

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

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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

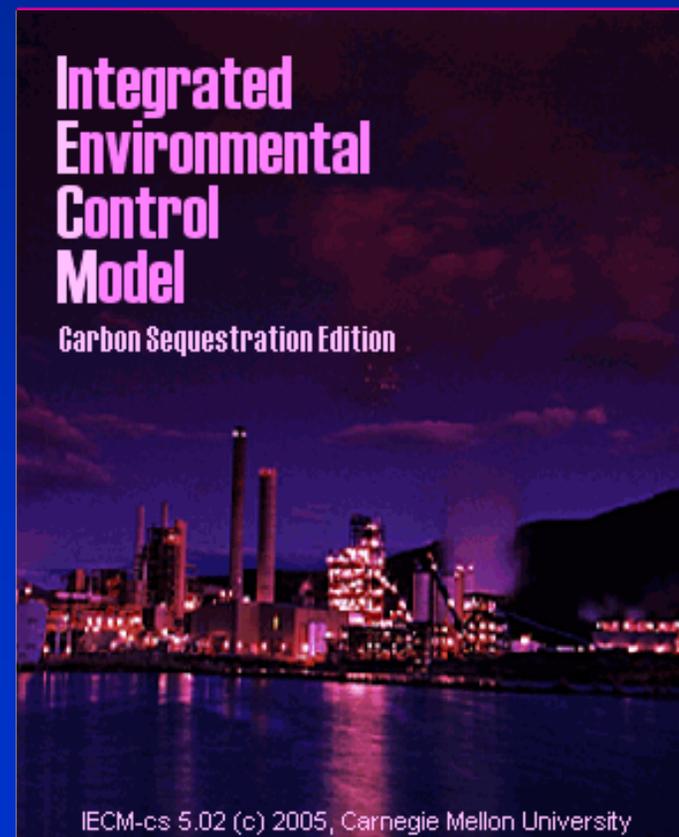
Approach

- 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
 - CO₂ 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)

Fuel Properties

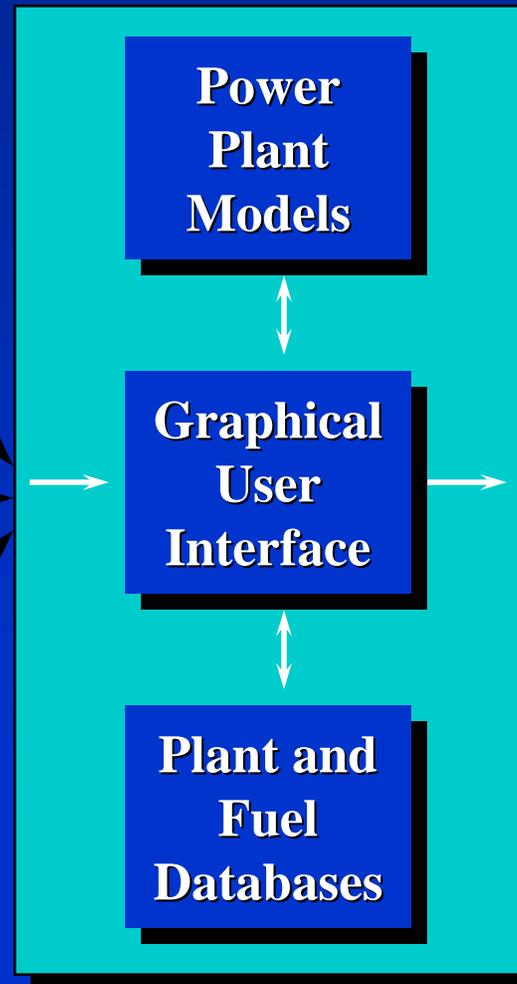
Heating Value
Composition
Delivered Cost

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

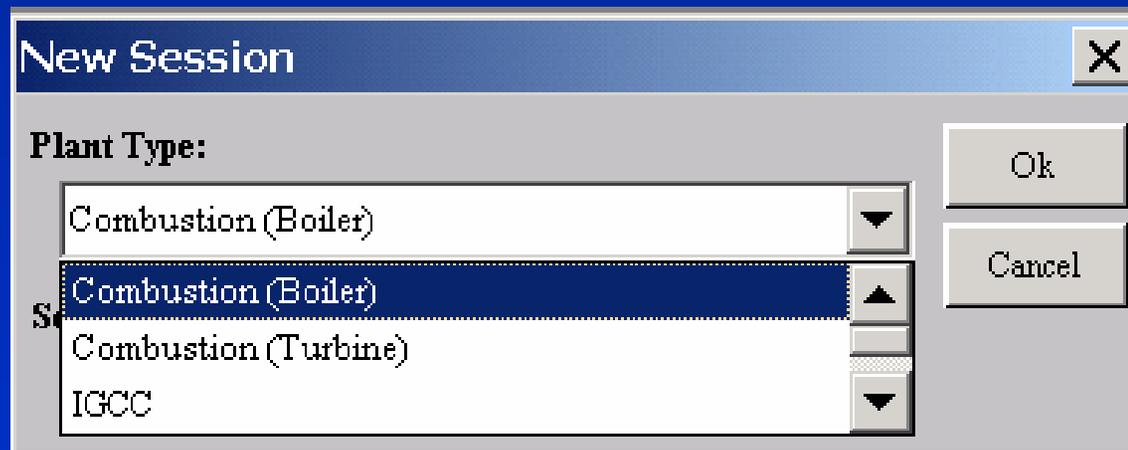
- Capital
- O&M
- COE

Advanced Power Systems with CO₂ Capture and Storage (CCS)

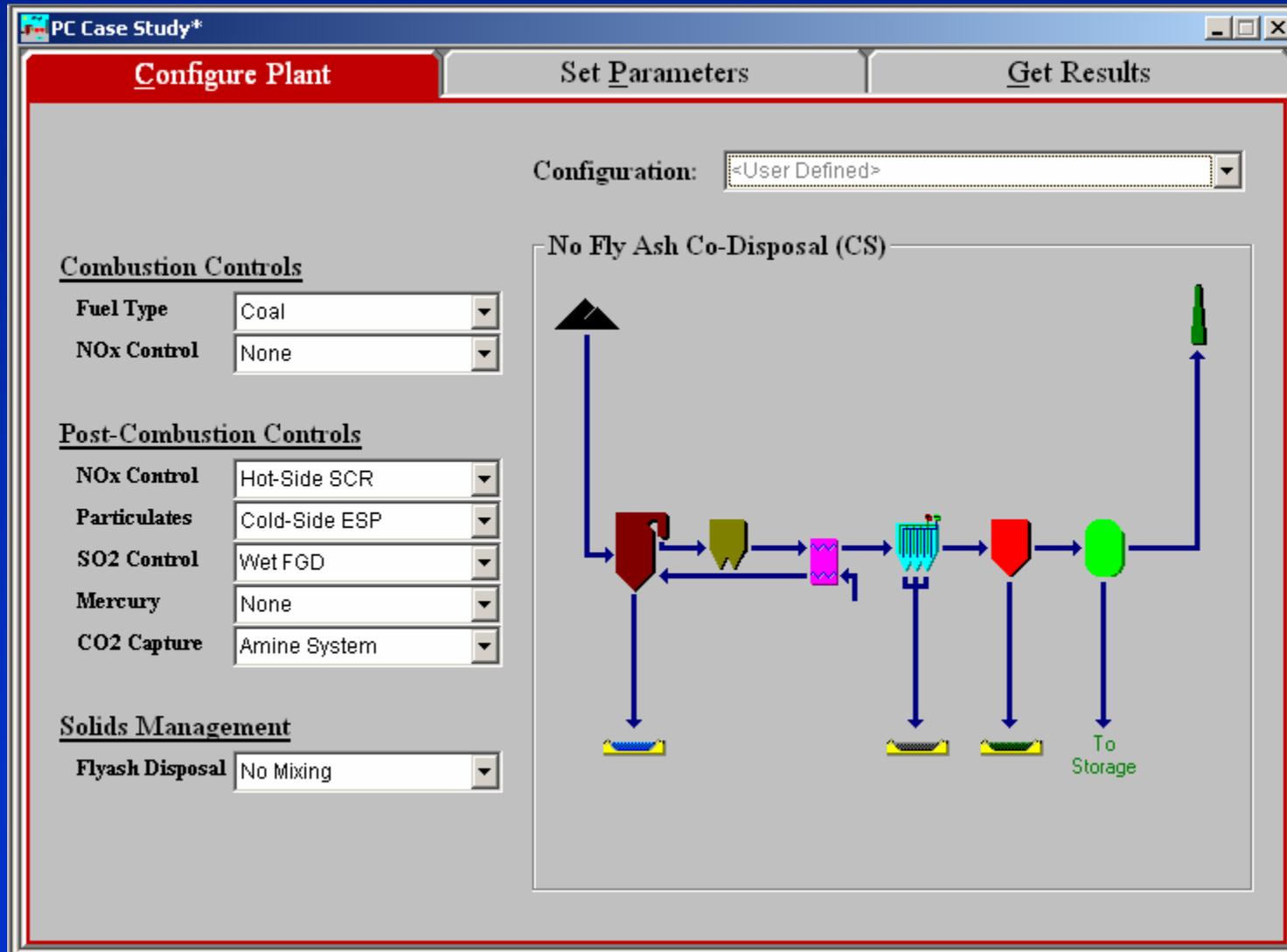
- PC plant with post-combustion capture
- PC plant with oxyfuel combustion
- NGCC plant with post-combustion capture
- IGCC plant with pre-combustion capture

A Quick Tour of the IECM

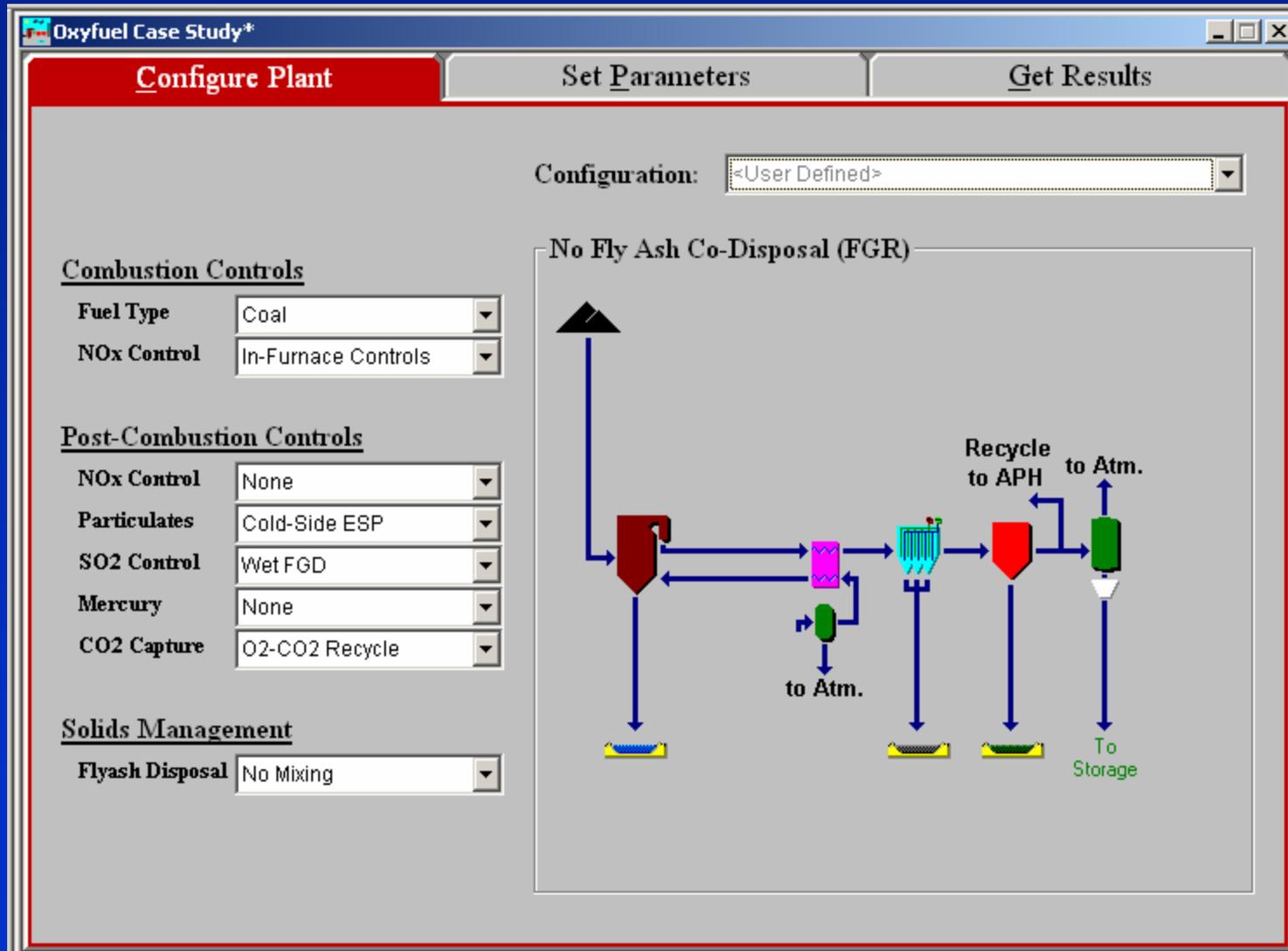
Select Plant Type



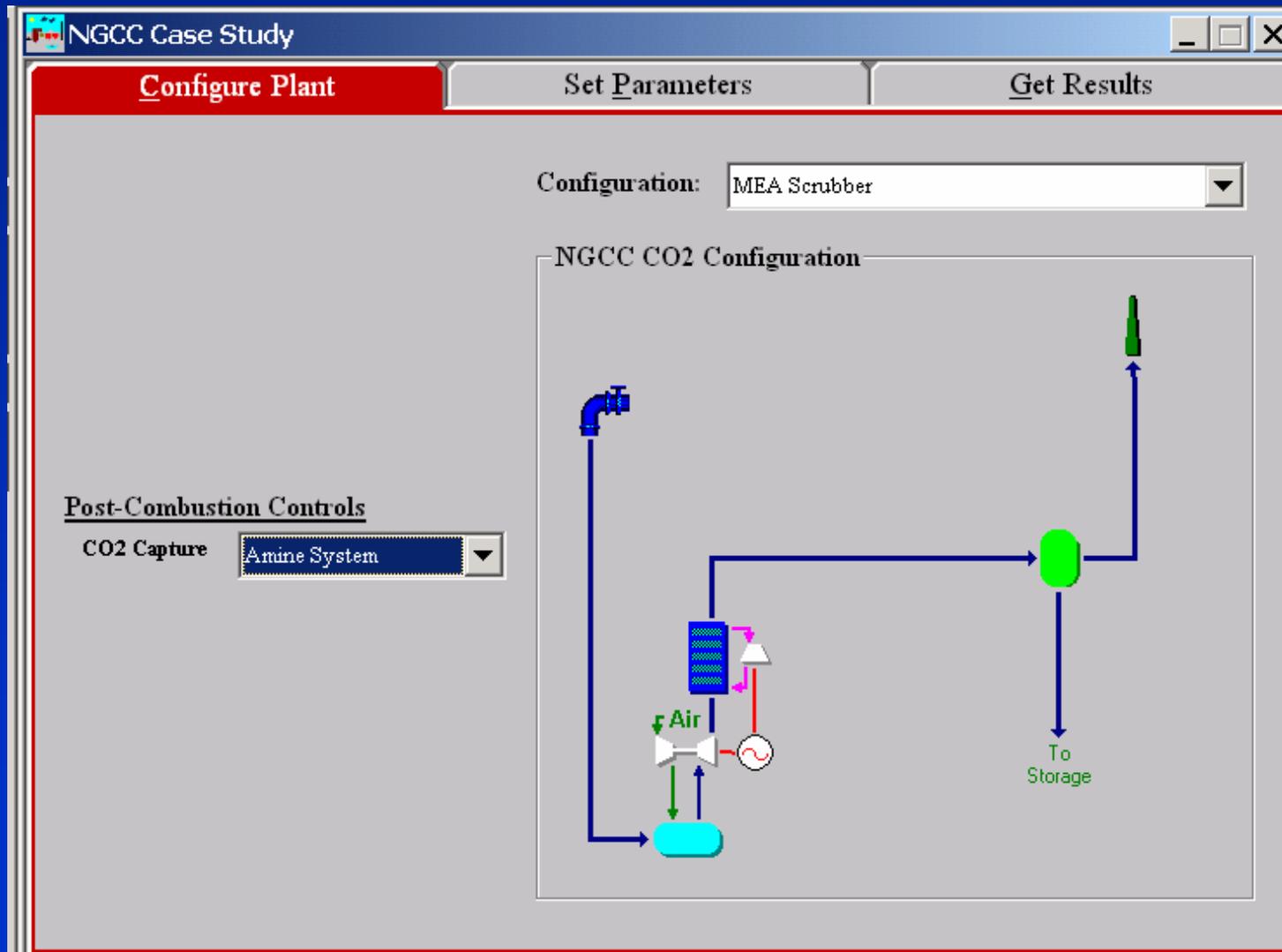
PC Plant with CCS



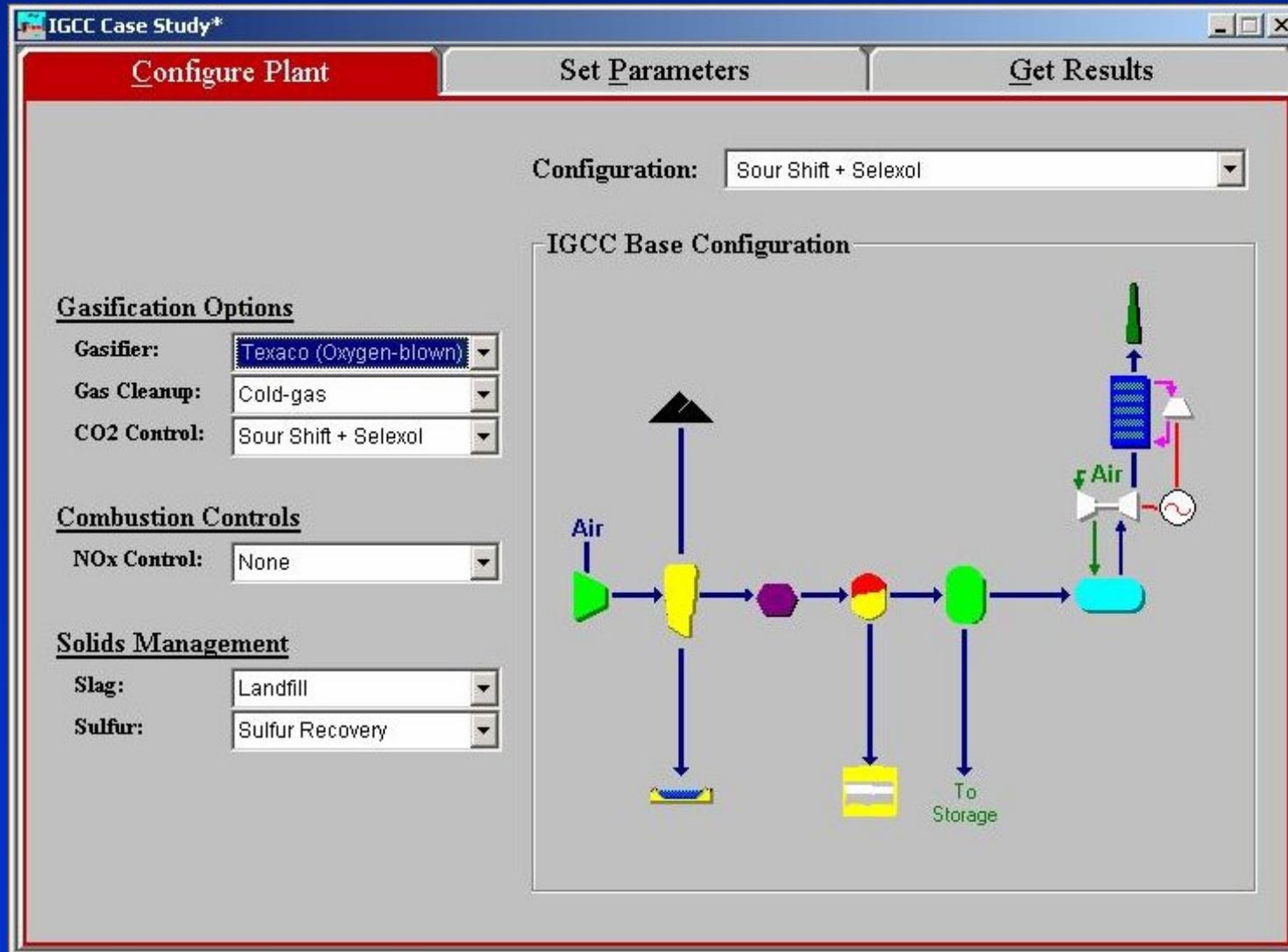
Oxyfuel Plant with CCS



NGCC Plant with CCS



IGCC Plant with CCS



Specify Fuel Properties

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

Current Fuel

Name: Default
 Rank: Bituminous
 Source: Default

Composition (wt% as received) and Higher Heating Value (Btu/lb)

Tot %: 100.0

	Property	Value	Save For All...
1	Heating Value	13260	<input type="checkbox"/> Plant Types <input type="checkbox"/> Fuel Types
2	Carbon	73.81	Save In Database
3	Hydrogen	4.88	
4	Oxygen	5.41	
5	Chlorine	0.06	Use Default Ash Properties
6	Sulfur	2.13	
7	Nitrogen	1.42	View Ash Properties
8	Ash	7.24	
9	Moisture	5.05	
10			
11			

Process Type: Fuel Properties

1. Properties | 2. Cost

Fuel Databases

Fuel: Appalachian Low Sulfur
 Rank: Bituminous
 Source: model_default_fuels.mdb (c:\progra-1\iecm)

Show All Plant Types
 Show All Fuel Types

	Property	Value	
1	Heating Value	1.308e+04	Open Database
2	Carbon	71.74	
3	Hydrogen	4.620	
4	Oxygen	6.090	New Database
5	Chlorine	7.000e-02	
6	Sulfur	0.6400	Use This Fuel
7	Nitrogen	1.420	
8	Ash	9.790	Delete This Fuel
9	Moisture	5.630	
10	Plant Type	<Any>	View Ash Properties
11	Fuel Type	Coal	

Set Power Block Parameters

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

	Title	Units	Unc	Value	Calc	Min	Max	Default
1	<u>Gas Turbine/Generator</u>							
2	Gas Turbine Model			GE 7FA+ ▼		Menu	Menu	GE 7FA+e
3	Gas Turbine Size (Nominal)	MW		410.5	<input checked="" type="checkbox"/>	0.0	5000	calc
4	No. of Gas Turbines	integer		2		Menu	Menu	2
5	Inlet Water Content	vol %		33.00	<input checked="" type="checkbox"/>	0.0	100.0	calc
6	Turbine Inlet Temperature	deg. F		2420	<input checked="" type="checkbox"/>	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	<u>Air Compressor</u>							
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	<u>Combustor</u>							
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	<input checked="" type="checkbox"/>	0.0	400.0	calc

Process Type: Power Block ▼

1. Gas Turbine | 2. Steam Cycle | 3. Emis. Factors | 4. Retrofit Cost | 5. Capital Cost | 6. O&M Cost

Specify Gasifier Parameters

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

	Title	Units	Unc	Value	Calc	Min	Max	Default
1	<u>Gasifier Area</u>							
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 H ₂ O/mol C		0.4419	<input checked="" type="checkbox"/>	0.0	1.000	calc
5	Oxygen Input from ASU	mol O ₂ /mol C		0.4550	<input checked="" type="checkbox"/>	0.0	1.000	calc
6	Total Carbon Loss	%		3		Menu	Menu	3
7	Sulfur Loss to Solids	%		0.0	<input checked="" type="checkbox"/>	0.0	100.0	calc
8	Coal Ash in Raw Syngas	%		0.0	<input checked="" type="checkbox"/>	0.0	100.0	calc
9	Percent Water in Slag Sluice	%		0.0	<input checked="" type="checkbox"/>	0.0	99.00	calc
10								
11	Number of Operating Trains	integer		2	<input checked="" type="checkbox"/>	Menu	Menu	Calc
12	Number of Spare Trains	integer		1		Menu	Menu	1
13								
14	<u>Raw Gas Cleanup Area</u>							
15	Particulate Removal Efficiency	%		100.0	<input checked="" type="checkbox"/>	0.0	100.0	calc
16								
17	Power Requirement	% MWg		1.234	<input checked="" type="checkbox"/>	0.0	6.000	calc
18								

Process Type:

1. Performance 2. Syngas Out 3. Retrofit Cost 4. Capital Cost 5. O&M Cost

Set Financial Parameters

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

	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	<input checked="" type="checkbox"/>	0.0	1.000	calc
4	Discount Rate (Before Taxes)	fraction		0.1030	<input checked="" type="checkbox"/>	0.0	2.000	calc
5	<i>Or, specify all the following:</i>							
6	Inflation Rate	%/yr		0.0	<input checked="" type="checkbox"/>	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	<input checked="" type="checkbox"/>	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

Process Type: Overall Plant

1. Diagram 2. Performance **3. Financing**

Get Results for Overall Plant

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

IGCC Sour Shift CO₂ Config

Gasification Options

Gasifier:	Texaco (Oxygen-blown)
Gas Cleanup:	Cold-gas
CO ₂ Control:	Sour Shift + Selexol

Post-Combustion Controls

NO _x Control:	None
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Solids Management

Slag:	Landfill
Sulfur:	Sulfur Plant

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

Results for Plant Mass Flows

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

	Plant Inputs	Flow Rate (ton/hr)		Plant Outputs	Flow Rate (ton/hr)
1	Coal	195.4	1	Slag	18.48
2	Oil	0.6697	2	Ash Disposed	0.0
3	Natural Gas	0.0	3	Other Solids Disposed	0.0
4	Petroleum Coke	0.0	4	Particulate Emissions to Air	2.591e-03
5	Other Fuels	5.860e-02	5	Captured CO2	464.9
6	Total Fuels	196.1	6	By-Product Ash Sold	0.0
7			7	By-Product Gypsum Sold	0.0
8	Lime/Limestone	0.0	8	By-Product Sulfur Sold	3.734
9	Sorbent	0.0	9	By-Product Sulfuric Acid Sold	0.0
10	Ammonia	0.0	10	Total Solids & Liquids	487.2
11	Activated Carbon	0.0	11		
12	Other Chemicals, Solvents & Catalyst	4.856e-03	12	<i>See Tab #4 for Total Gases</i>	
13	Total Chemicals	4.856e-03	13		
14			14		
15	Process Water	62.25	15		

Process Type: Overall Plant

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

Results for Plant Costs

IGCC Case Study*

Configure Plant **Set Parameters** **Get Results**

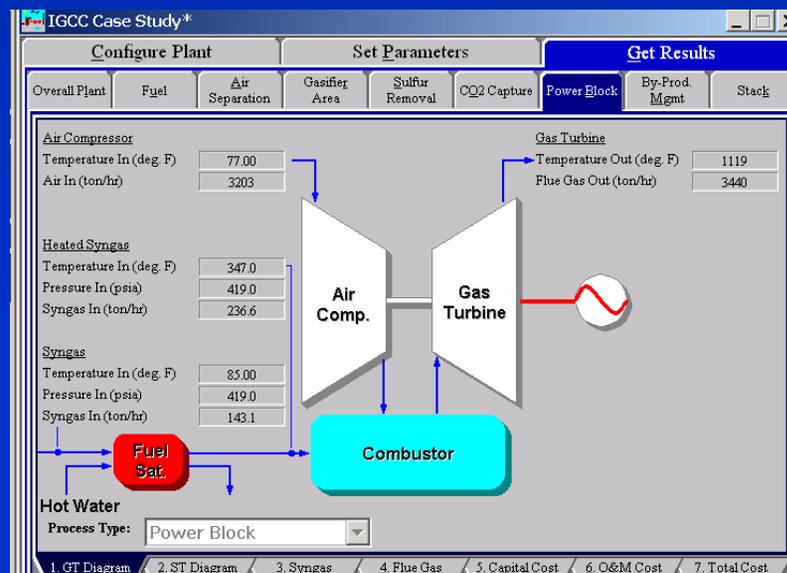
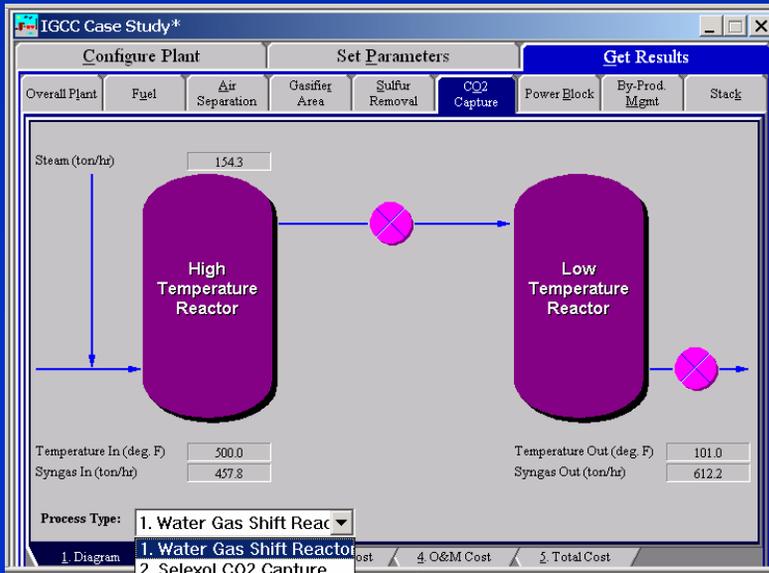
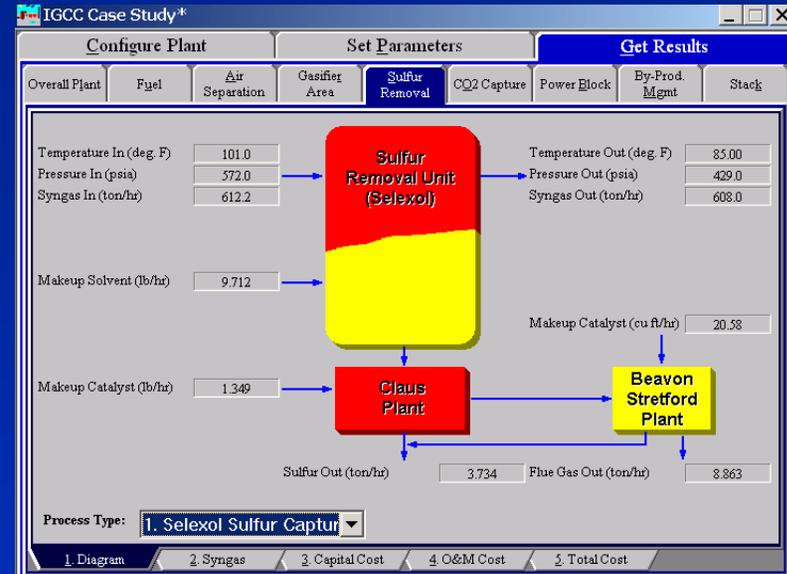
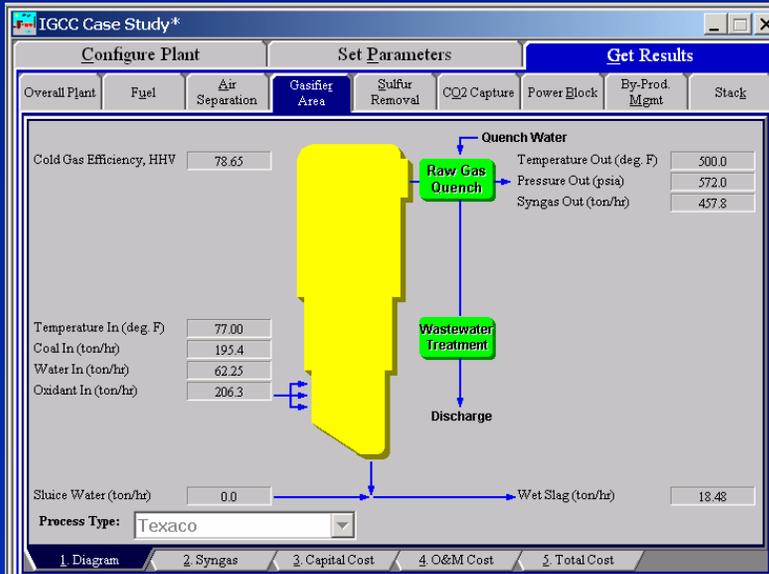
Overall Plant Fuel Air Separation Gasifier Area Sulfur Removal CO₂ Capture Power Block By-Prod. Mgmt Stack

	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	CO ₂ Capture	143.9	292.8	57.34	17.75
7	Power Block	300.4	611.4	21.95	6.795
8	Post-Combustion NO _x 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: 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



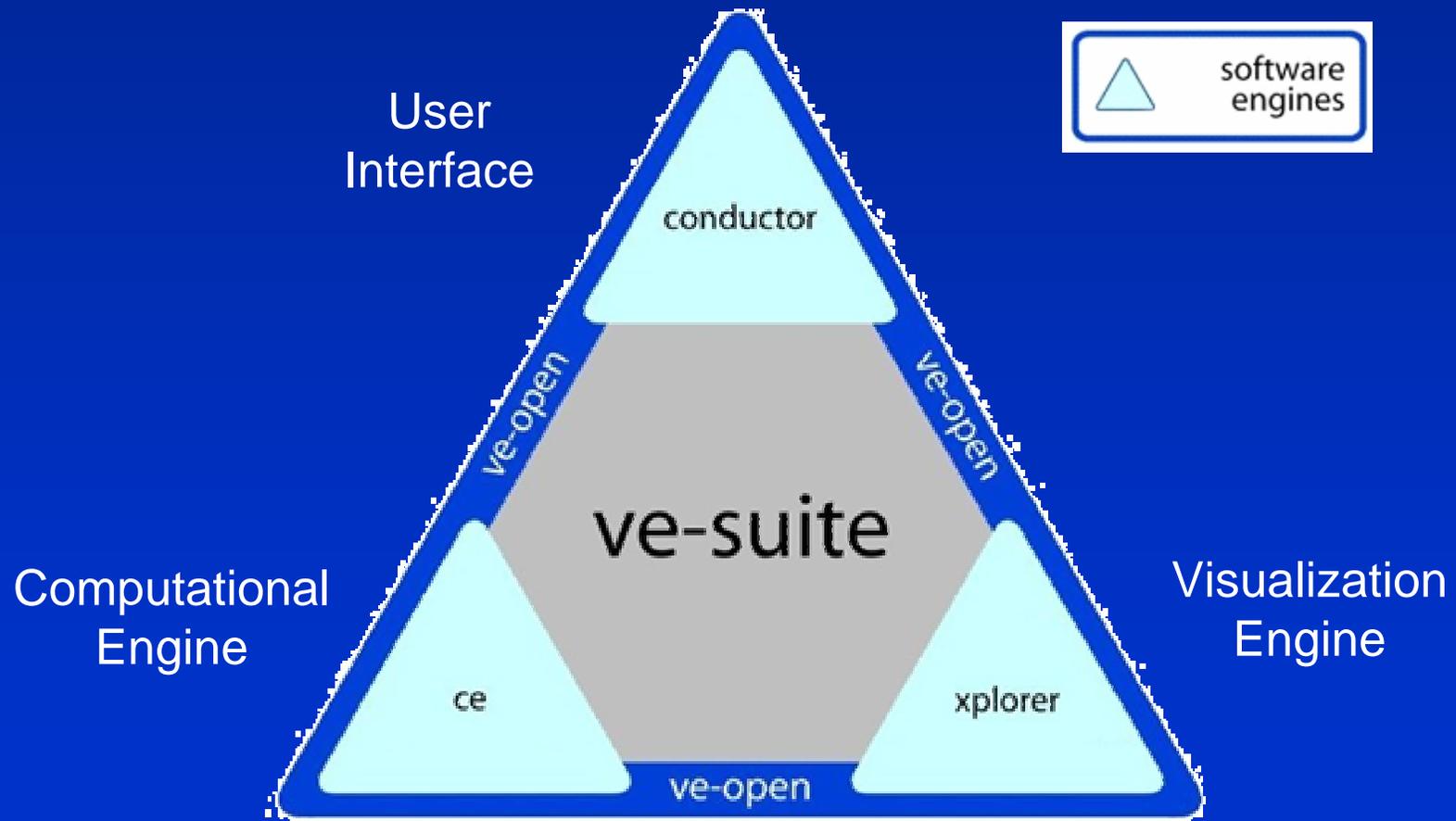
VE-Suite

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

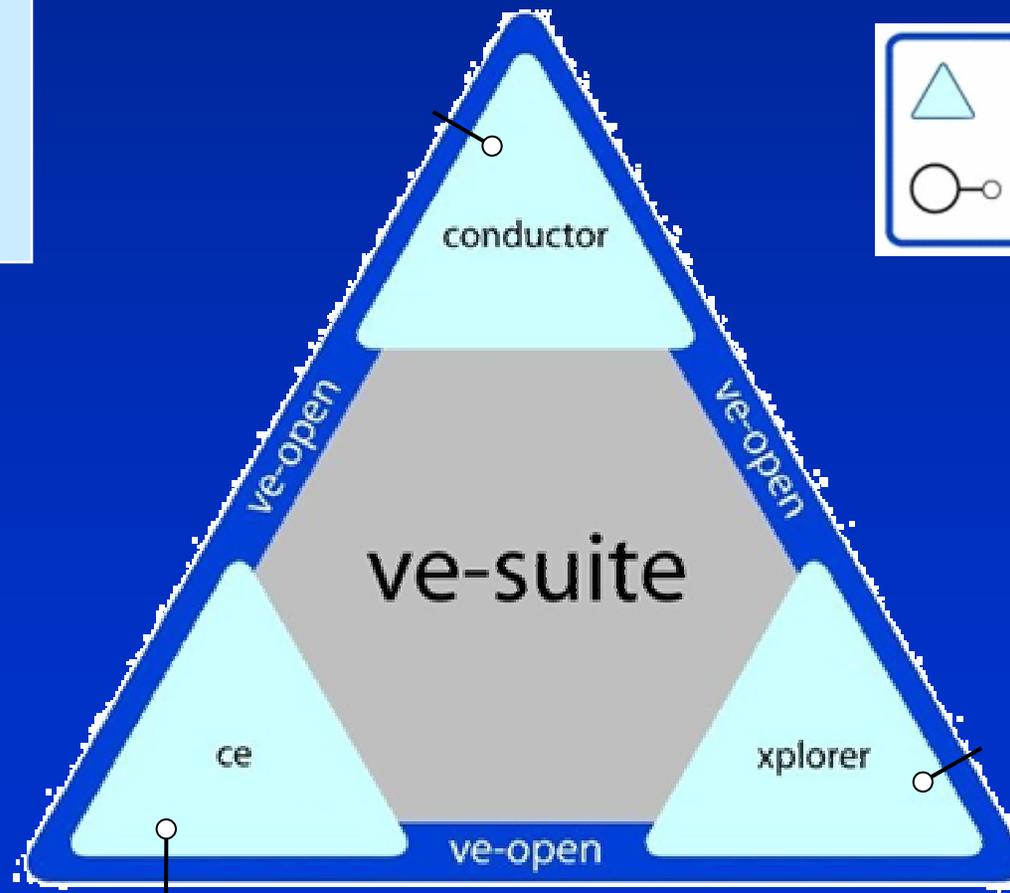
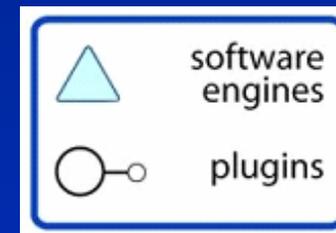
The VE-Suite Framework



Connecting Models to VE-Suite

Model "A"

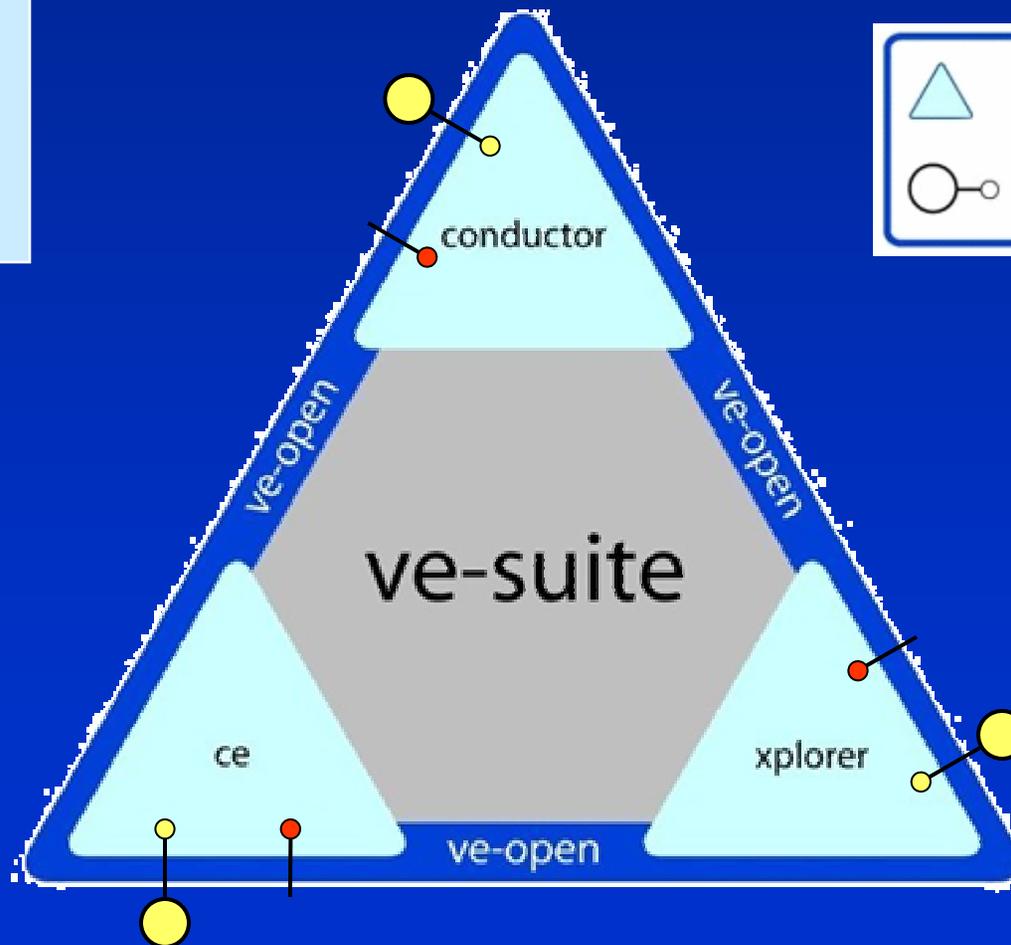
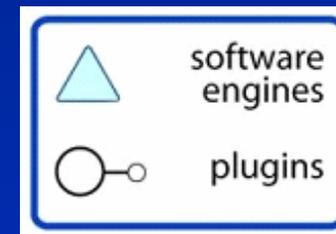
Computation Code Graphic Objects User Interface



Connecting Models to VE-Suite

Model "B"

Computation Code Graphic Objects User Interface



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”

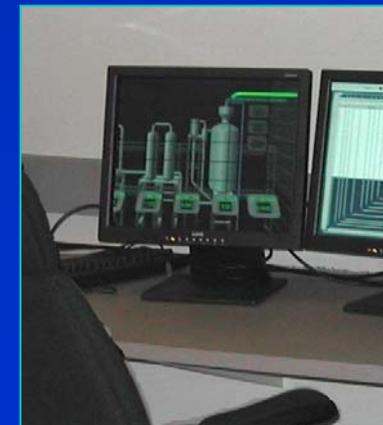
Physical Setup



2-D interface
& keyboard
controls

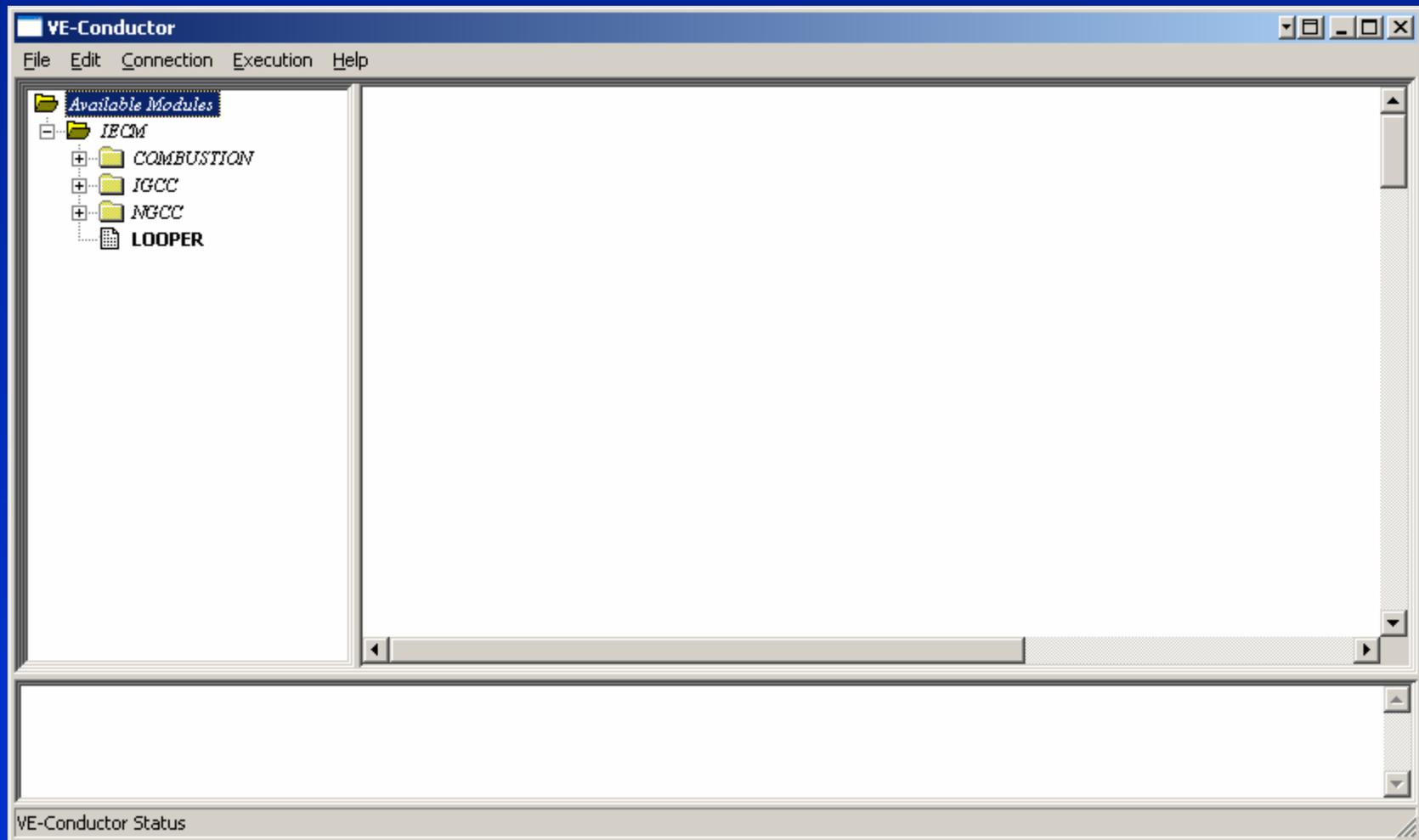


3-D wall
or monitor
display

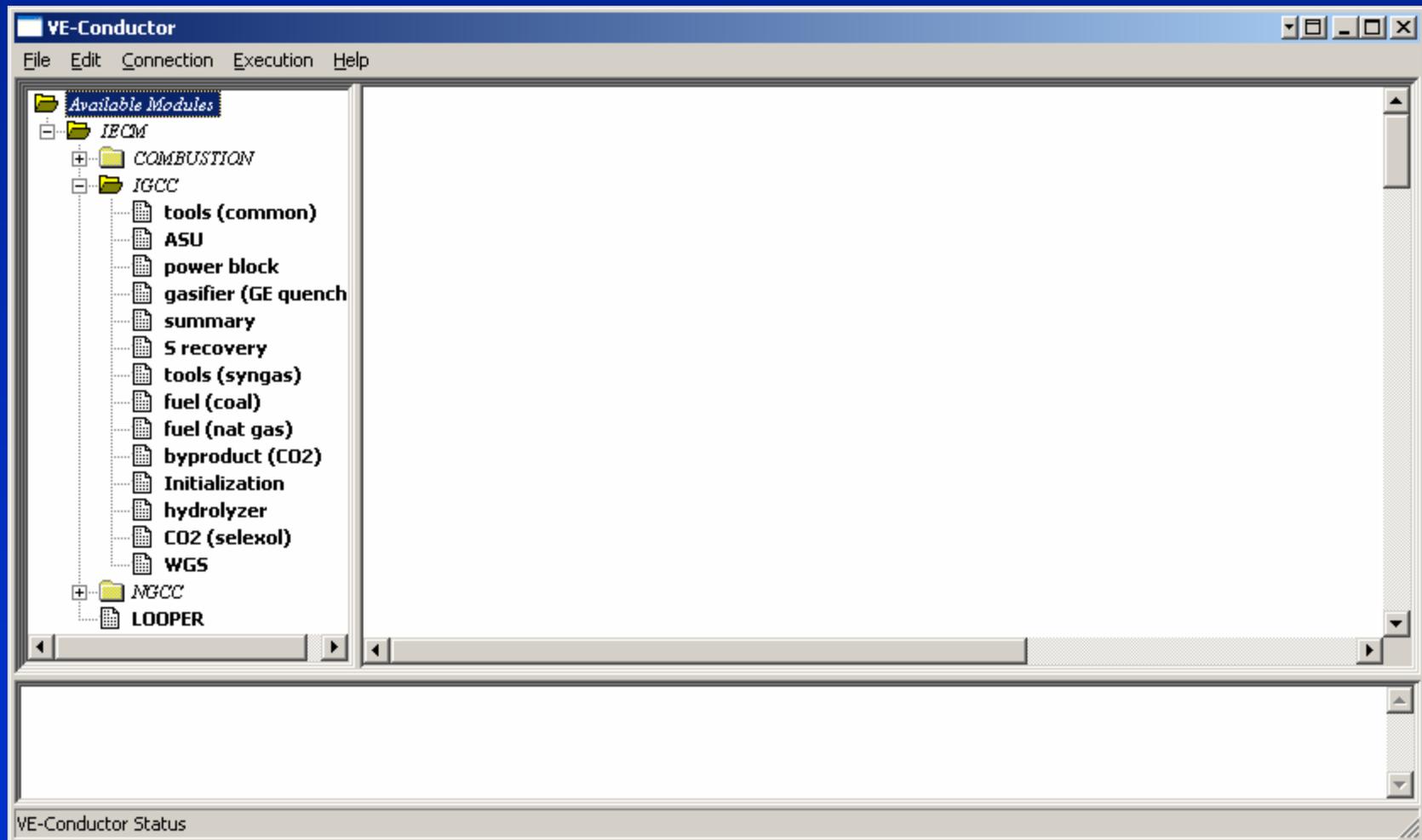


Illustrative Applications to Advanced Power Systems

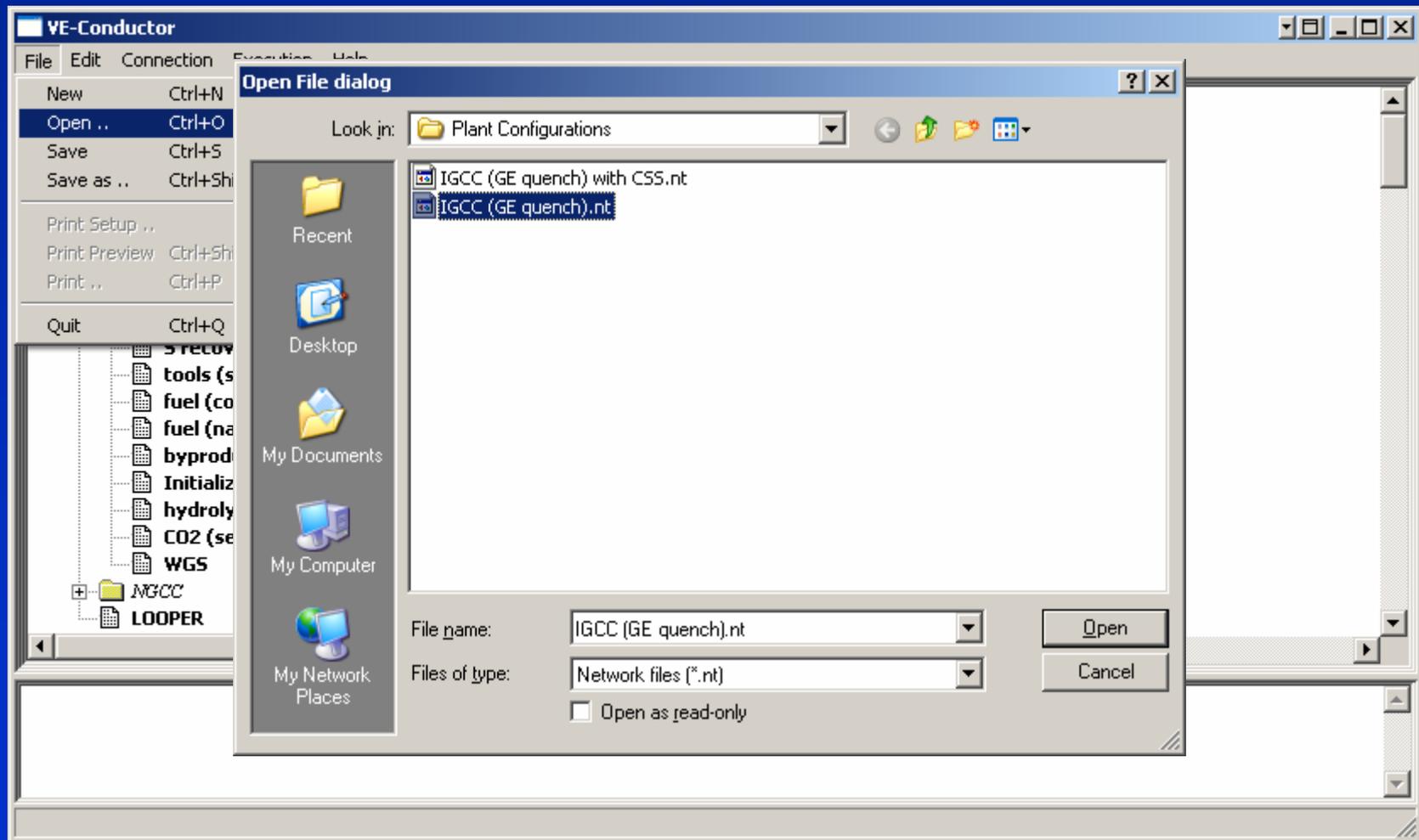
All IECM Plant Types are Now Available in VE-Suite



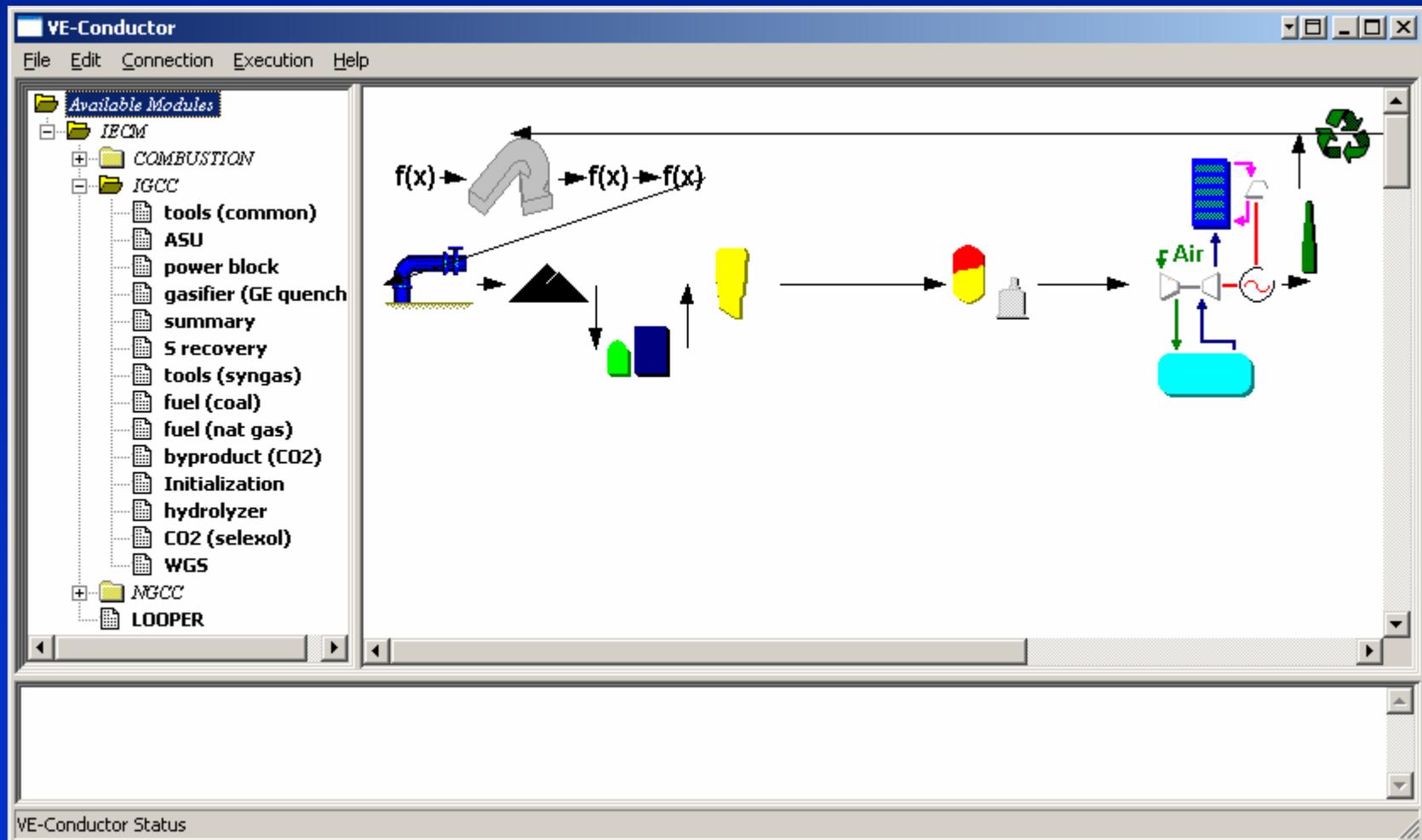
View Available IGCC Components



Select a Pre-Configured IGCC Flowsheet



Selected IGCC Flowsheet



Power Block Performance Inputs

VE-Conductor

File Edit Connection Execution Help

Available Modules

- IECM
 - COMBUSTION
 - IGCC
 - tools (common)
 - ASU
 - power block
 - gasifier (GE quench)
 - summary
 - S recovery
 - tools (syngas)
 - fuel (coal)
 - fuel (nat gas)
 - byproduct (CO2)
 - Initialization
 - hydrolyzer
 - CO2 (selexol)
 - WGS
 - MGCC
 - LOOPER

IGCC_GTS Inputs

Gas Turbine | Steam Cycle | Gas Turbine Retrofit Cost | IGCC Power Capital Cost | IGCC Power O&M Cost

Gas Turbine/Generator

Gas Turbine Model: GE 7FA

No. of Gas Turbines (integer): 1

Fuel Gas Moisture Content (vol %): 0 override calc value

Turbine Inlet Temperature (degF): 0 override calc value

Turbine Back Pressure (psia): 2

Adiabatic Turbine Efficiency (%): 95

Shaft/Generator Efficiency (%): 98

Air Compressor

Pressure Ratio (outlet/inlet) (ratio): 15.7

Adiabatic Compressor Efficiency (%): 70

Combustor

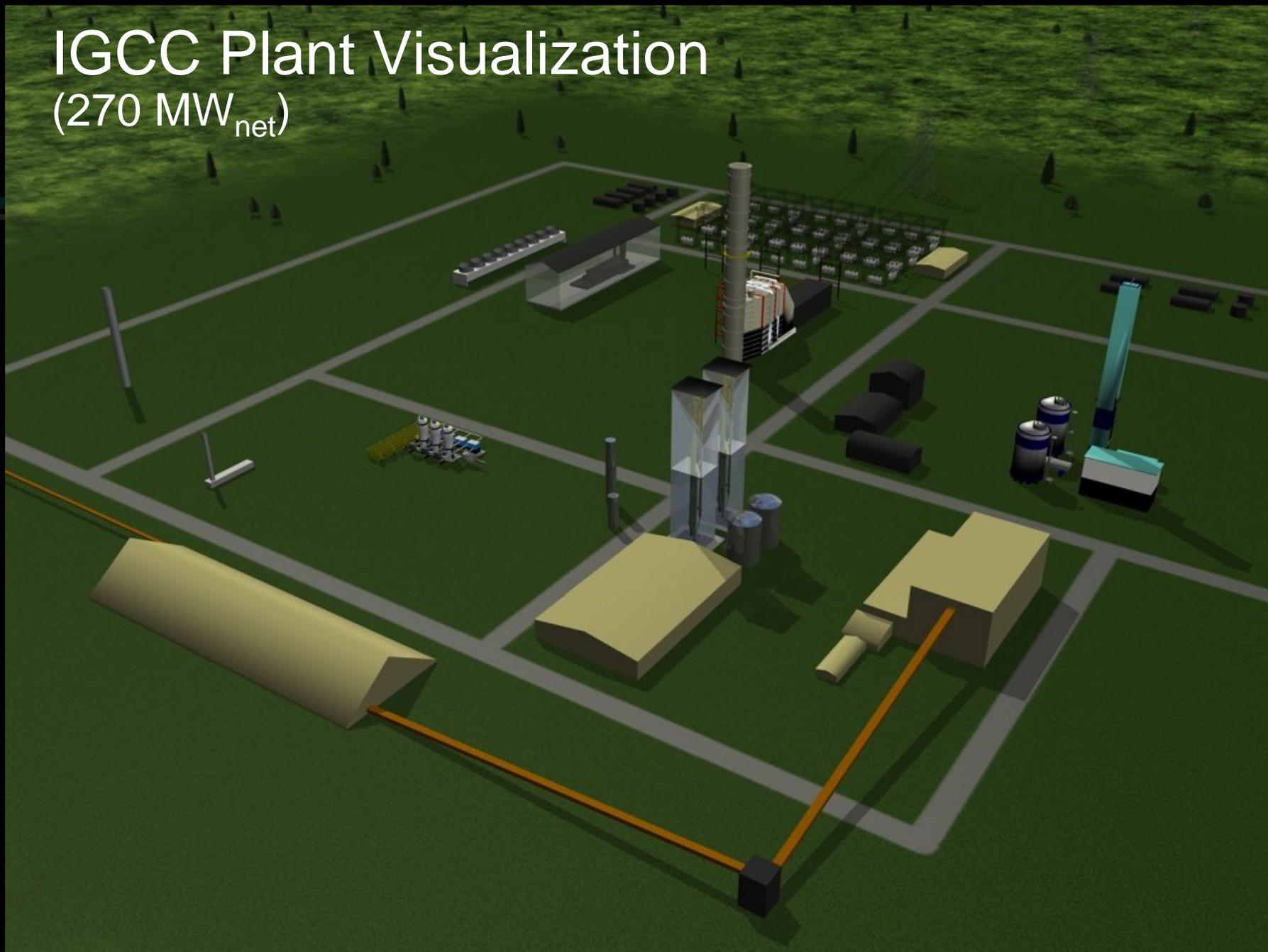
Combustor Pressure Drop (psia): 4

Excess Air For Combustor (% stoich.): 0 override calc value

OK Cancel

VE-Conductor Status

IGCC Plant Visualization (270 MW_{net})



Increase Plant Size

The screenshot shows the VE-Conductor software interface. On the left is a tree view of 'Available Modules' with folders for IECM, COMBUSTION, and IGCC. The IGCC folder is expanded, showing various tool files. On the right is the 'IGCC_GTS Inputs' dialog box, which has several tabs: 'Gas Turbine', 'Steam Cycle', 'Gas Turbine Retrofit Cost', 'IGCC Power Capital Cost', and 'IGCC Power O&M Cost'. The 'Gas Turbine' tab is active. The dialog contains several input fields and checkboxes. A red circle highlights the 'No. of Gas Turbines (integer)' field, which currently has the value '3'. Other fields include 'Gas Turbine Model' (GE 7FA), 'Fuel Gas Moisture Content (vol %)' (0), 'Turbine Inlet Temperature (degF)' (0), 'Turbine Back Pressure (psia)' (2), 'Adiabatic Turbine Efficiency (%)' (95), 'Shaft/Generator Efficiency (%)' (98), 'Air Compressor Pressure Ratio (outlet/inlet) (ratio)' (15.7), 'Adiabatic Compressor Efficiency (%)' (70), 'Combustor Pressure Drop (psia)' (4), and 'Excess Air For Combustor (% stoich.)' (0). There are 'override calc value' checkboxes next to the moisture content, turbine inlet temperature, and excess air fields. The dialog has 'OK' and 'Cancel' buttons at the bottom.

Parameter	Value	Override Calc Value
Gas Turbine Model	GE 7FA	
No. of Gas Turbines (integer)	3	
Fuel Gas Moisture Content (vol %)	0	<input type="checkbox"/>
Turbine Inlet Temperature (degF)	0	<input type="checkbox"/>
Turbine Back Pressure (psia)	2	
Adiabatic Turbine Efficiency (%)	95	
Shaft/Generator Efficiency (%)	98	
Air Compressor Pressure Ratio (outlet/inlet) (ratio)	15.7	
Adiabatic Compressor Efficiency (%)	70	
Combustor Pressure Drop (psia)	4	
Excess Air For Combustor (% stoich.)	0	<input type="checkbox"/>

IGCC Plant (800 MW_{net})



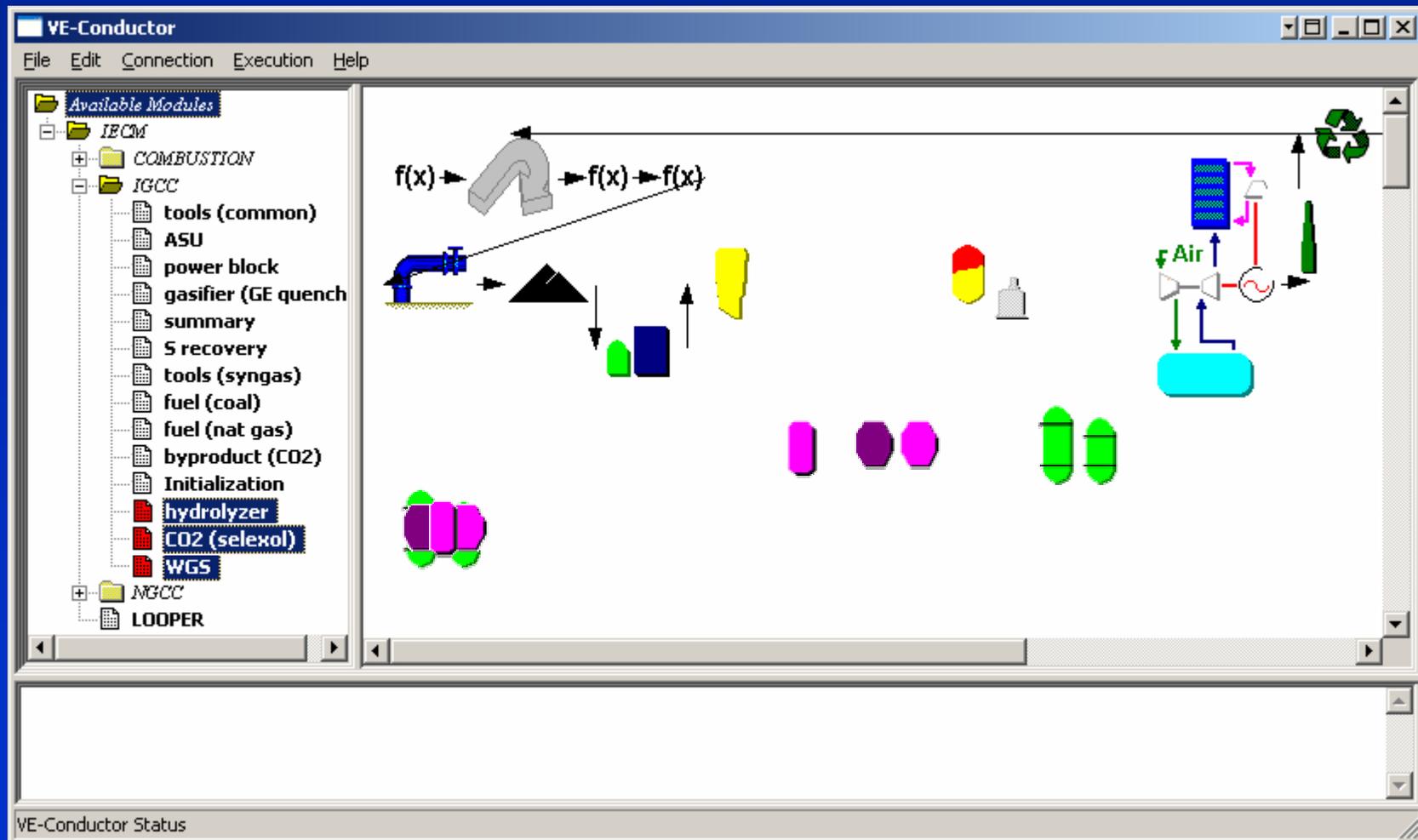
Remove “Links” to Add CO₂ Capture and Storage

The screenshot displays the VE-Conductor software interface. On the left, a tree view under "Available Modules" shows a hierarchy: IECM > COMBUSTION > IGCC. Under IGCC, several modules are listed, including "byproduct (CO2)". The main workspace shows a process flow diagram with various units and streams. A context menu is open over a link, with the "Delete Link" option highlighted. The menu items are:

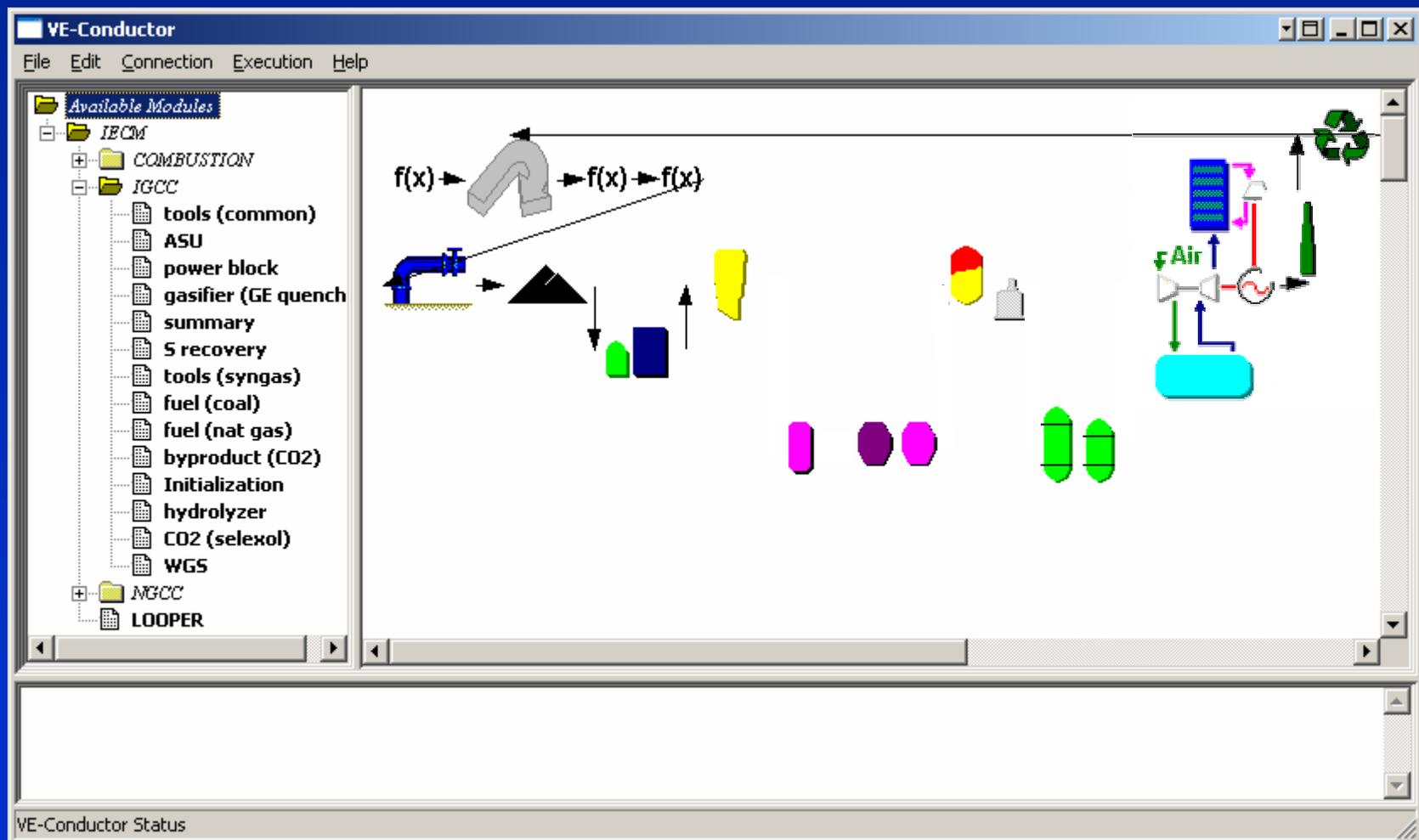
- Action
- Add Tag
- Add Link Connector
- Edit Tag
- Delete Link Connector
- Delete Link**
- Delete Tag
- Del Module
- Show Module Description
- Show Module Result
- ParaView 3D Result
- Show Link Content
- Financial Data
- Geometry Config

The status bar at the bottom of the window reads "VE-Conductor Status".

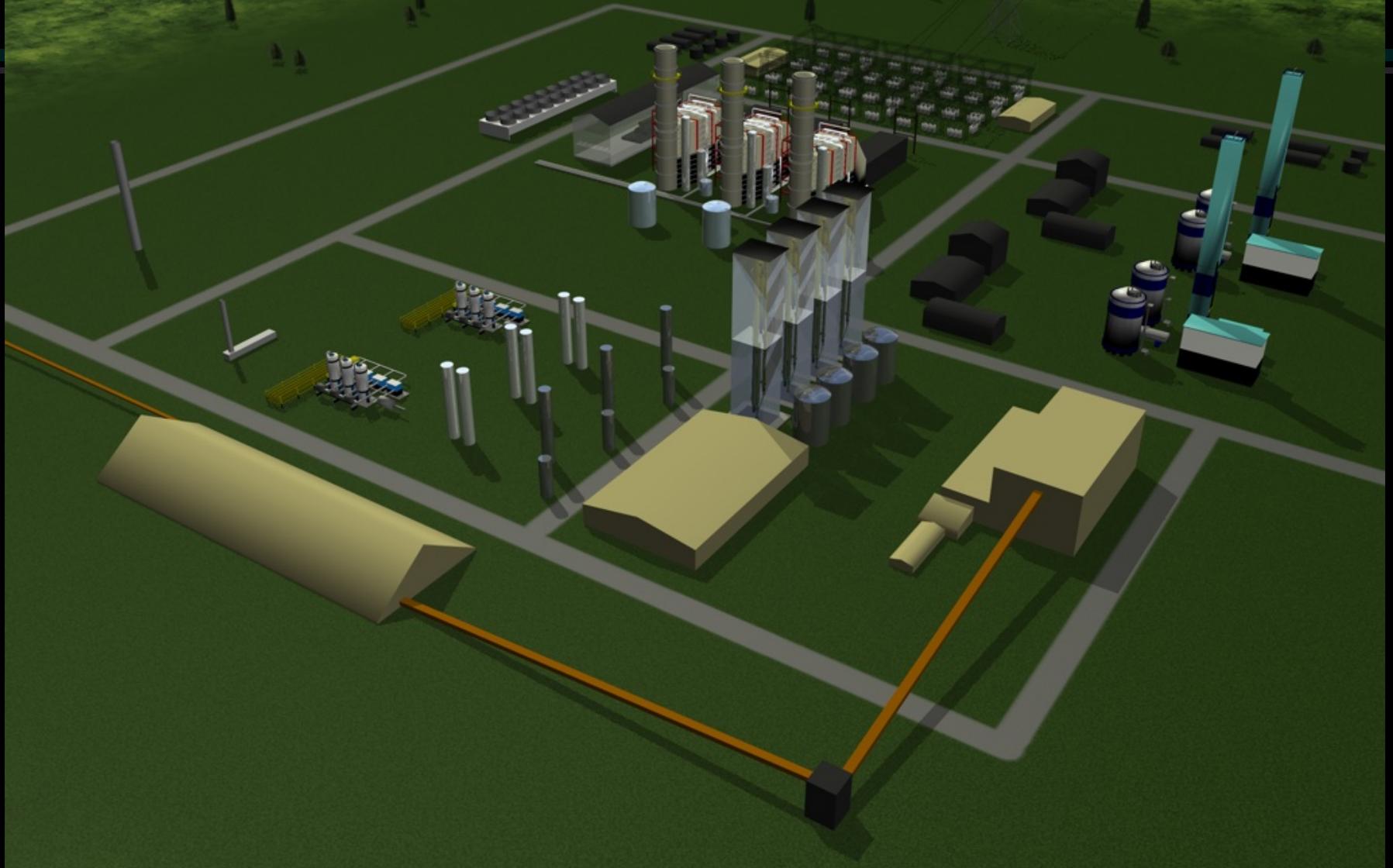
Manually Add CSS Technologies



New Flowsheet: IGCC with CSS



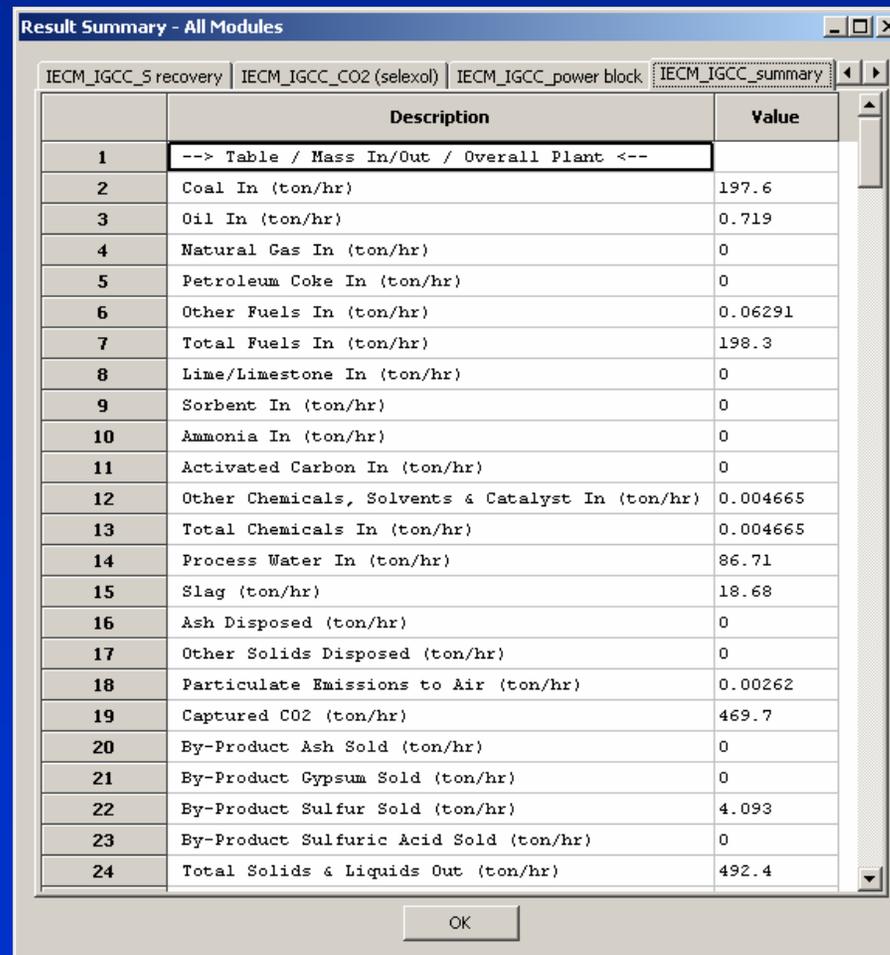
IGCC w/CCS (740 MW_{net})



IGCC w/CCS Flyby



Mass Flow Summary (VE-Suite)



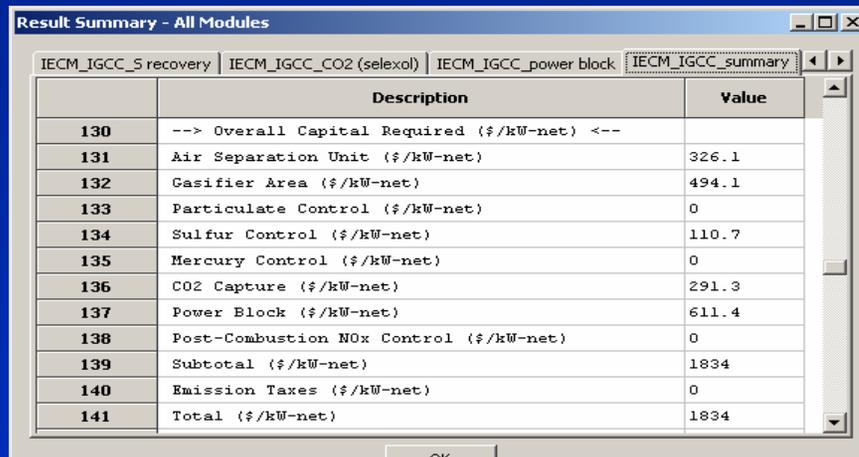
Result Summary - All Modules

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

	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

OK

Plant Cost Results (VE-Suite)

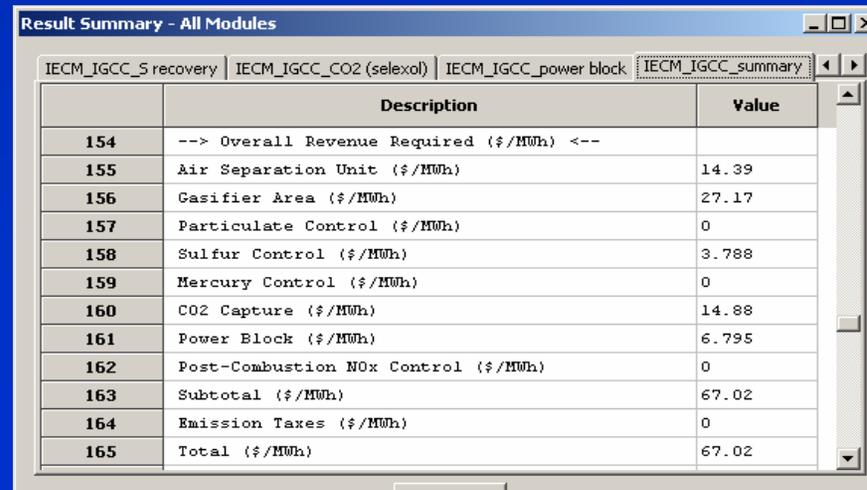


Result Summary - All Modules

	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

Total Capital Cost
(\$/kW)

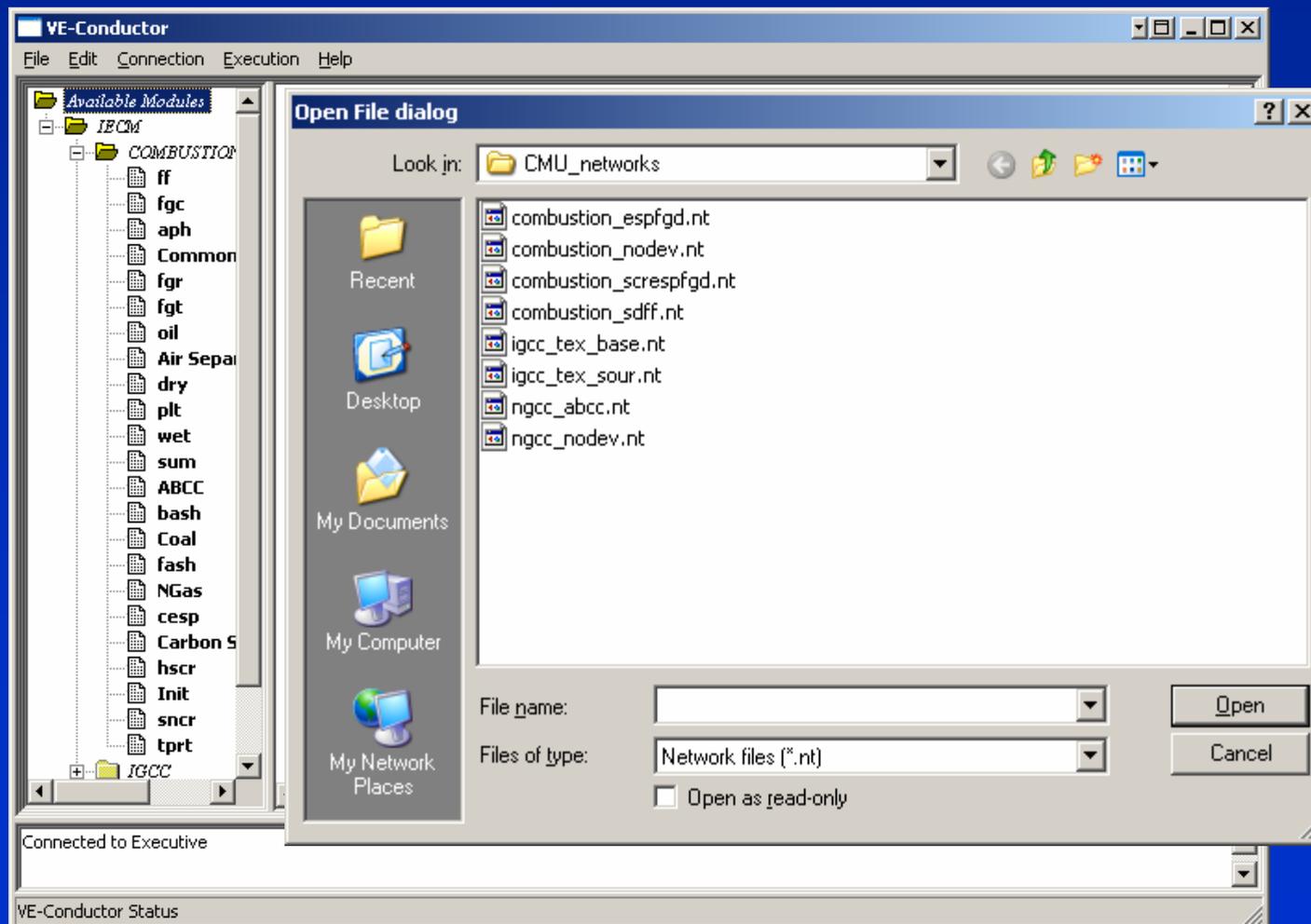
Cost of Electricity
(\$/MWh)



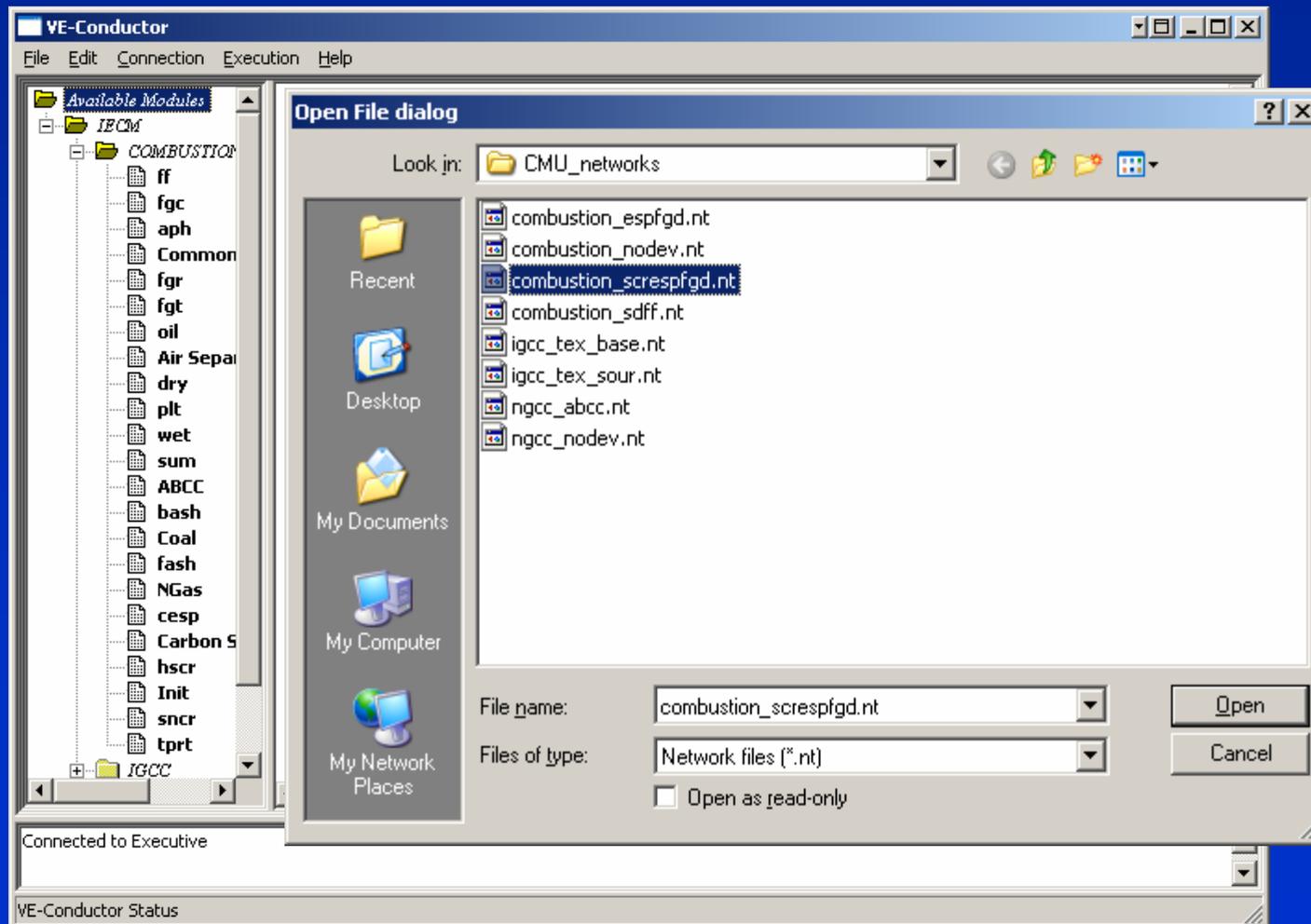
Result Summary - All Modules

	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

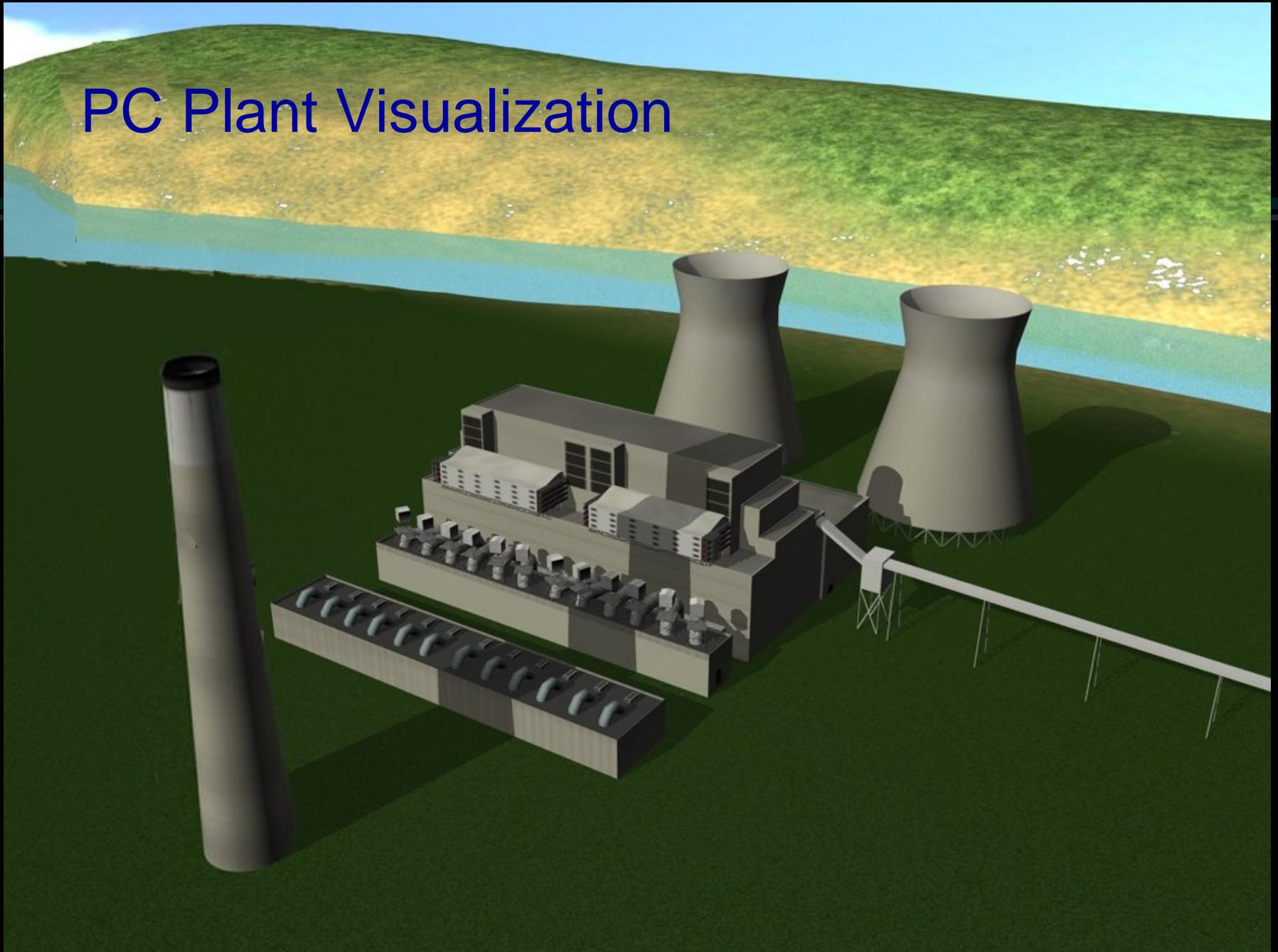
Configure Other Plant Types



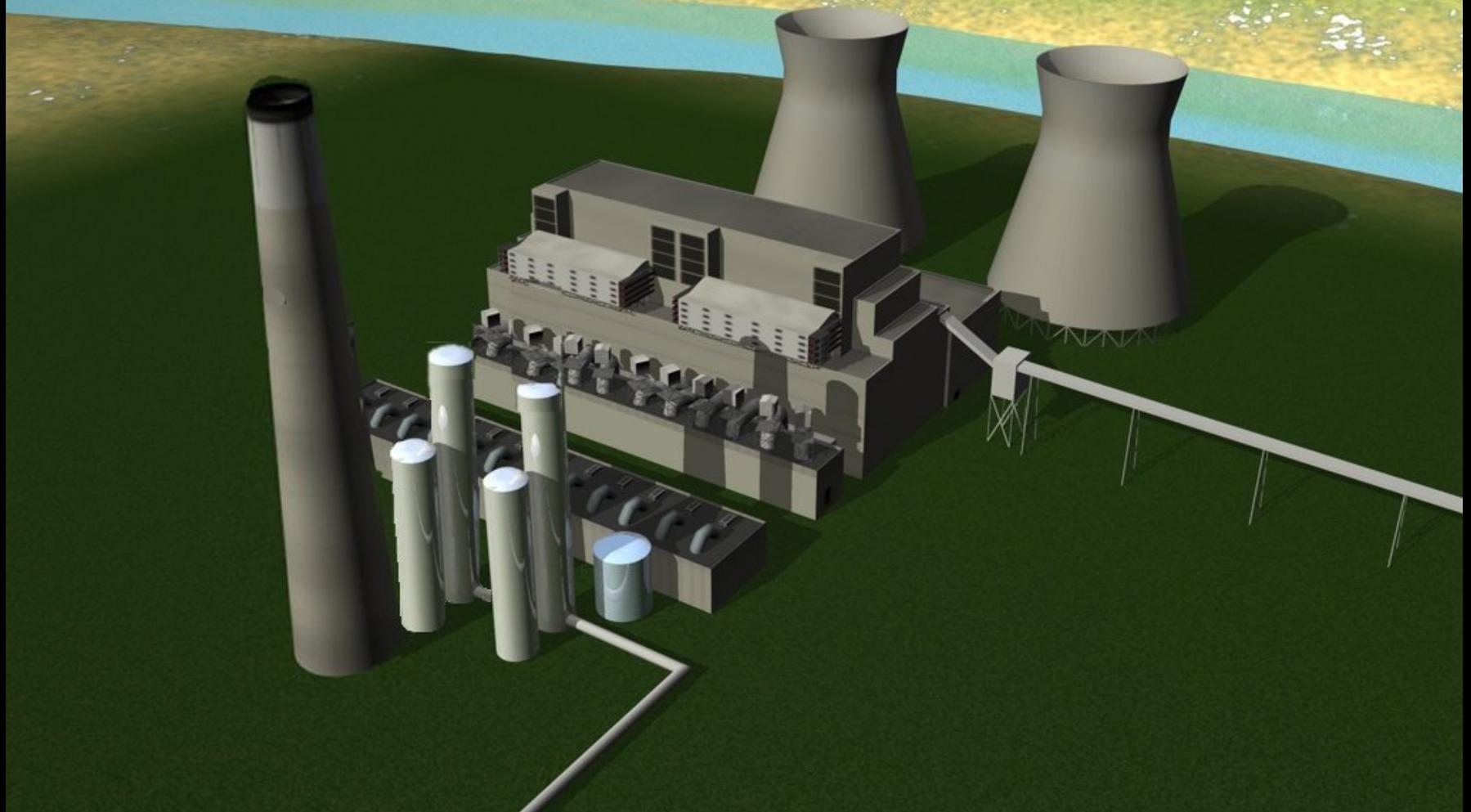
Configure Other Plant Types



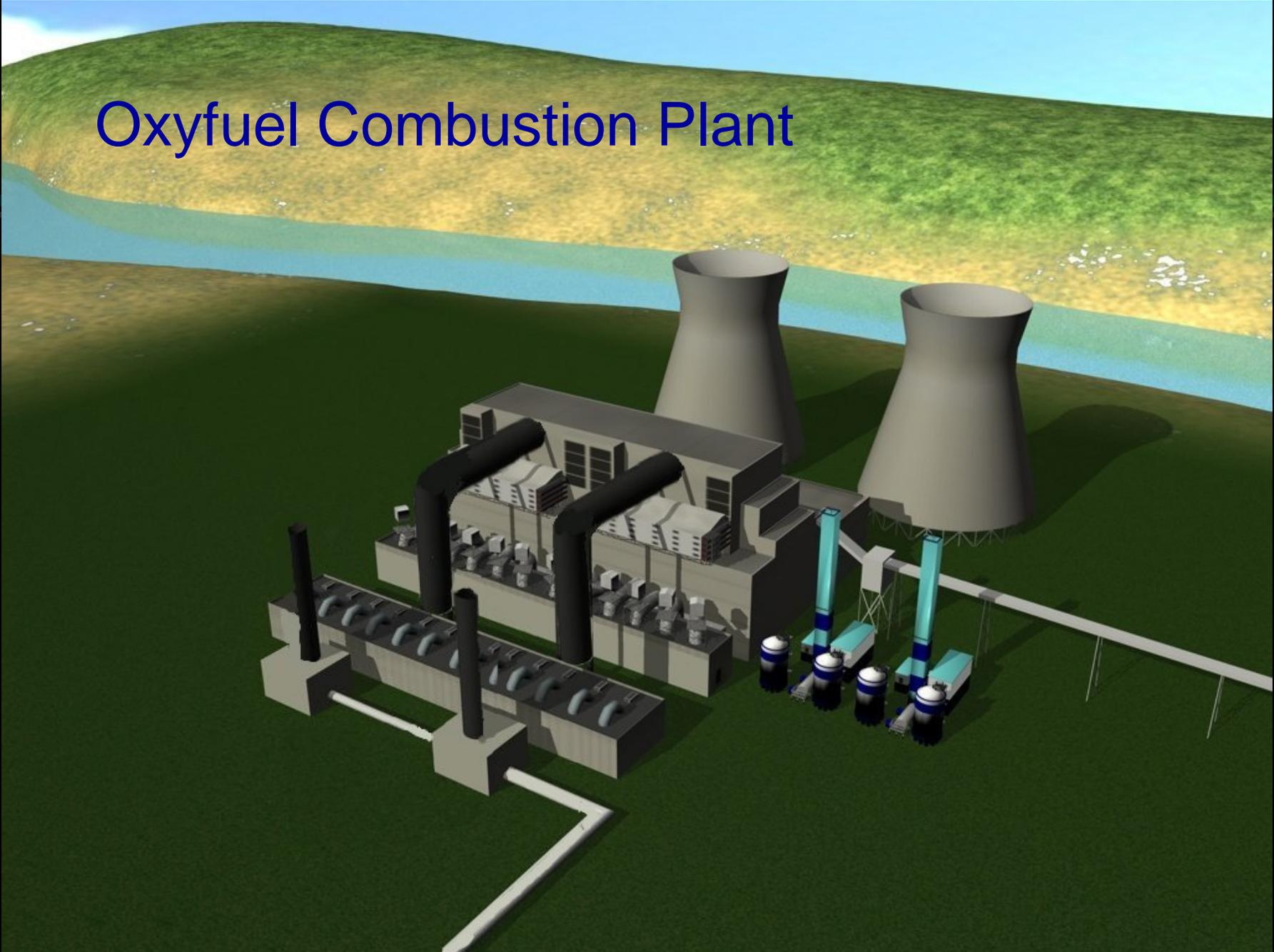
PC Plant Visualization



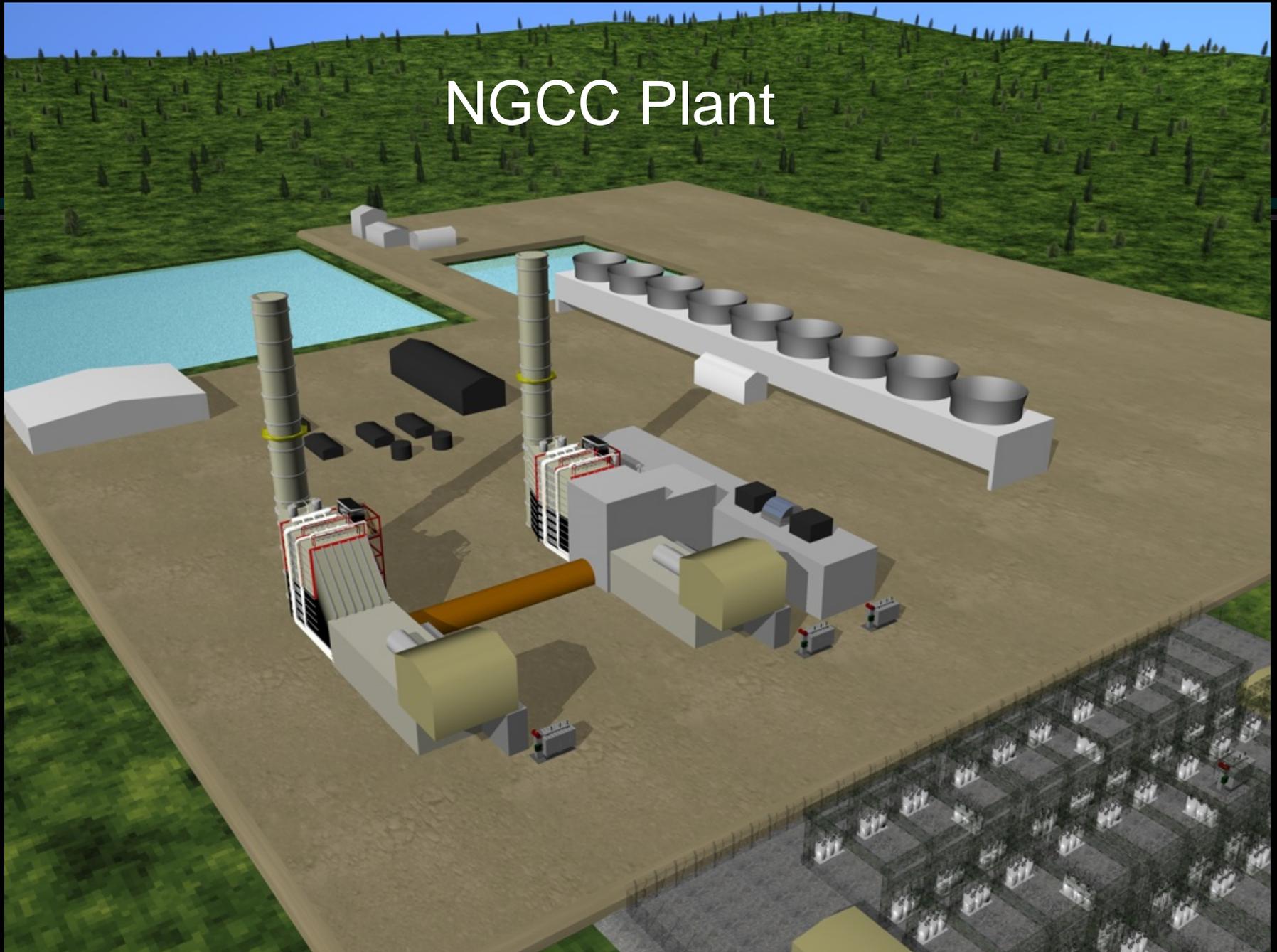
PC Plant w/ CCS (Advanced amine system)



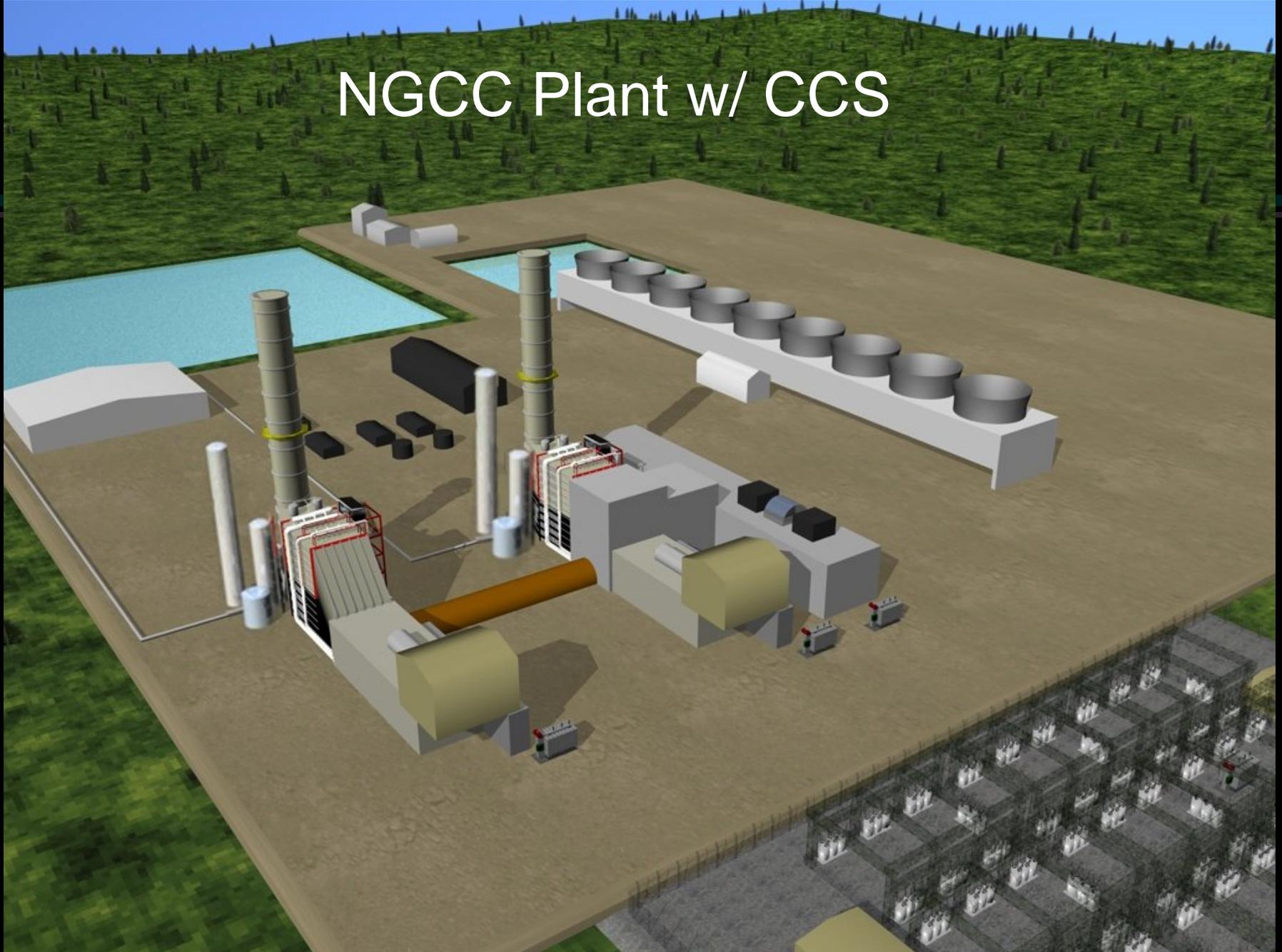
Oxyfuel Combustion Plant



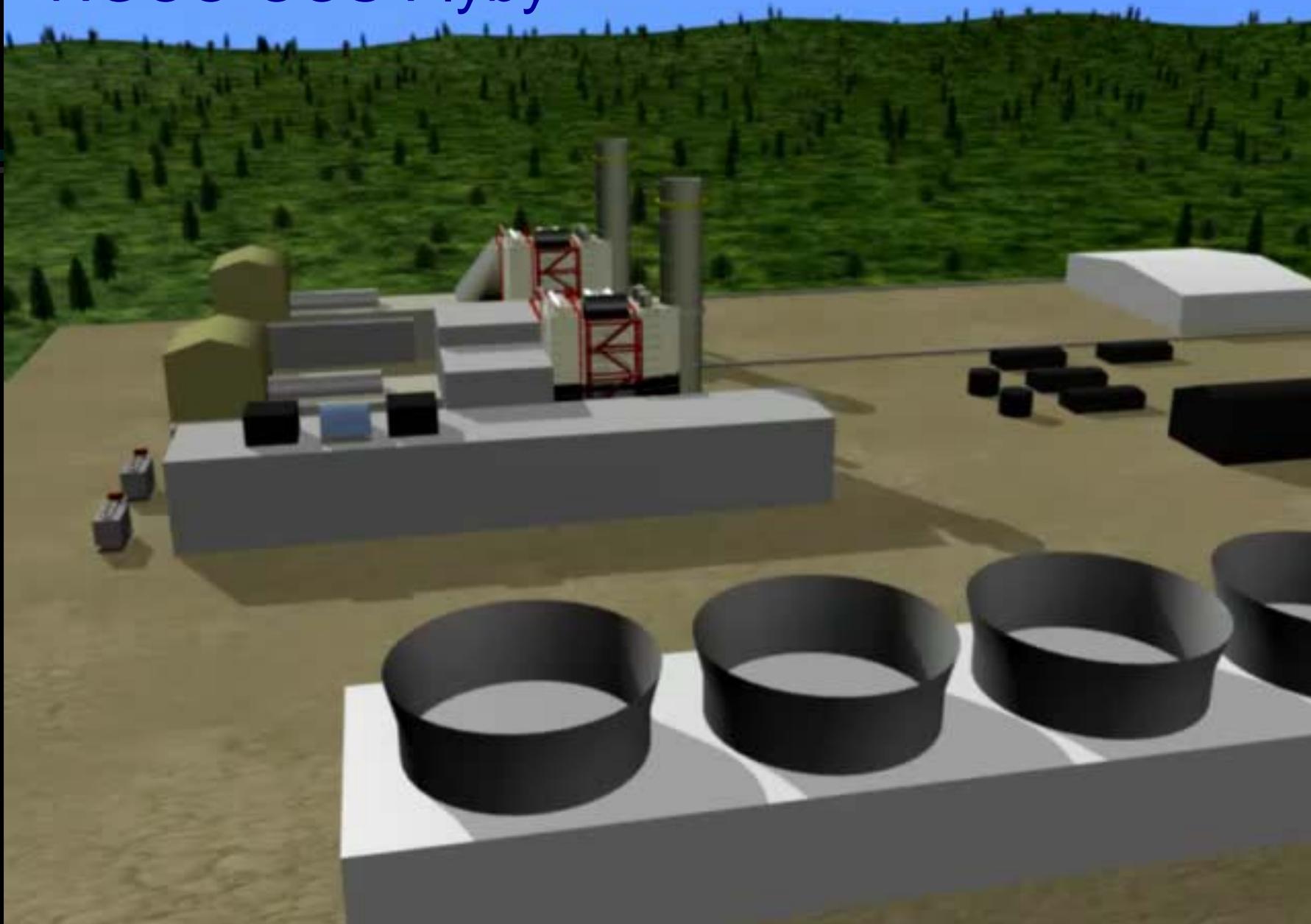
NGCC Plant



NGCC Plant w/ CCS



NGCC-CCS Flyby

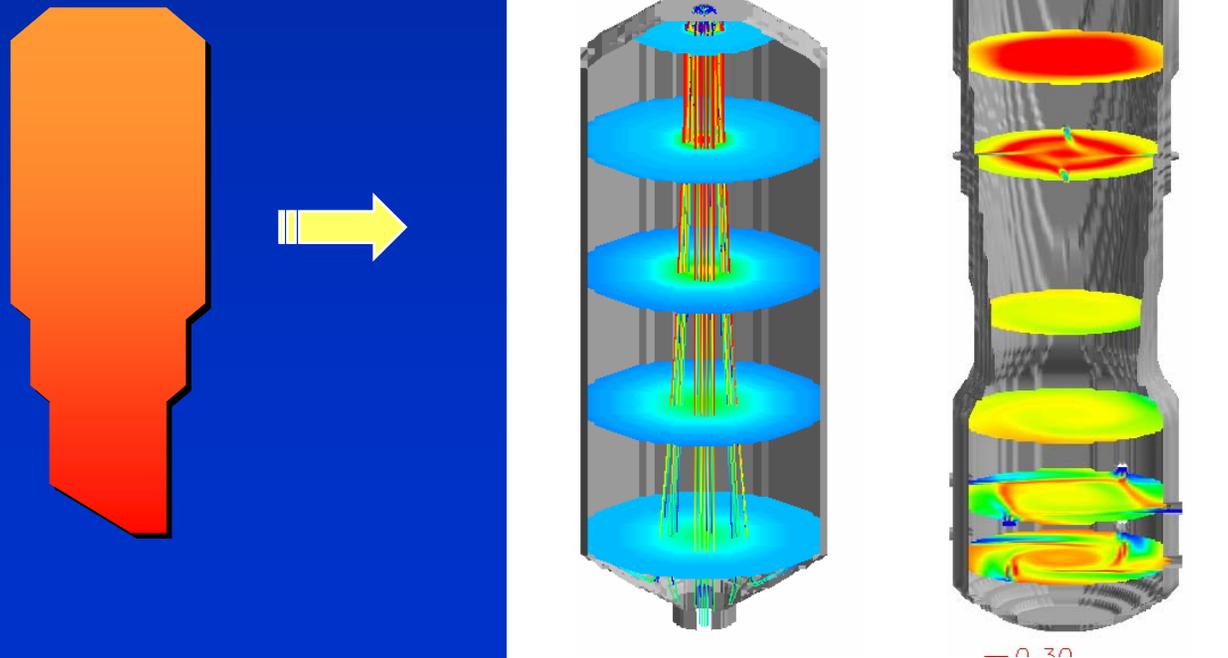


Next Steps

- 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

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