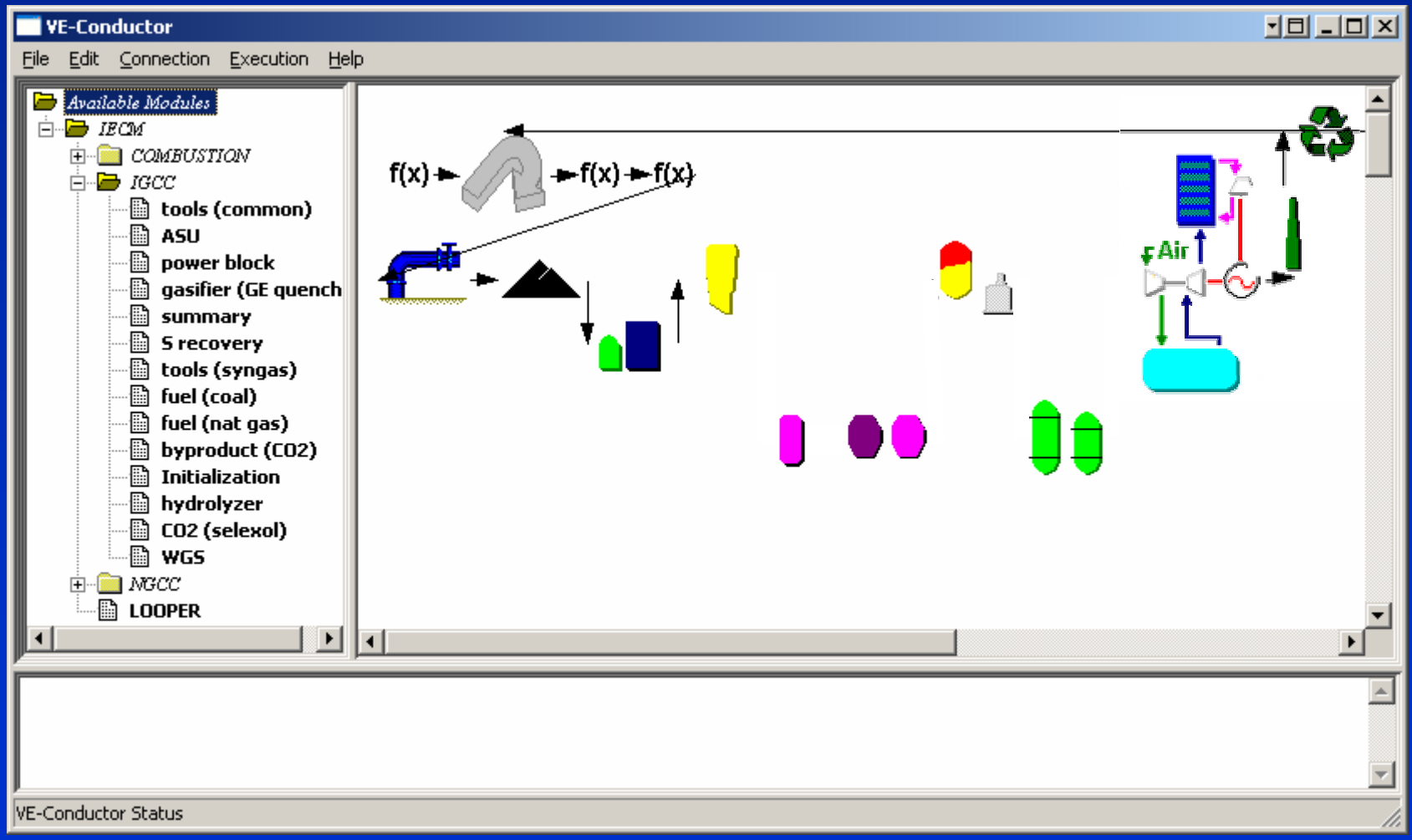
Remove "Links" to Add CO_2 Capture and Storage



Manually Add CSS Technologies



New Flowsheet: IGCC with CSS



IGCC w/CCS
(740 MW_{net})

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IGCC w/CCS Flyby

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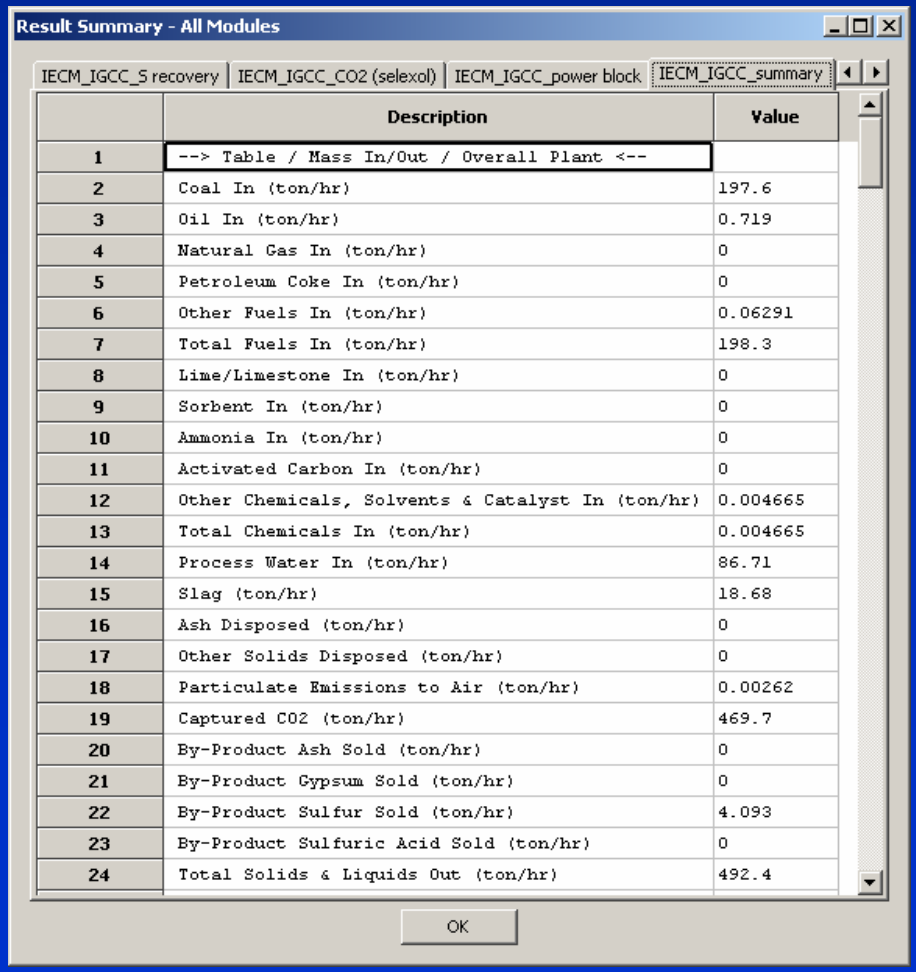
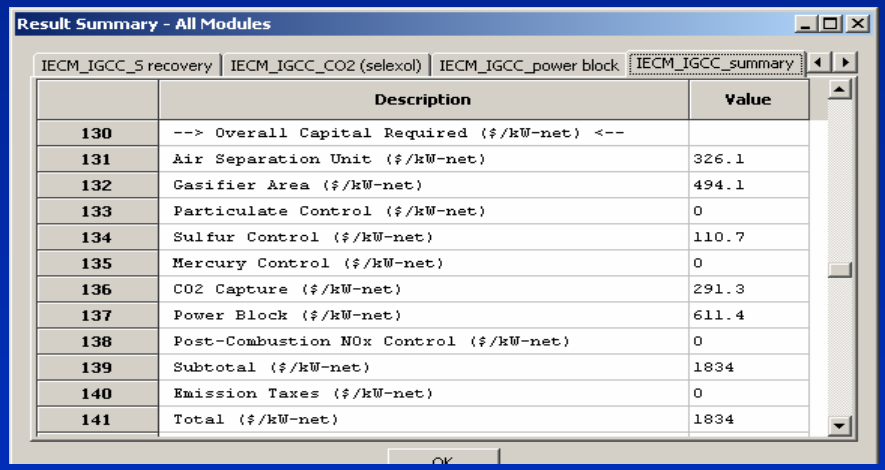
Mass Flow Summary (VE-Suite)



	Description	Value
1	--> Table / Mass In/Out / Overall Plant <--	
2	Coal In (ton/hr)	197.6
3	Oil In (ton/hr)	0.719
4	Natural Gas In (ton/hr)	0
5	Petroleum Coke In (ton/hr)	0
6	Other Fuels In (ton/hr)	0.06291
7	Total Fuels In (ton/hr)	198.3
8	Lime/Limestone In (ton/hr)	0
9	Sorbent In (ton/hr)	0
10	Ammonia In (ton/hr)	0
11	Activated Carbon In (ton/hr)	0
12	Other Chemicals, Solvents & Catalyst In (ton/hr)	0.004665
13	Total Chemicals In (ton/hr)	0.004665
14	Process Water In (ton/hr)	86.71
15	Slag (ton/hr)	18.68
16	Ash Disposed (ton/hr)	0
17	Other Solids Disposed (ton/hr)	0
18	Particulate Emissions to Air (ton/hr)	0.00262
19	Captured CO2 (ton/hr)	469.7
20	By-Product Ash Sold (ton/hr)	0
21	By-Product Gypsum Sold (ton/hr)	0
22	By-Product Sulfur Sold (ton/hr)	4.093
23	By-Product Sulfuric Acid Sold (ton/hr)	0
24	Total Solids & Liquids Out (ton/hr)	492.4

Plant Cost Results (VE-Suite)

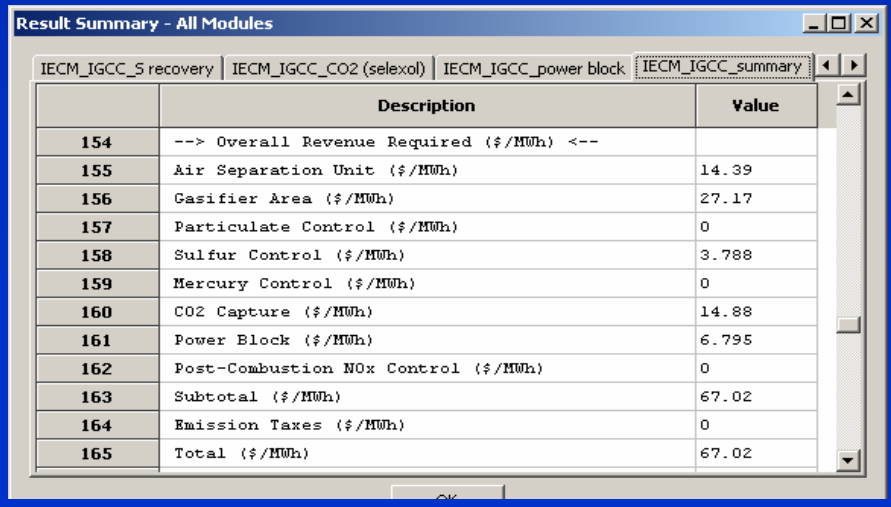

Result Summary - All Modules

IECM_IGCC_S recovery | IECM_IGCC_CO2 (selexol) | IECM_IGCC_power block | IECM_IGCC_summary

	Description	Value
130	--> Overall Capital Required ($/kW-net) <--	
131	Air Separation Unit ($/kW-net)	326.1
132	Gasifier Area ($/kW-net)	494.1
133	Particulate Control ($/kW-net)	0
134	Sulfur Control ($/kW-net)	110.7
135	Mercury Control ($/kW-net)	0
136	CO2 Capture ($/kW-net)	291.3
137	Power Block ($/kW-net)	611.4
138	Post-Combustion NOx Control ($/kW-net)	0
139	Subtotal ($/kW-net)	1834
140	Emission Taxes ($/kW-net)	0
141	Total ($/kW-net)	1834

OK

Total Capital Cost
($/kW)


Result Summary - All Modules

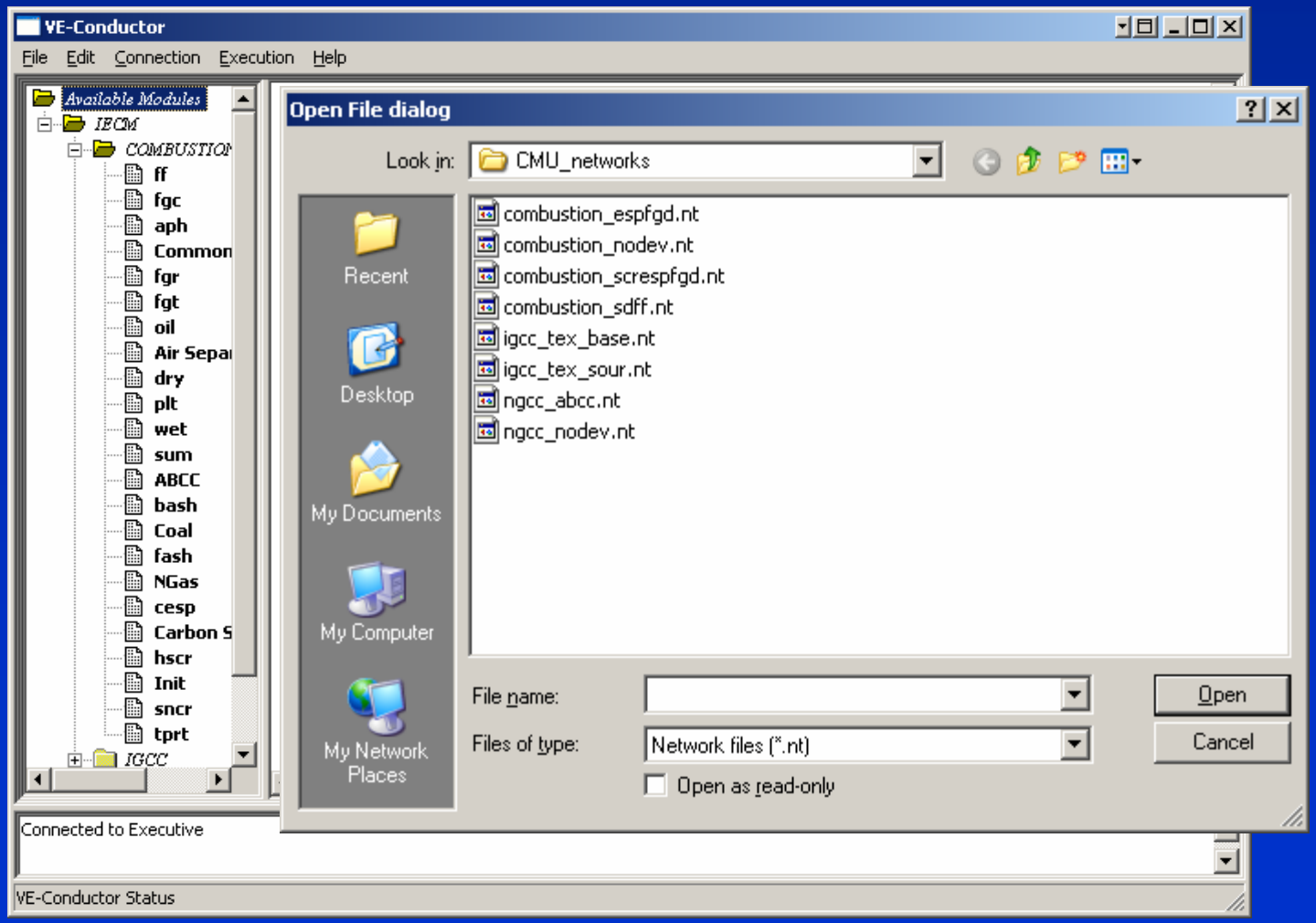
IECM_IGCC_S recovery | IECM_IGCC_CO2 (selexol) | IECM_IGCC_power block | IECM_IGCC_summary

	Description	Value
154	--> Overall Revenue Required ($/MWh) <--	
155	Air Separation Unit ($/MWh)	14.39
156	Gasifier Area ($/MWh)	27.17
157	Particulate Control ($/MWh)	0
158	Sulfur Control ($/MWh)	3.788
159	Mercury Control ($/MWh)	0
160	CO2 Capture ($/MWh)	14.88
161	Power Block ($/MWh)	6.795
162	Post-Combustion NOx Control ($/MWh)	0
163	Subtotal ($/MWh)	67.02
164	Emission Taxes ($/MWh)	0
165	Total ($/MWh)	67.02

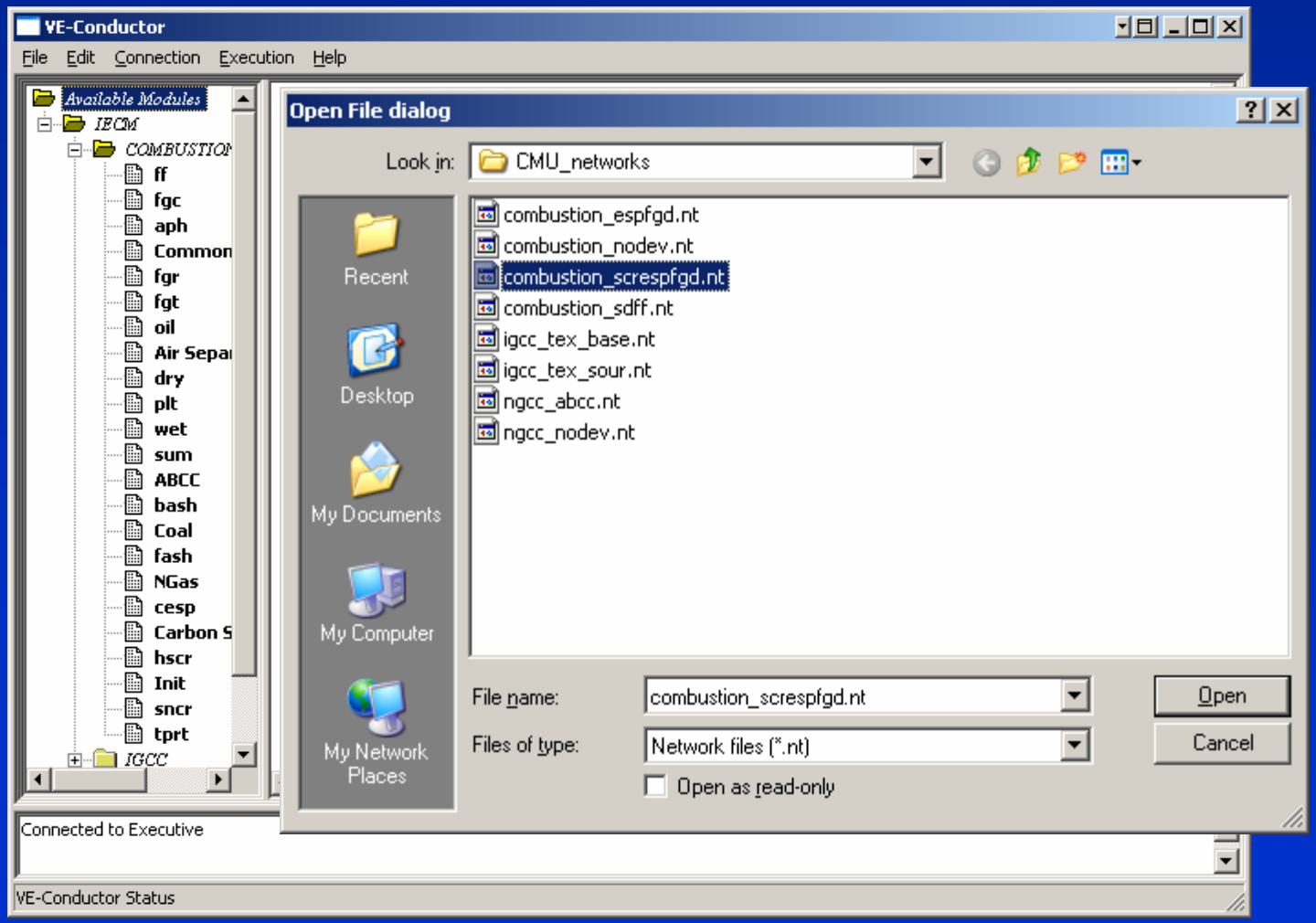
OK

Cost of Electricity
($/MWh)

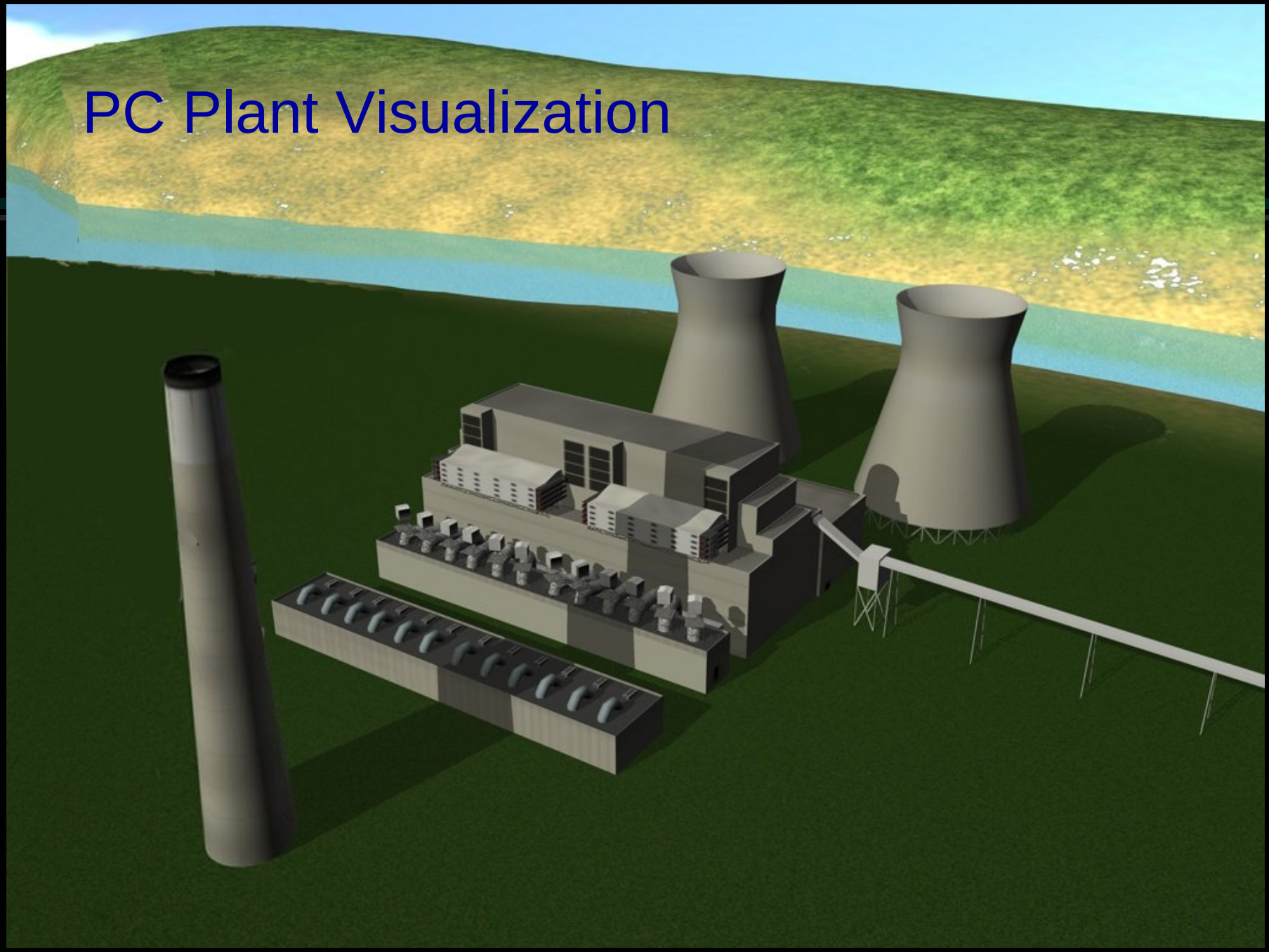
Configure Other Plant Types



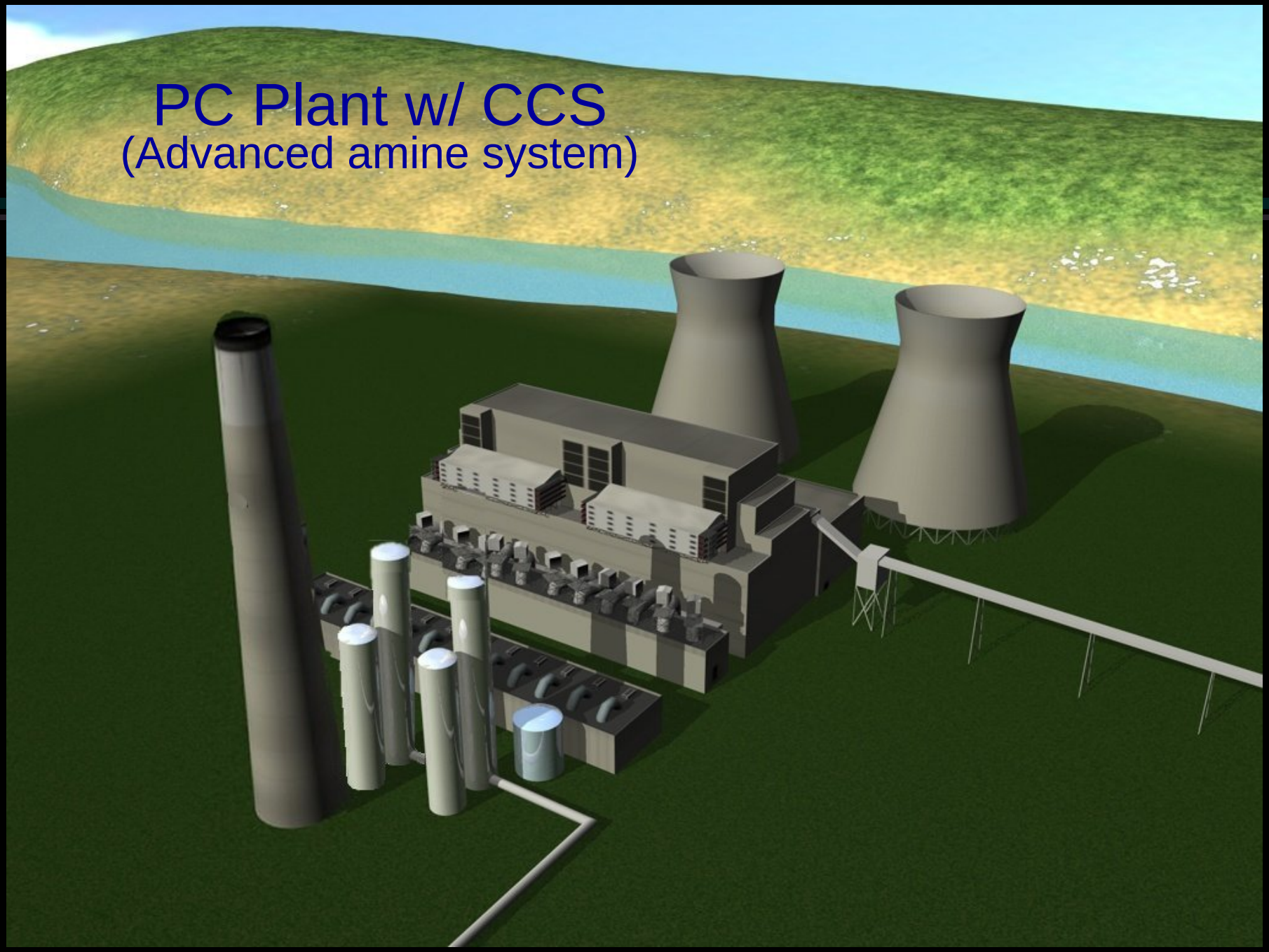
Configure Other Plant Types



PC Plant Visualization



PC Plant w/ CCS
(Advanced amine system)



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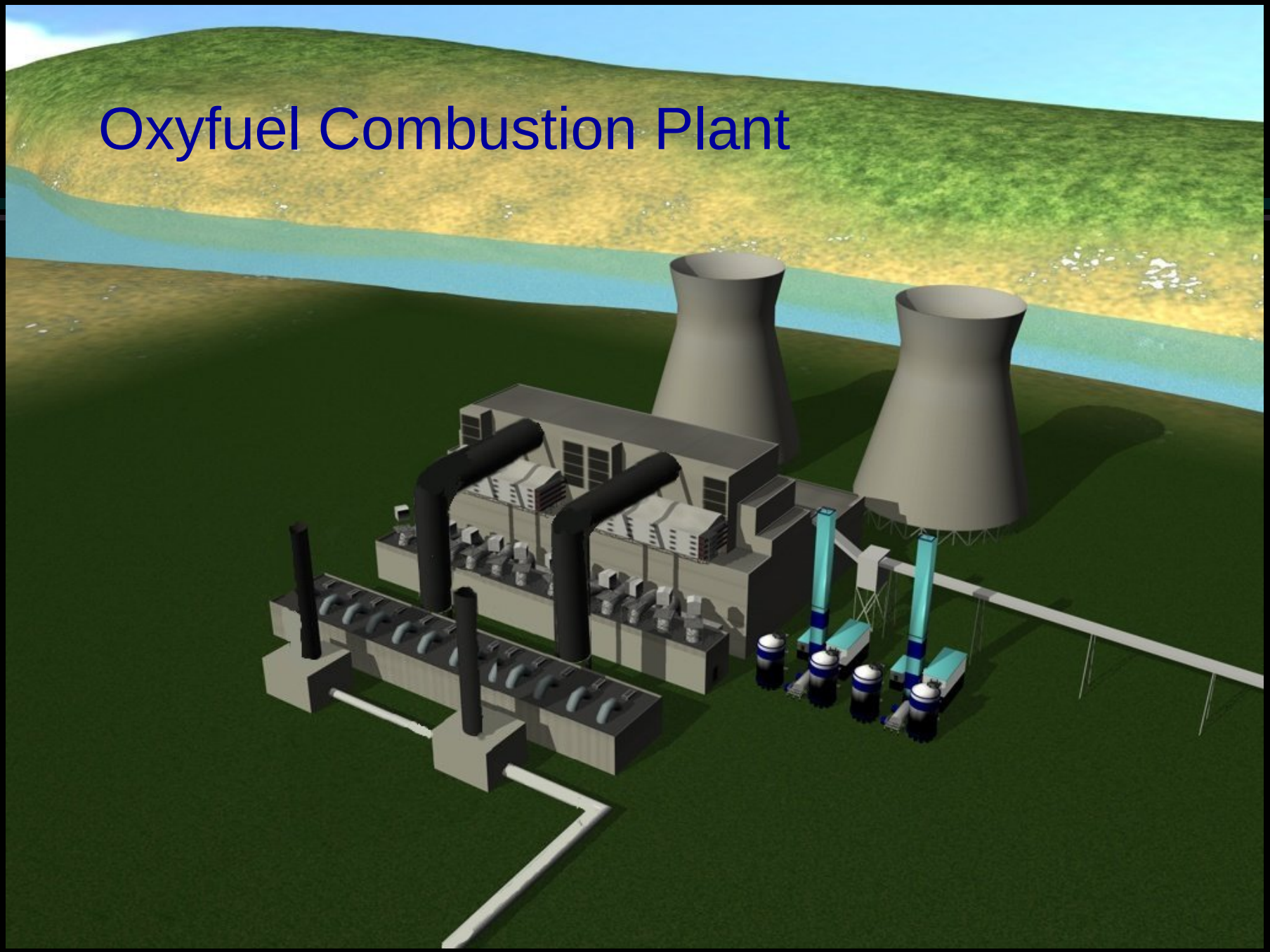
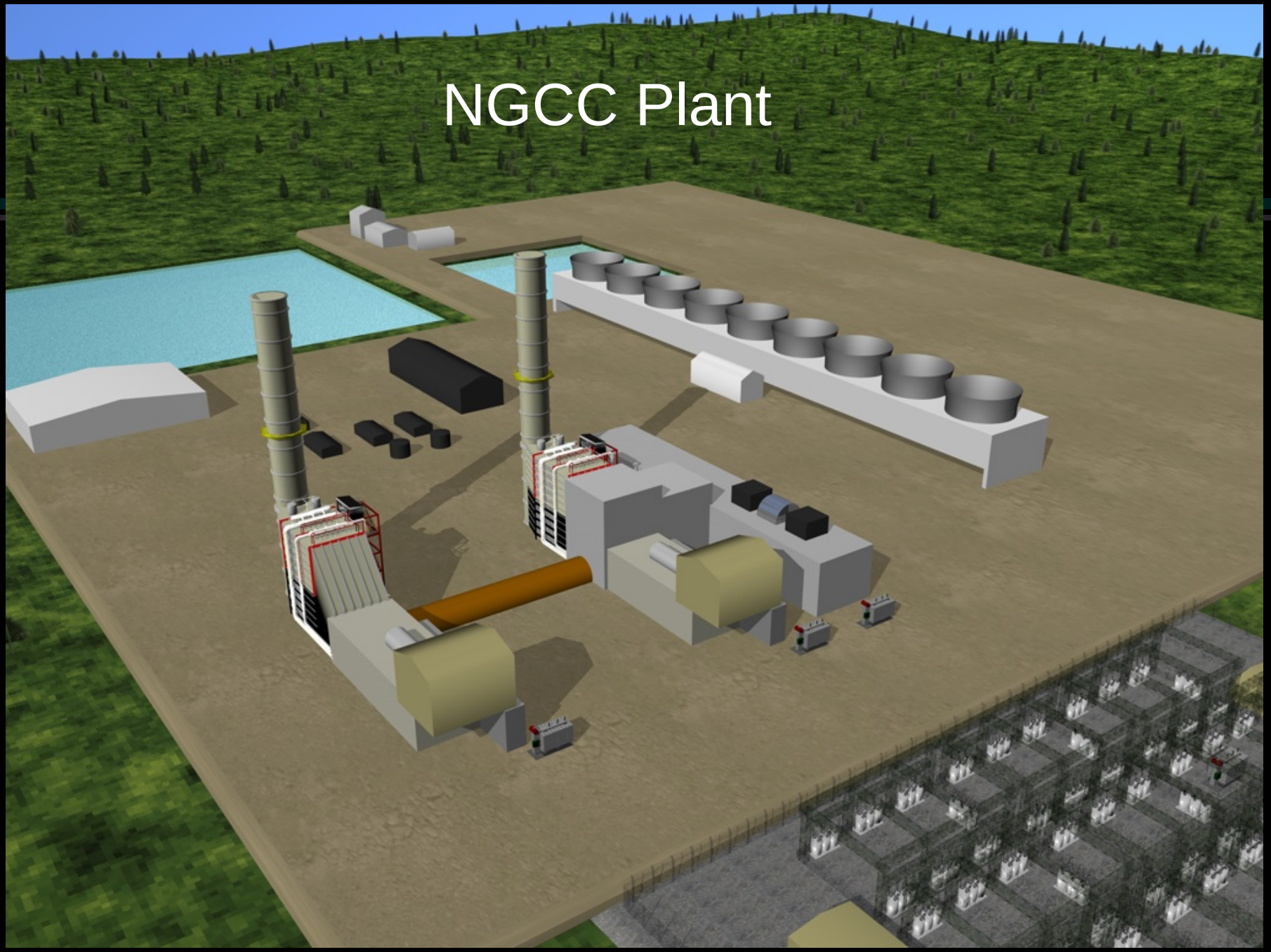
Oxyfuel Combustion Plant



NGCC Plant



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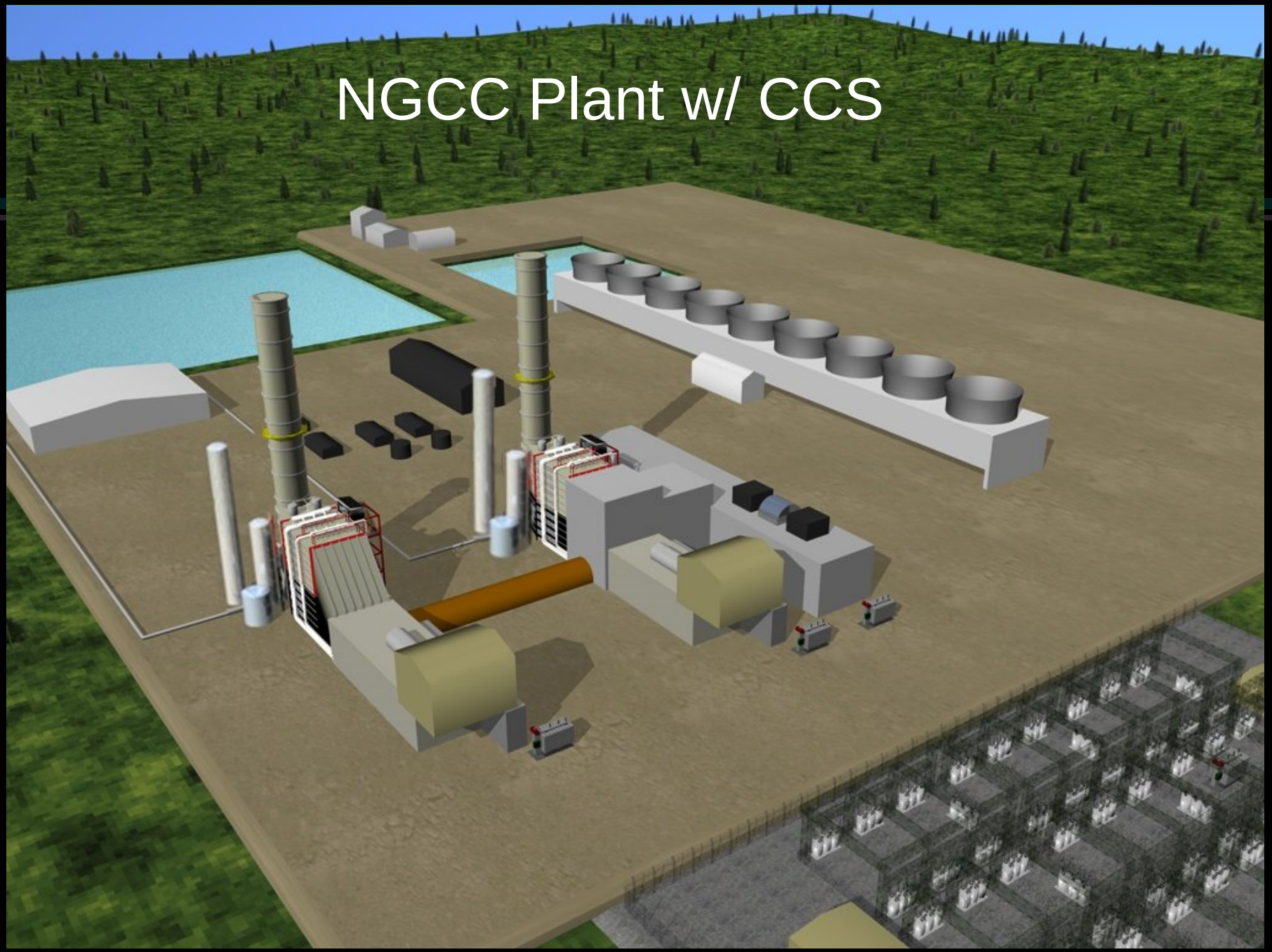
NGCC Plant w/ CCS



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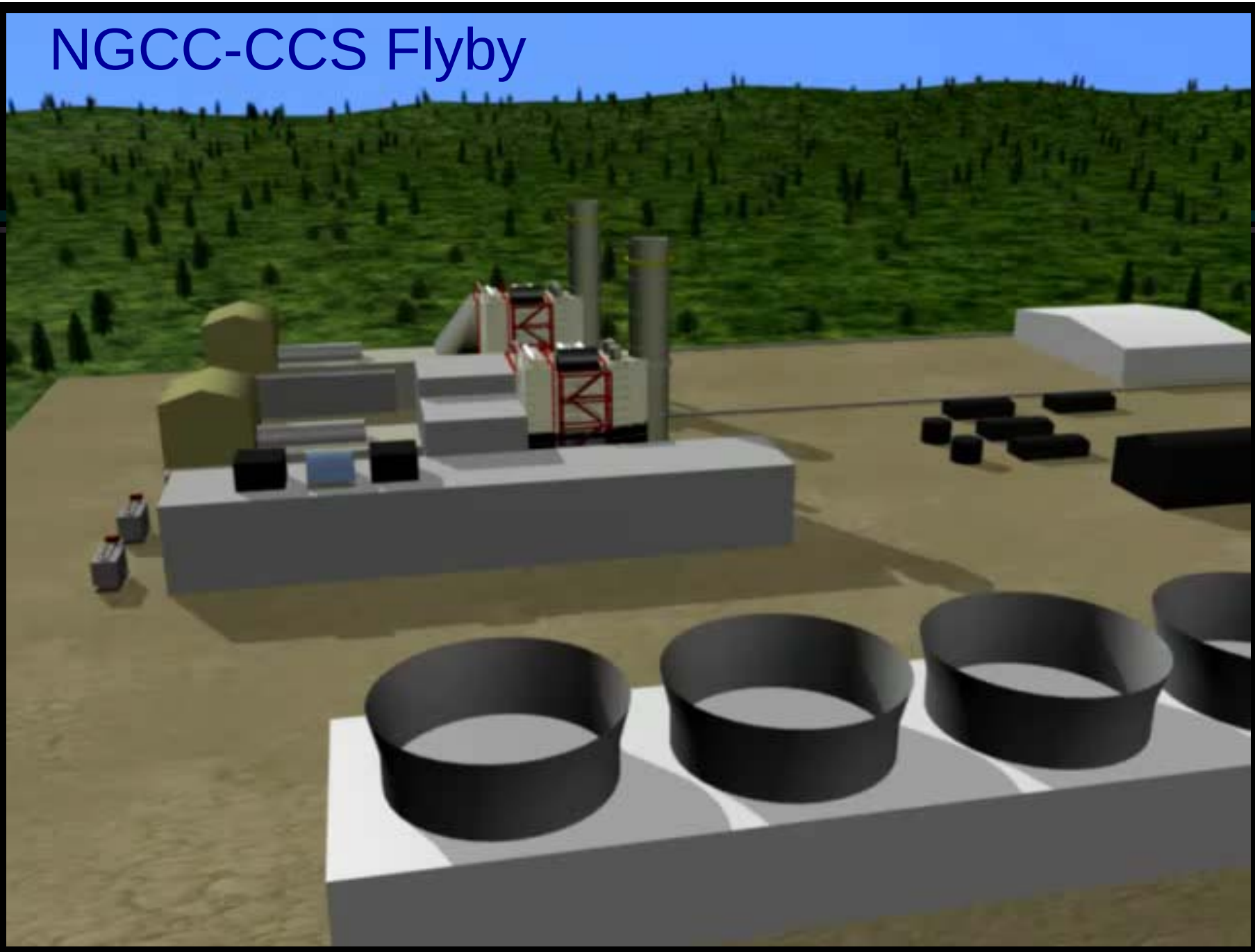
NGCC-CCS Flyby



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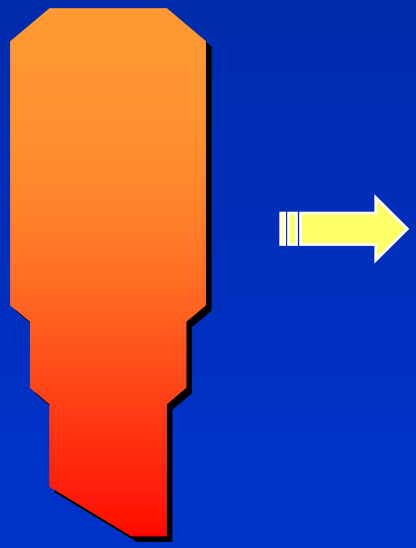
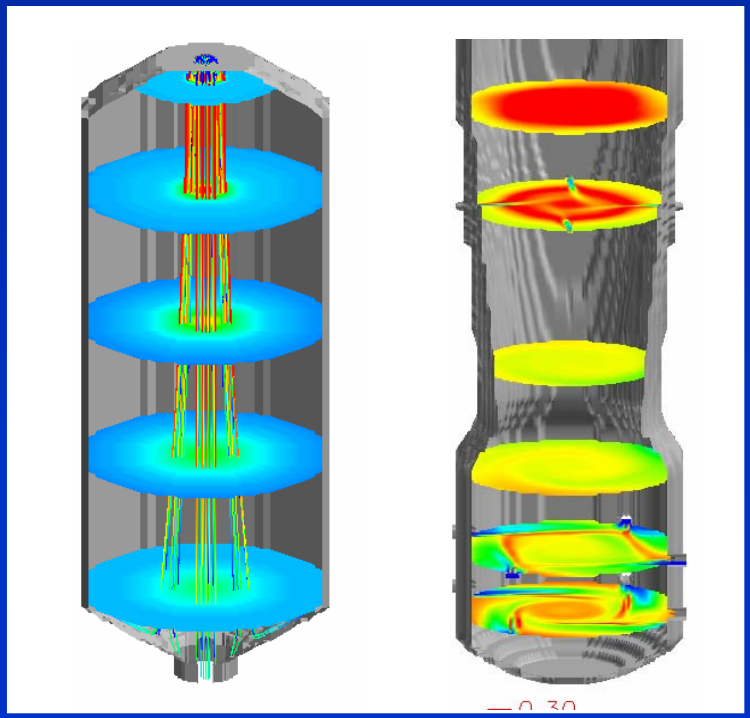
Next Steps

- Link and import CFD components and graphics
- Standardize and test array of elements to be passed between component models
- Link and import vendor component graphics and layouts to VE-Suite
- Incorporate IECM uncertainty analysis tools and graphical outputs

Future Work

- Automate development of reduced form models to facilitate faster computation and ease of use





Source: M.Bockelie, REI, 2004

Thank You

rubin@cmu.edu