Integrated Modeling of Carbon Management Technologies for Electric Power Systems

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Some Questions to be Addressed

- What carbon management technologies may be used in a particular application (e.g., existing vs. new plants)?
- What are the key parameters that affect the performance, emissions, and cost of a given option?
- How do the alternative options compare in terms of performance, reliability, and cost?
- What are the uncertainties and technological risks of different carbon management options?
- What are the priorities and benefits of R&D to reduce key uncertainties in new process designs?

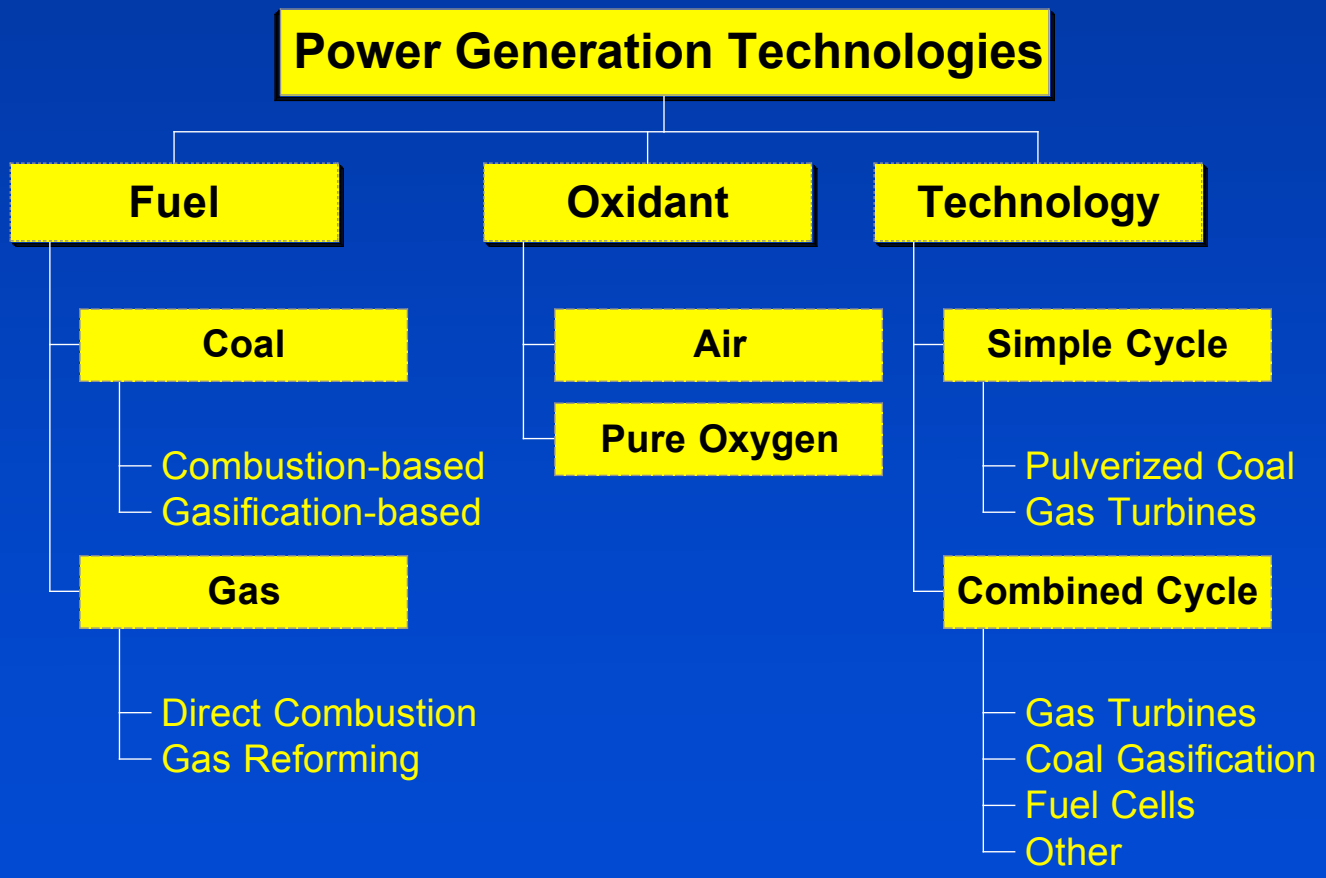
Scope and Objectives

- Identify potential options for power generation with carbon capture and sequestration, suitable for, (a) existing plants, and (b) new plants
- Develop a model to quantify performance, emissions, and cost of alternative options, and their dependency on key plant and technology design parameters, operating parameters, and carbon management methods
- Characterize uncertainty in key parameters of the carbon management system
- Integrate carbon management technologies with other plant environmental control systems
- Conduct case studies to illustrate model applications

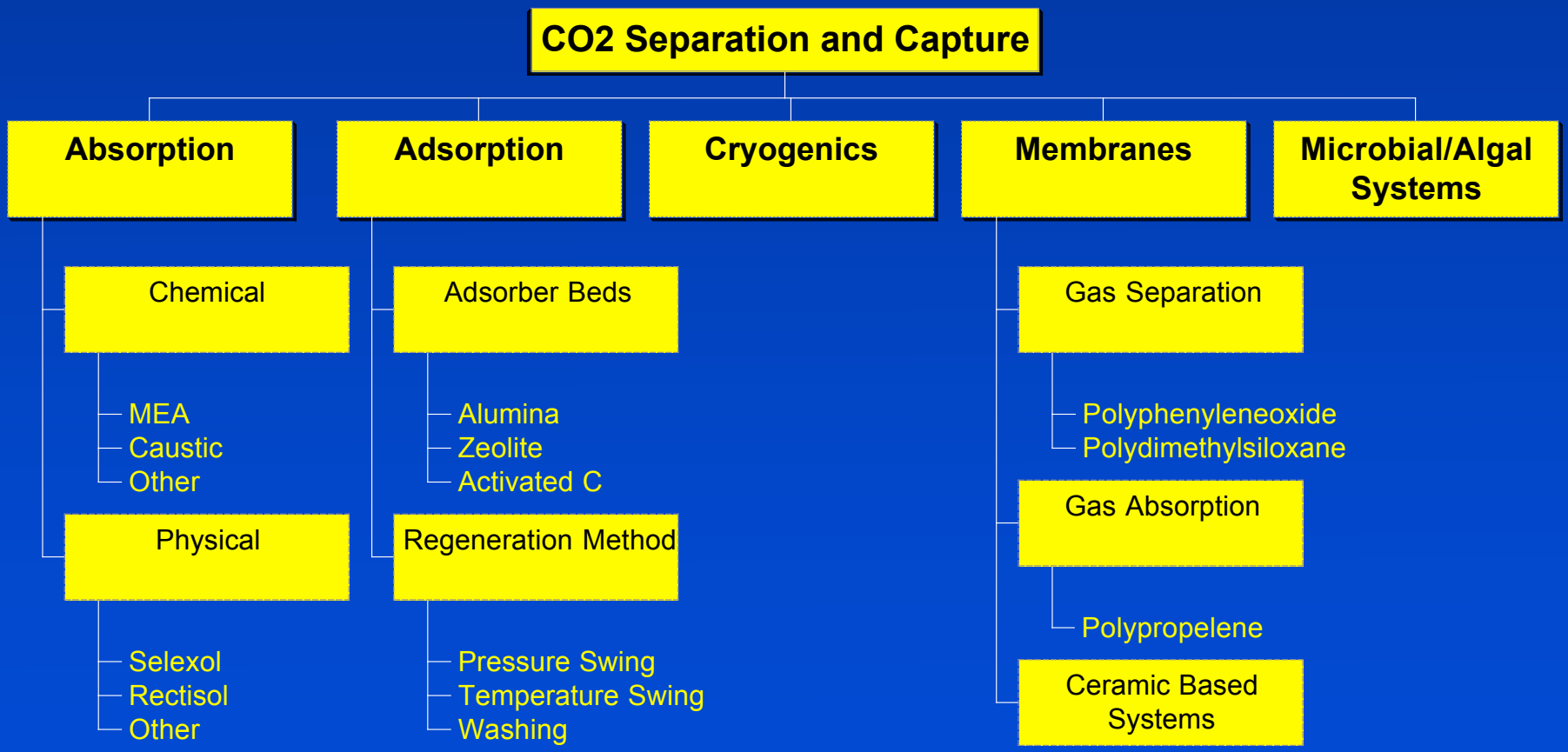
Current Applications

- **Enhanced oil recovery (EOR)**
  - Dow MEA (Some plants in TX and NM, now shut down)
  - Common in 1970s and 1980s (100-1200 tons CO_2/d)
- **Fertilizer industry**
  - H_2 and CO_2 separation ⇒ Urea production
  - Dow MEA (Indo Gulf Fertilizer Co.) - 150 tons CO_2/d
- **Carbonation of brine (soda ash)**
  - Kerr-McGee MEA (North American Chemical Co., operational since 1978) - 800 tons CO_2/d
- **Food-grade**
  - Fluor Daniel / Dow MEA (Northeast Energy Associates, MA) - 320 tons CO_2/d
- **Commercial CO_2 capture and sequestration facility**
  - Injection into deep saline aquifer (Sleipner West gas field, Norway, installed in 1996) - ~3000 tons CO_2/d

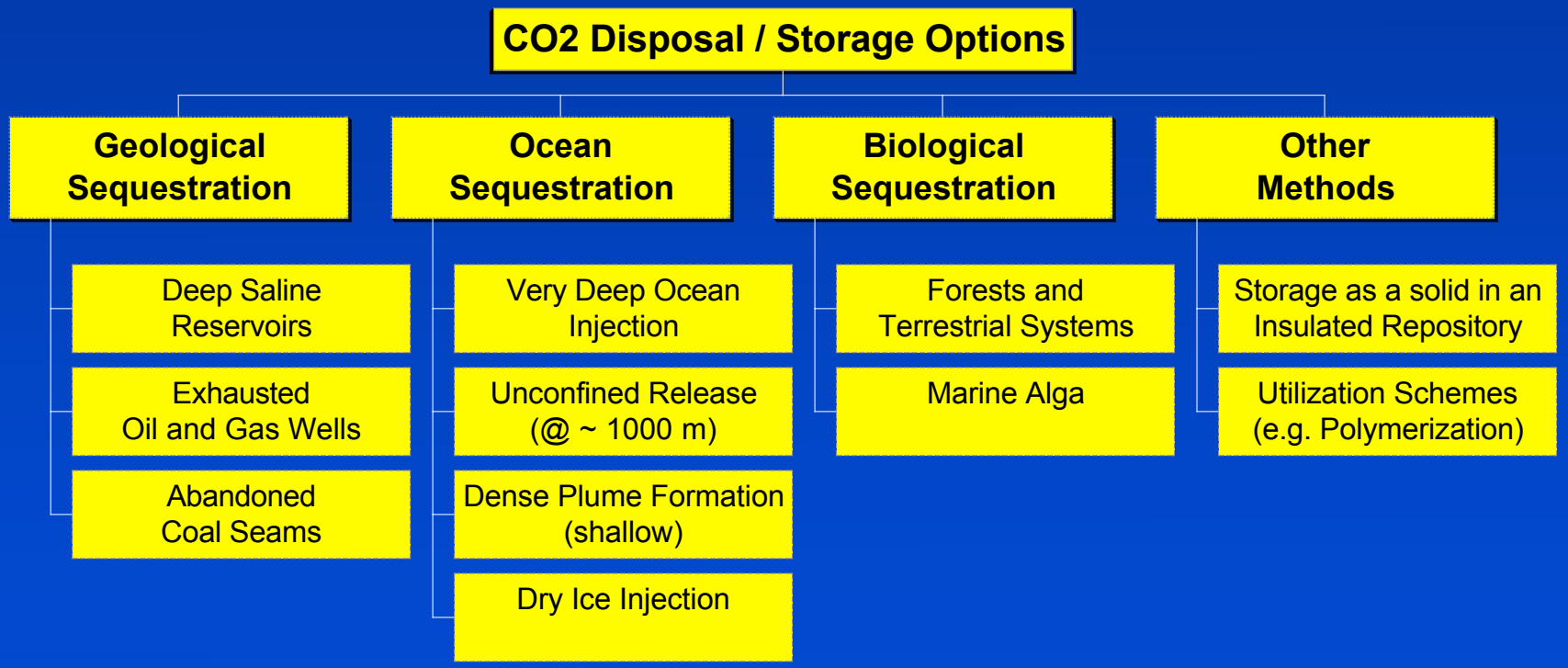
Power Generation Options Using Fossil Fuels



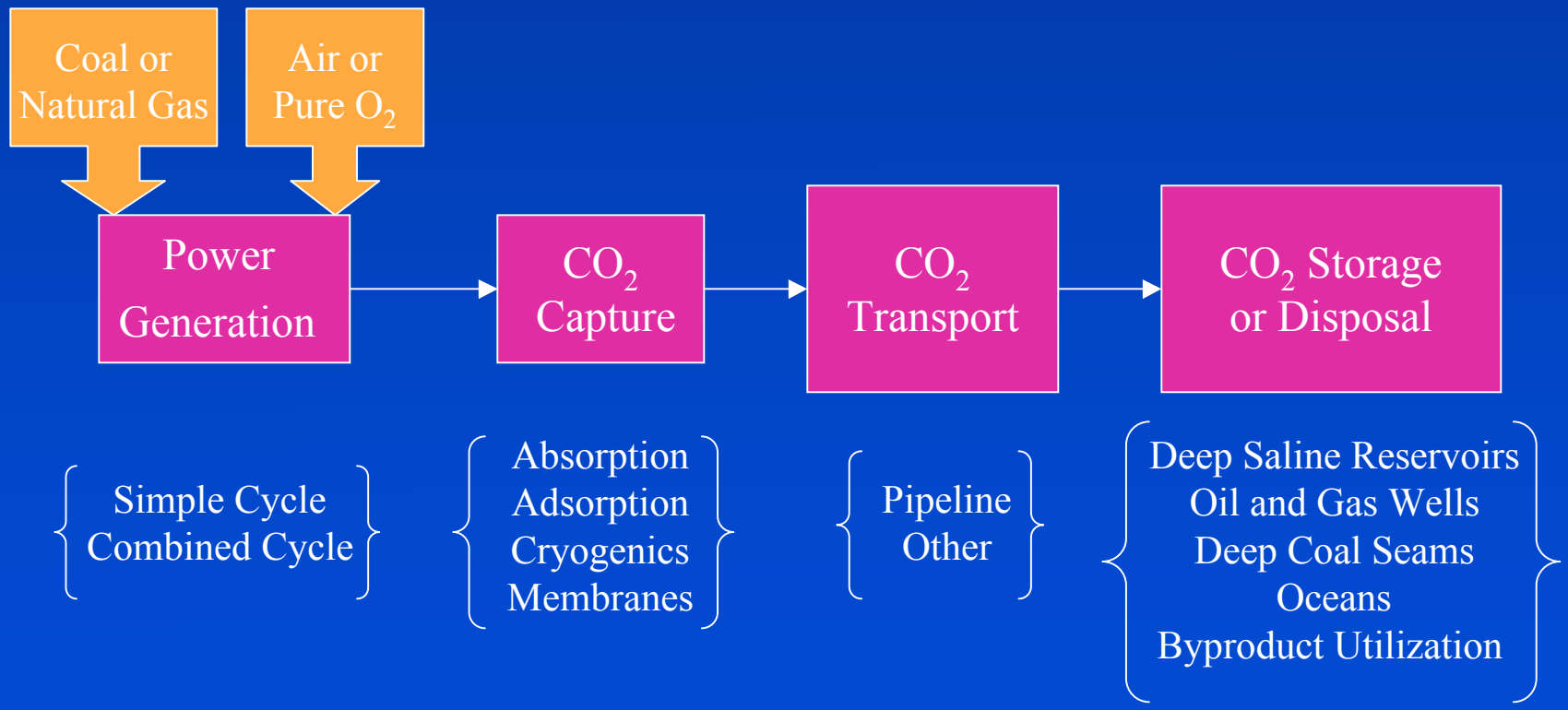
CO_2 Capture Technologies



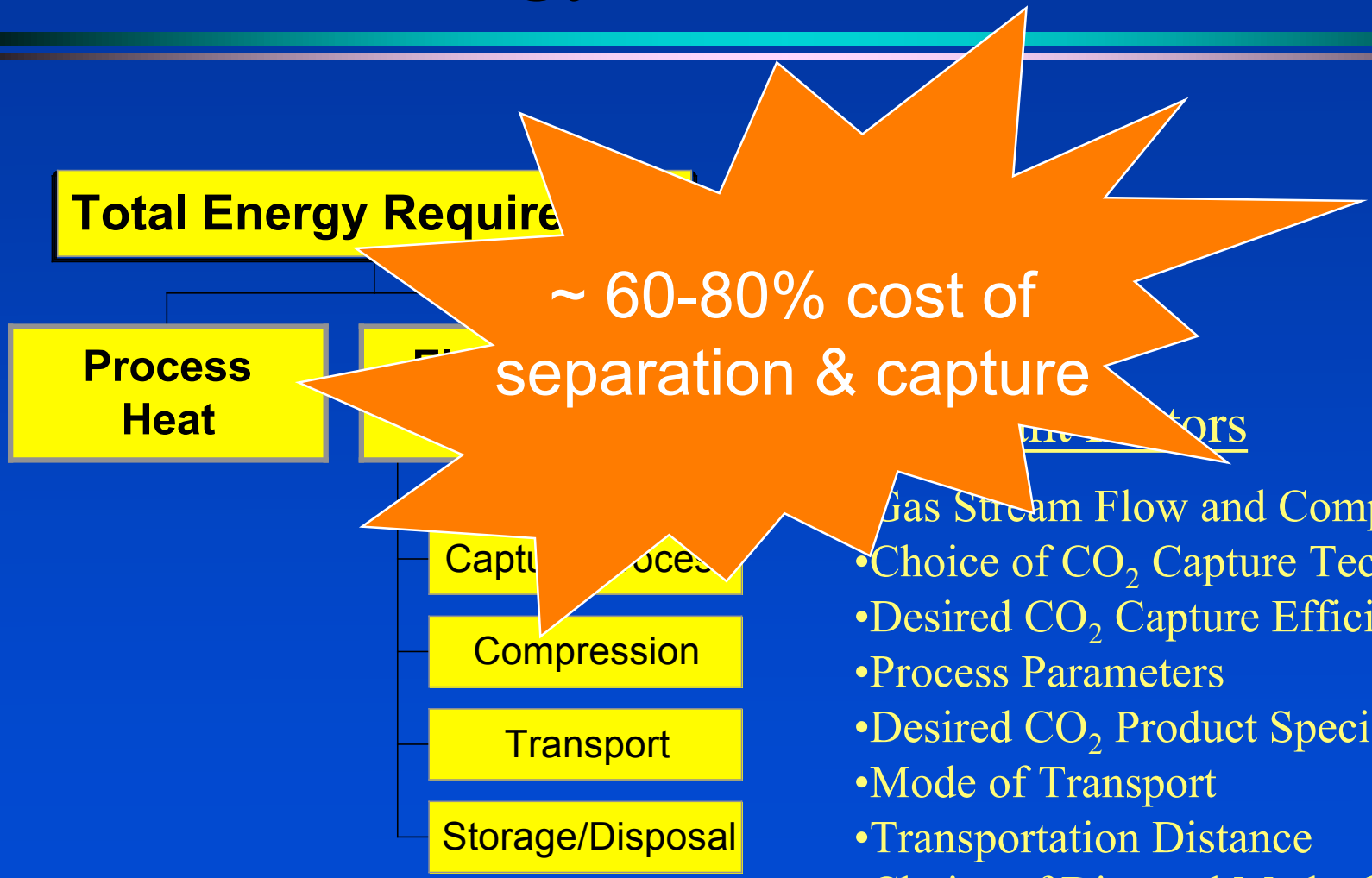
CO_2 Sequestration Options



Modeling Framework for Carbon Management Options



Energy Considerations

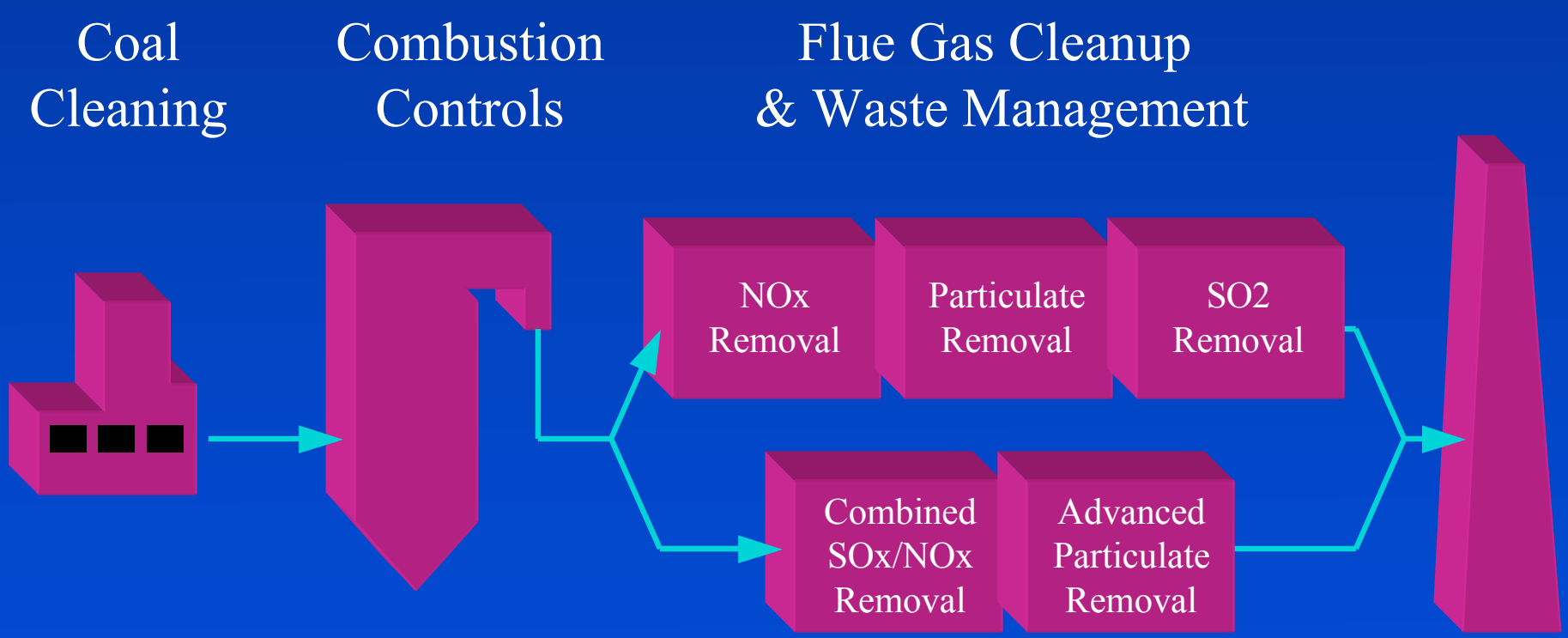


- Gas Stream Flow and Composition
- Choice of CO_2 Capture Technology
- Desired CO_2 Capture Efficiency
- Process Parameters
- Desired CO_2 Product Specifications
- Mode of Transport
- Transportation Distance
- Choice of Disposal Method

Current Status

- Developed preliminary models (performance, emissions, and cost) for several CO_2 capture options, CO_2 transport options, and CO_2 storage options
- Initial focus on modeling of current commercial technologies (amine scrubbing systems) for combustion-based power systems
- Integrated the new CO_2 module with the IECM combustion-based power plant model developed for the USDOE

Integrated Environmental Control Model (IECM)



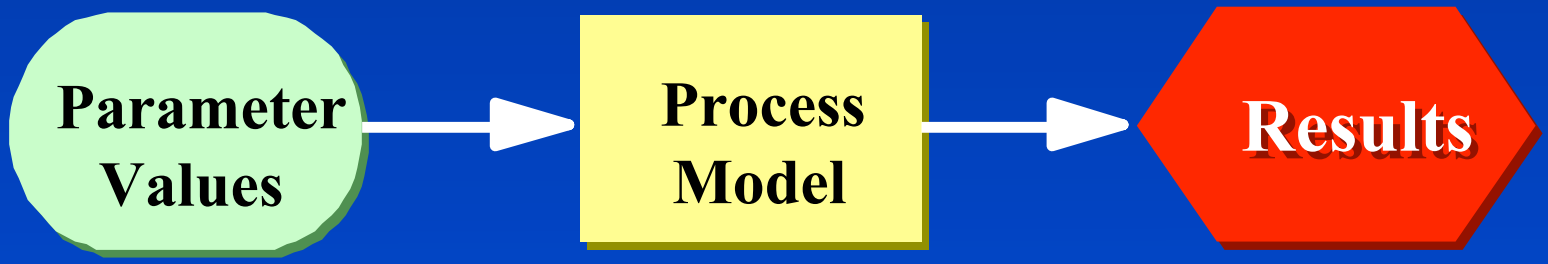
Objectives

- Develop a comprehensive modeling framework to estimate the performance, environmental emissions, and cost of coal-based power generation technologies
- Develop a method for comparing alternative options on a systematic basis, including the effects of uncertainty

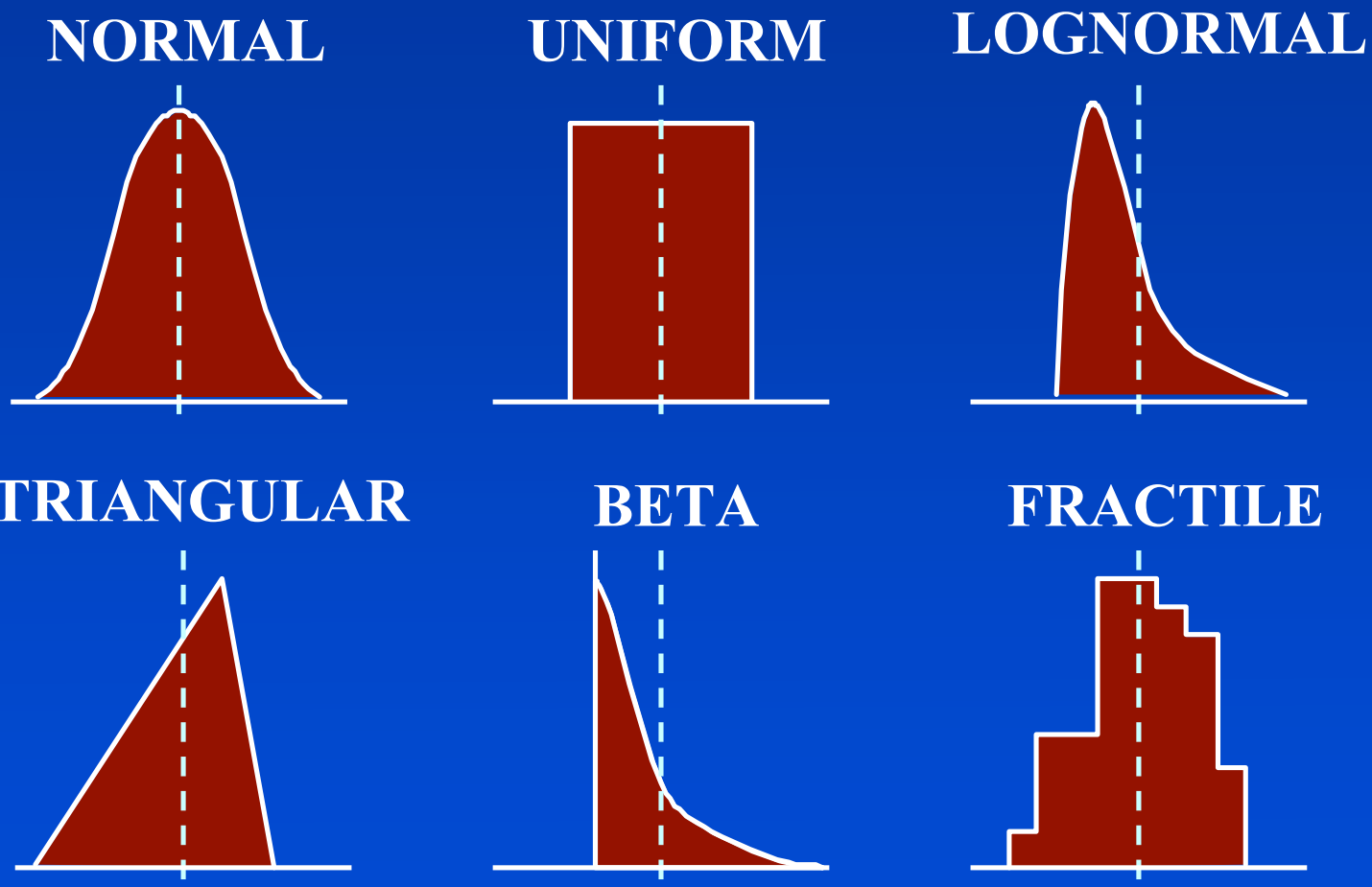
Probabilistic Software Capability

- Allows you to specify parameter values as distribution functions, as well as conventional deterministic (point) estimates
- Allows you to explicitly quantify the effects of uncertainty in performance, emissions, and cost, yielding confidence intervals for uncertain results

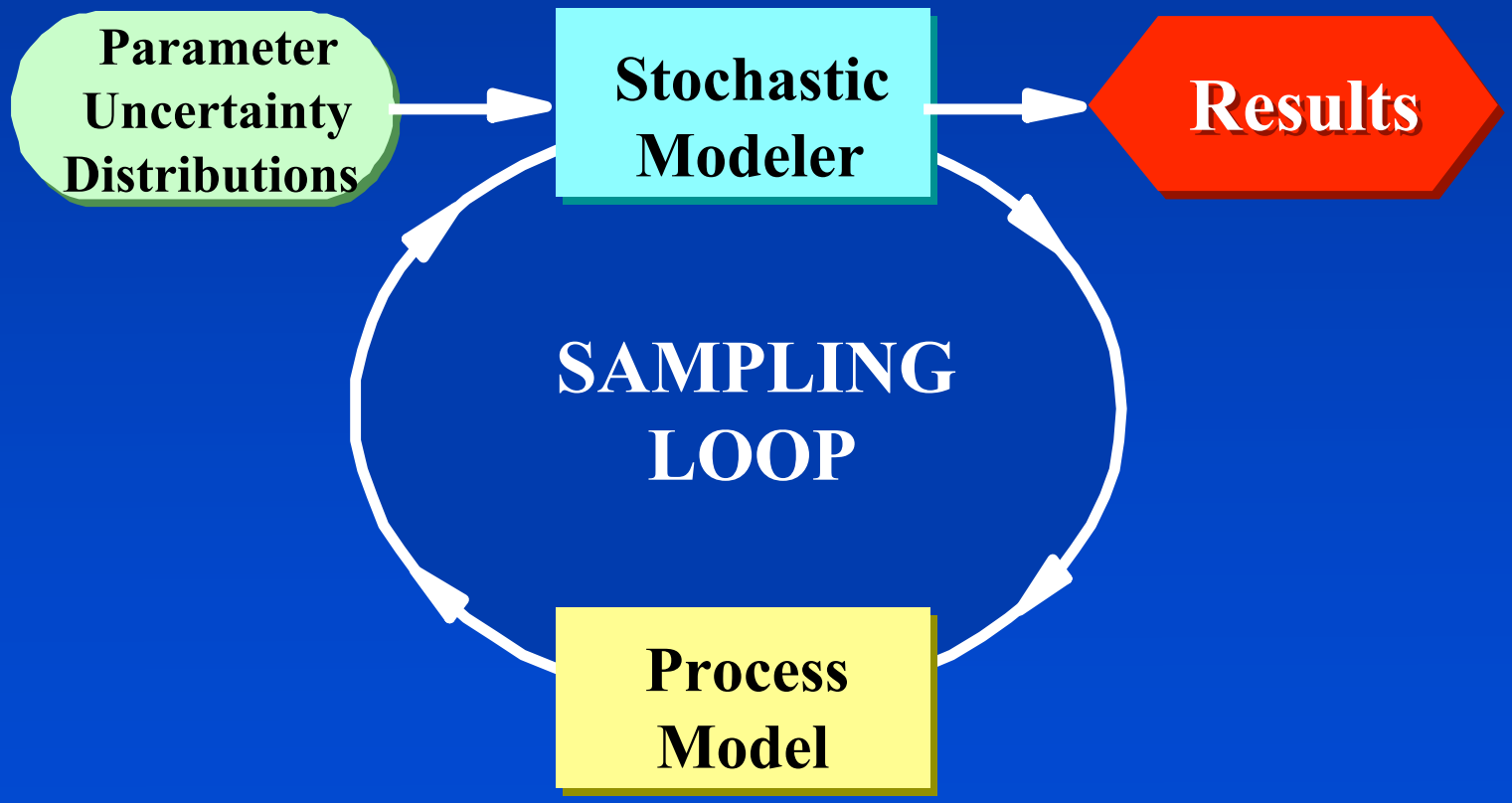
Conventional Process Modeling (Deterministic Simulation)



Parameter Uncertainty Distributions

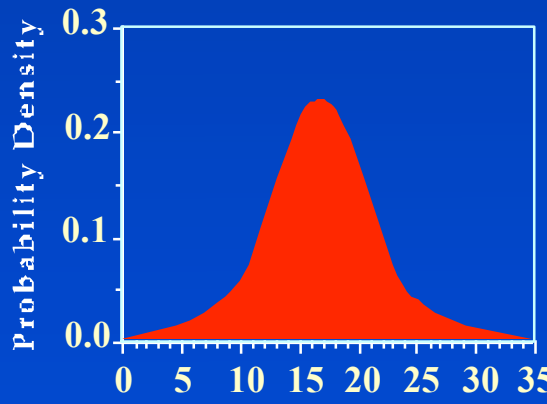


Stochastic Simulation

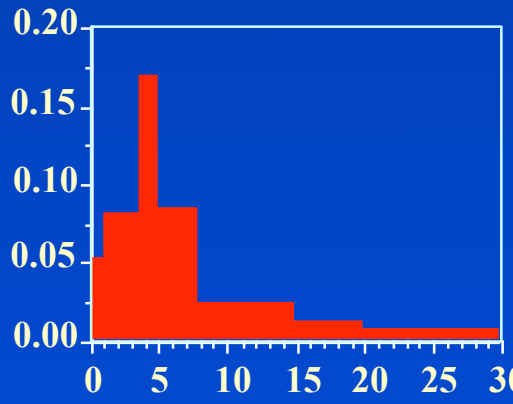


Expert Judgments on Key Model Parameters

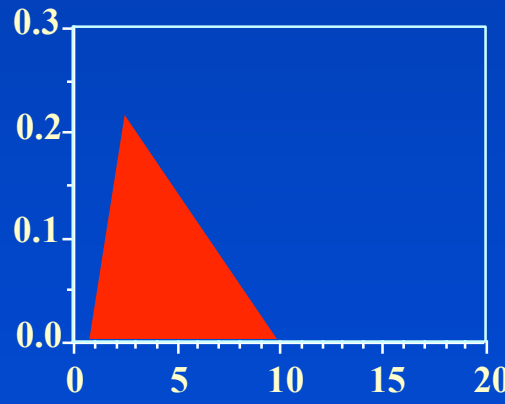
Sorbent Sulfur Loading



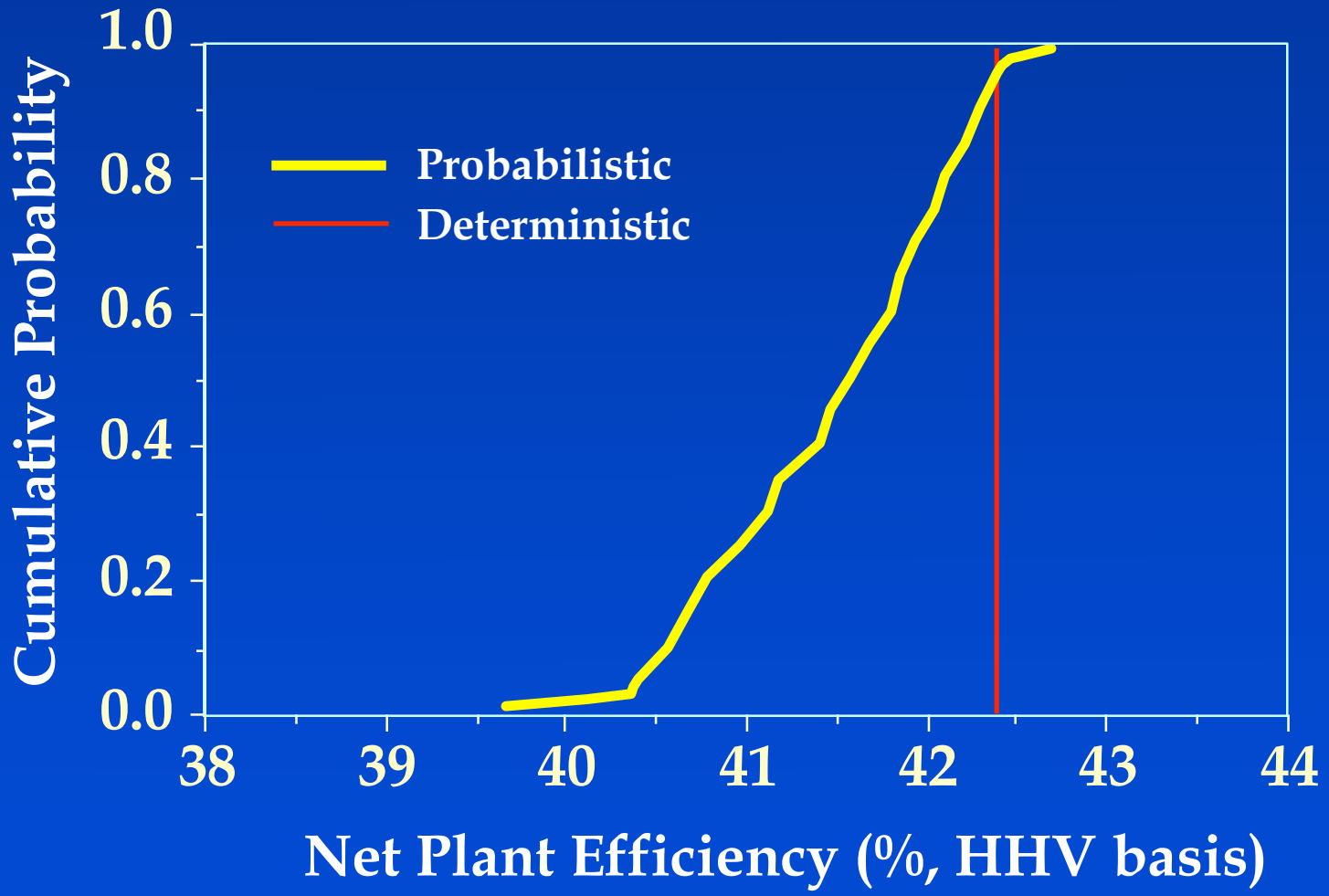
Gasifier Fines Carryover



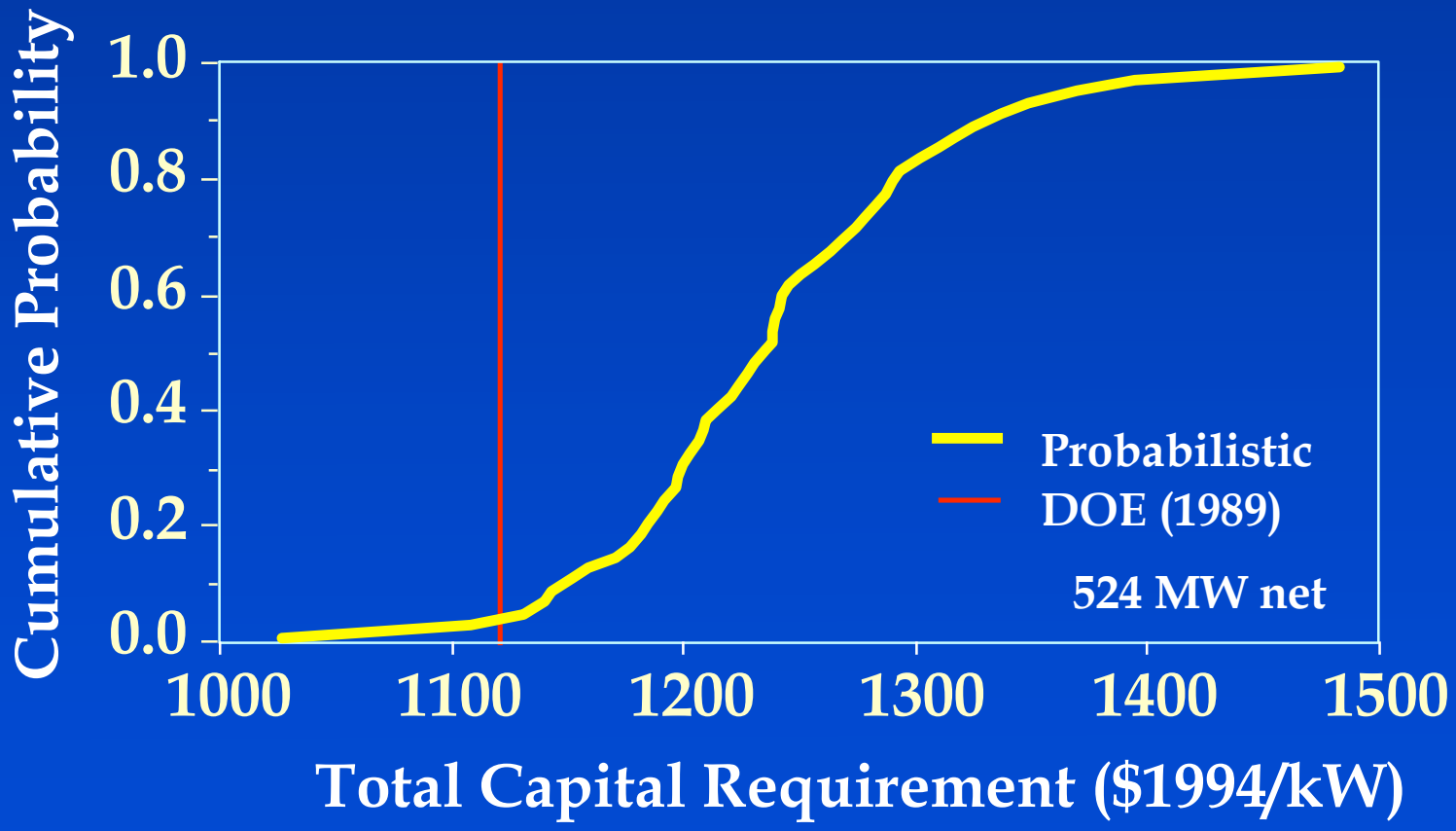
Carbon Retention in Bottom Ash



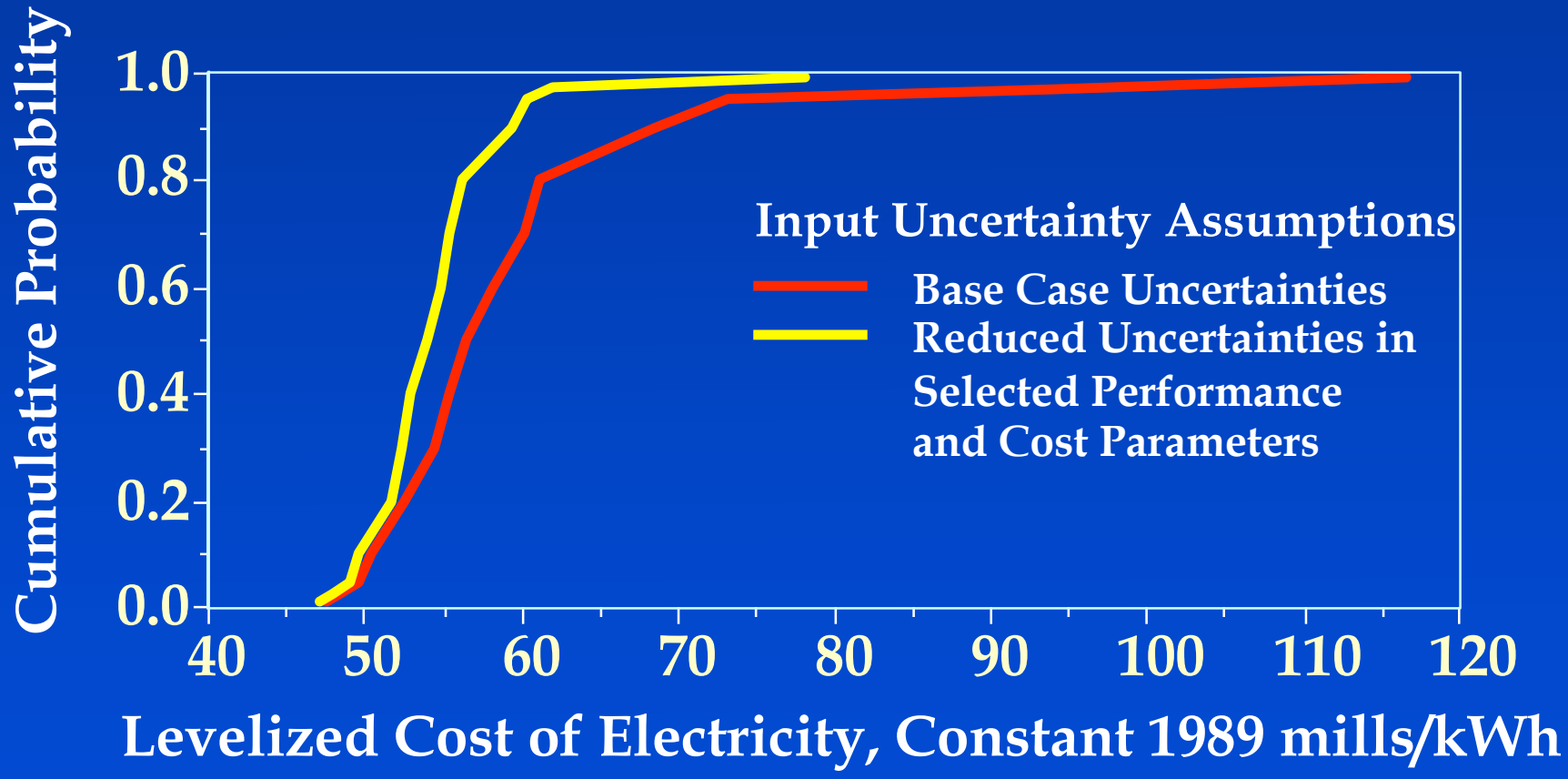
Calculated Plant Efficiency



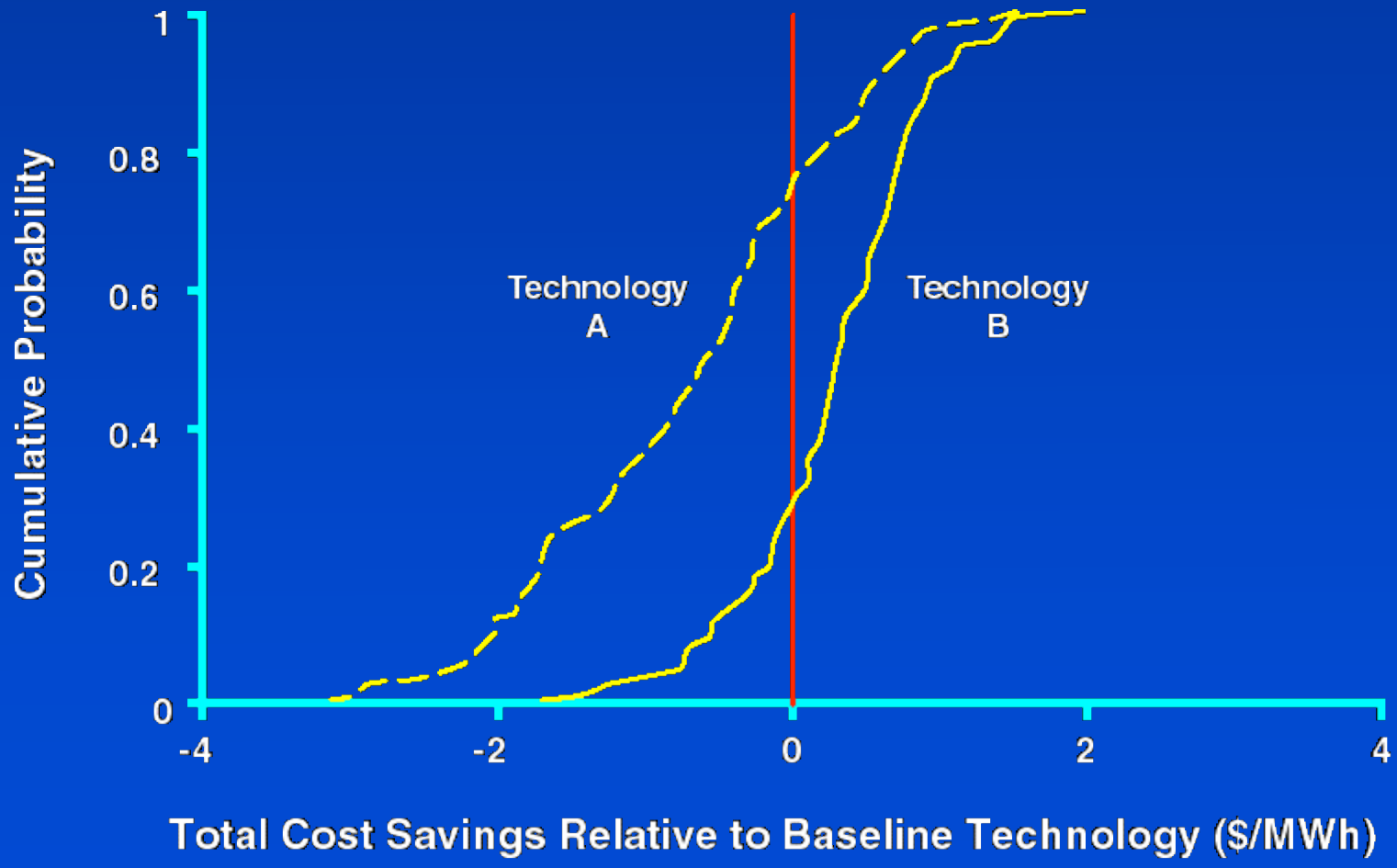
Total Plant Capital Cost



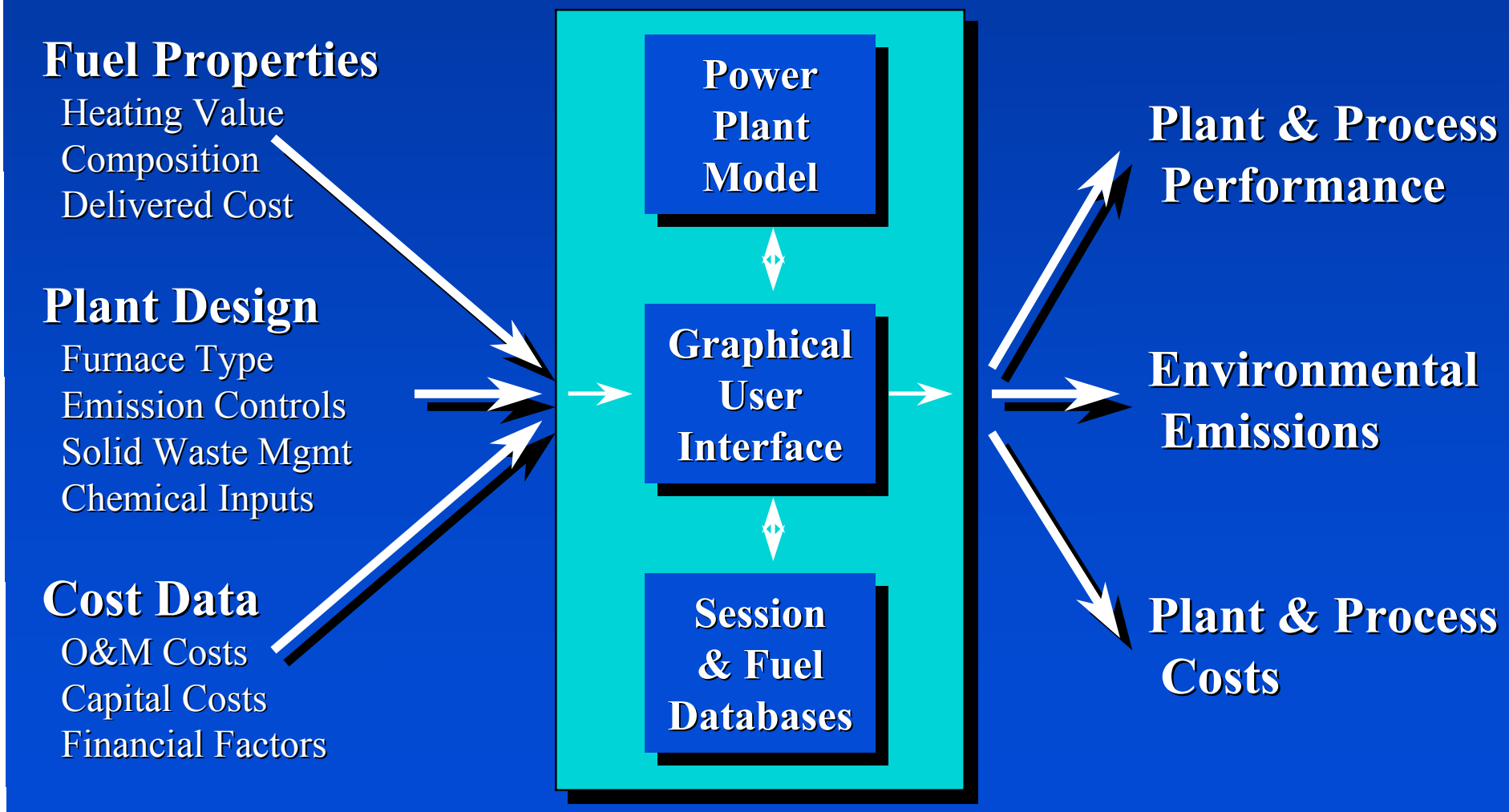
Value of Targeted Research



Probabilistic Comparison of Competing Technologies



IECM Software Package



The IECM is Available for Downloading

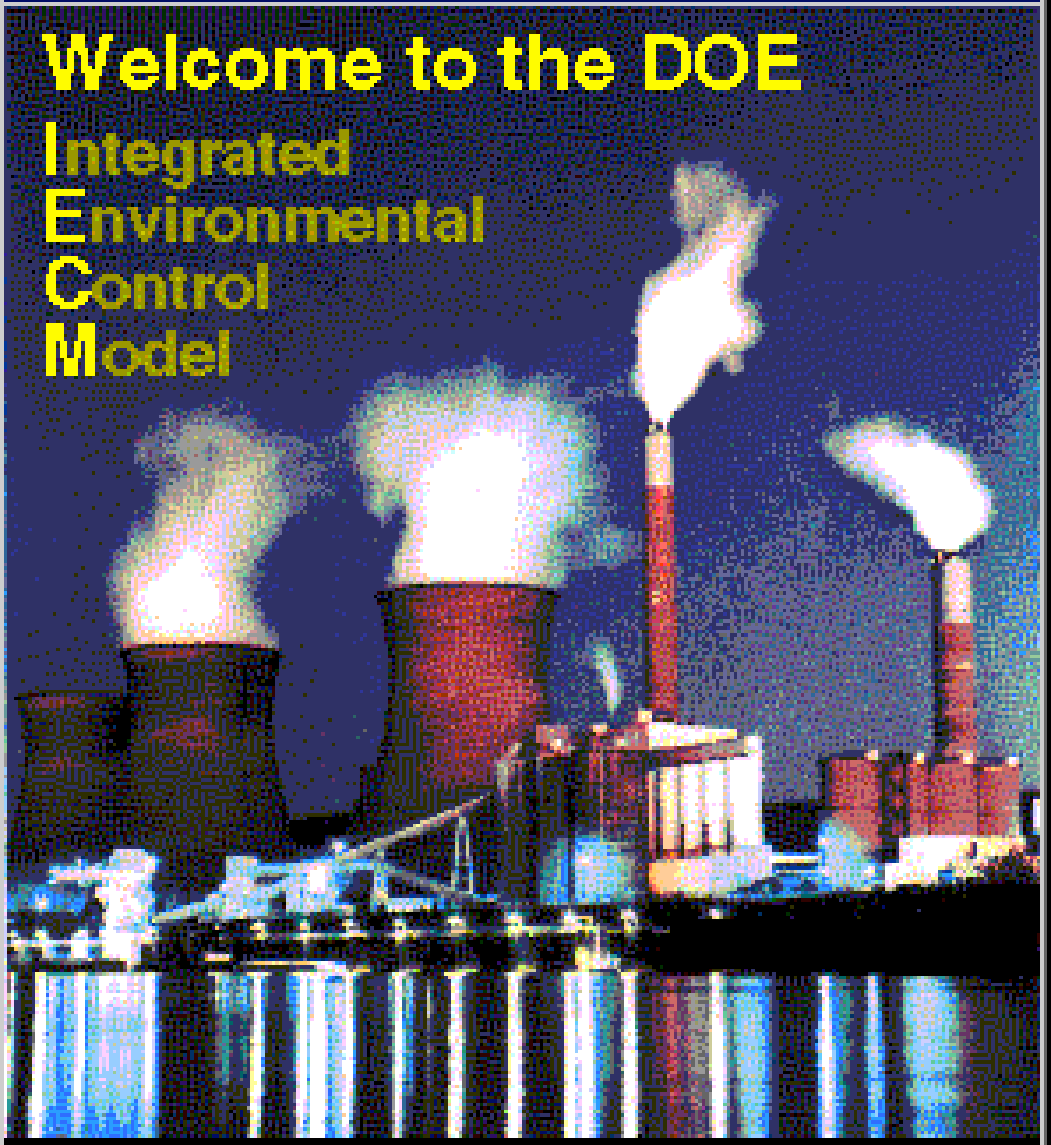
- **Web Access:**
  - ftp://ftp.netl.doe.gov/pub/IECM

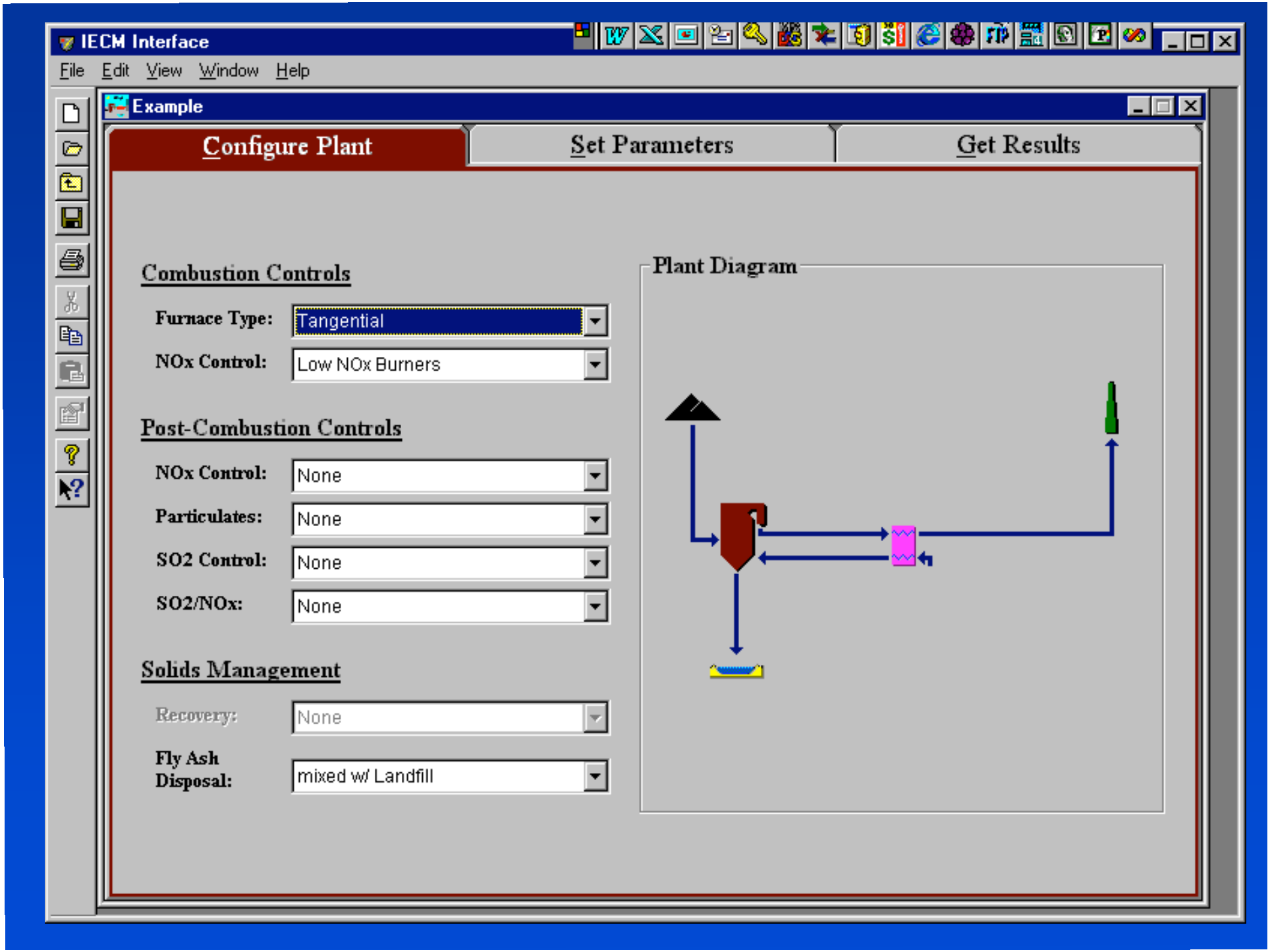
Preliminary IECM User Group

- ABB Power Plant Control
- American Electric Power
- Consol, Inc.
- Energy & Env. Research Corp.
- Exportech Company, Inc.
- FirstEnergy Corp.
- FLS Miljo A/S
- Foster Wheeler Development Corp.
- Lehigh University
- Lower Colorado River Authority
- McDermott Technology, Inc.
- Mitsui Babcock Energy LTD.
- National Power Plc.
- Niksa Energy Associates
- Pacific Corp.
- Pennsylvania Electric Association
- Potomac Electric Power Co.
- Savvy Engineering
- Sierra Pacific Power Co.
- Southern Company Services, Inc.
- Stone & Webster Engineering Corp.
- Tampa Electric Co.
- University of California, Berkeley
- US Environmental Protection Agency

About the IECM Interface

Welcome to the DOE Integrated Environmental Control Model




IECM Interface
File Edit View Window Help
Example
Configure Plant
Set Parameters
Get Results
Combustion Controls
Furnace Type:
Tangential
NOx Control:
Low NOx Burners
Post-Combustion Controls
NOx Control:
None
Particulates:
None
SO2 Control:
None
SO2/NOx:
None
Solids Management
Recovery:
None
Fly Ash Disposal:
mixed w/ Landfill
Plant Diagram

IECM Interface

File Edit View Window Help

Example

Configure Plant | Set Parameters | Get Results

Combustion Controls

Furnace Type: Tangential

NOx Control: Low NOx Burners

Post-Combustion Controls

NOx Control: Hot-Side SCR

Particulates: None

SO2 Control: None

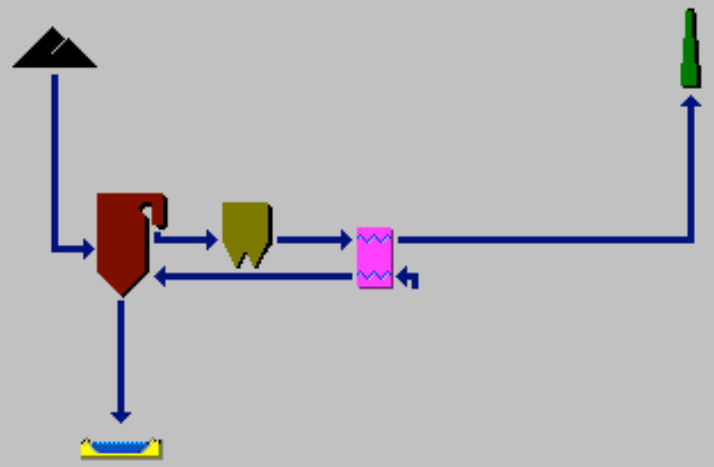
SO2/NOx: None

Solids Management

Recovery: None

Fly Ash Disposal: mixed w/ Landfill

Plant Diagram



IECM Interface

File Edit View Window Help

Example

Configure Plant | Set Parameters | Get Results

Combustion Controls

Furnace Type: Tangential

NOx Control: Low NOx Burners

Post-Combustion Controls

NOx Control: Hot-Side SCR

Particulates: Cold-Side ESP

SO2 Control: None

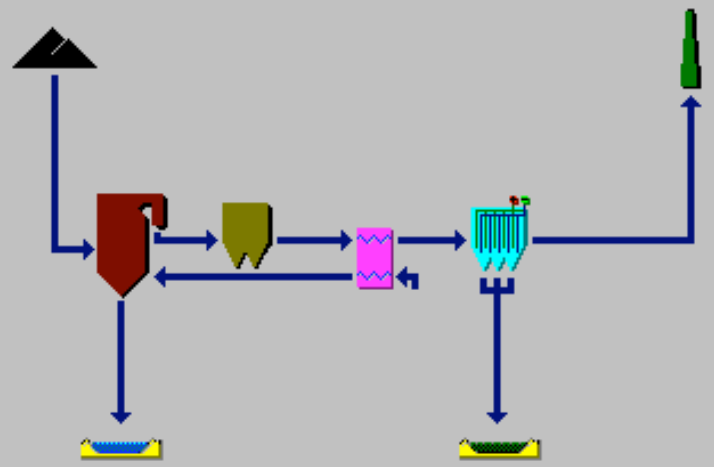
SO2/NOx: None

Solids Management

Recovery: None

Fly Ash Disposal: mixed w/ Landfill

Plant Diagram



IECM Interface

File Edit View Window Help

Example

Configure Plant | Set Parameters | Get Results

Combustion Controls

Furnace Type: Tangential

NOx Control: Low NOx Burners

Post-Combustion Controls

NOx Control: Hot-Side SCR

Particulates: Cold-Side ESP

SO2 Control: Wet FGD

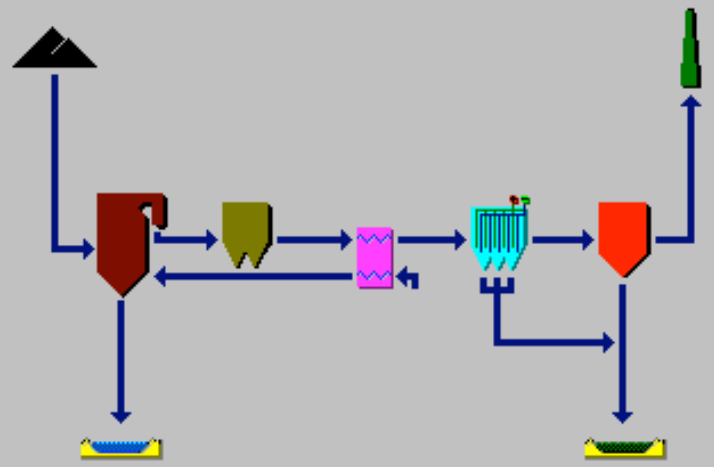
SO2/NOx: None

Solids Management

Recovery: None

Fly Ash Disposal: mixed w/ Landfill

Plant Diagram



IECM Interface

File Edit View Window Help

Untitled

Configure Plant | Set Parameters | Get Results

Combustion Controls

Furnace Type: Tangential

NOx Control: Low NOx Burners

Post-Combustion Controls

NOx Control: Hot-Side SCR

Particulates: Cold-Side ESP

SO2 Control: Wet FGD

SO2/NOx: None

CO2 Control: Absorption - MEA

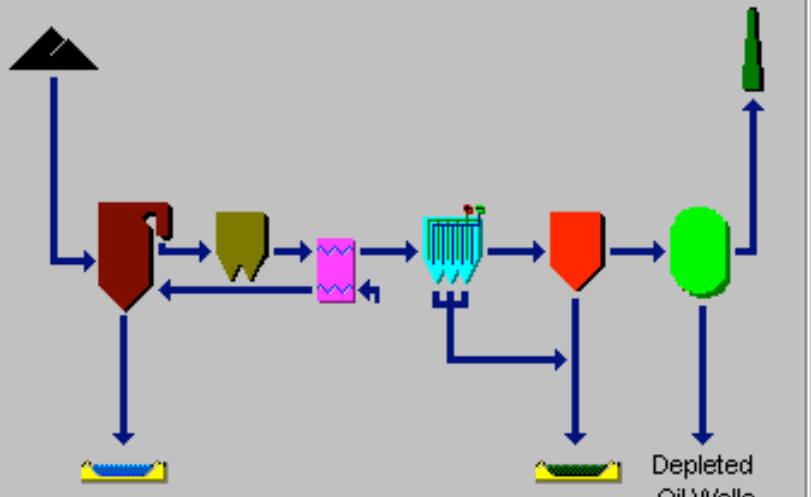
By-Product Management

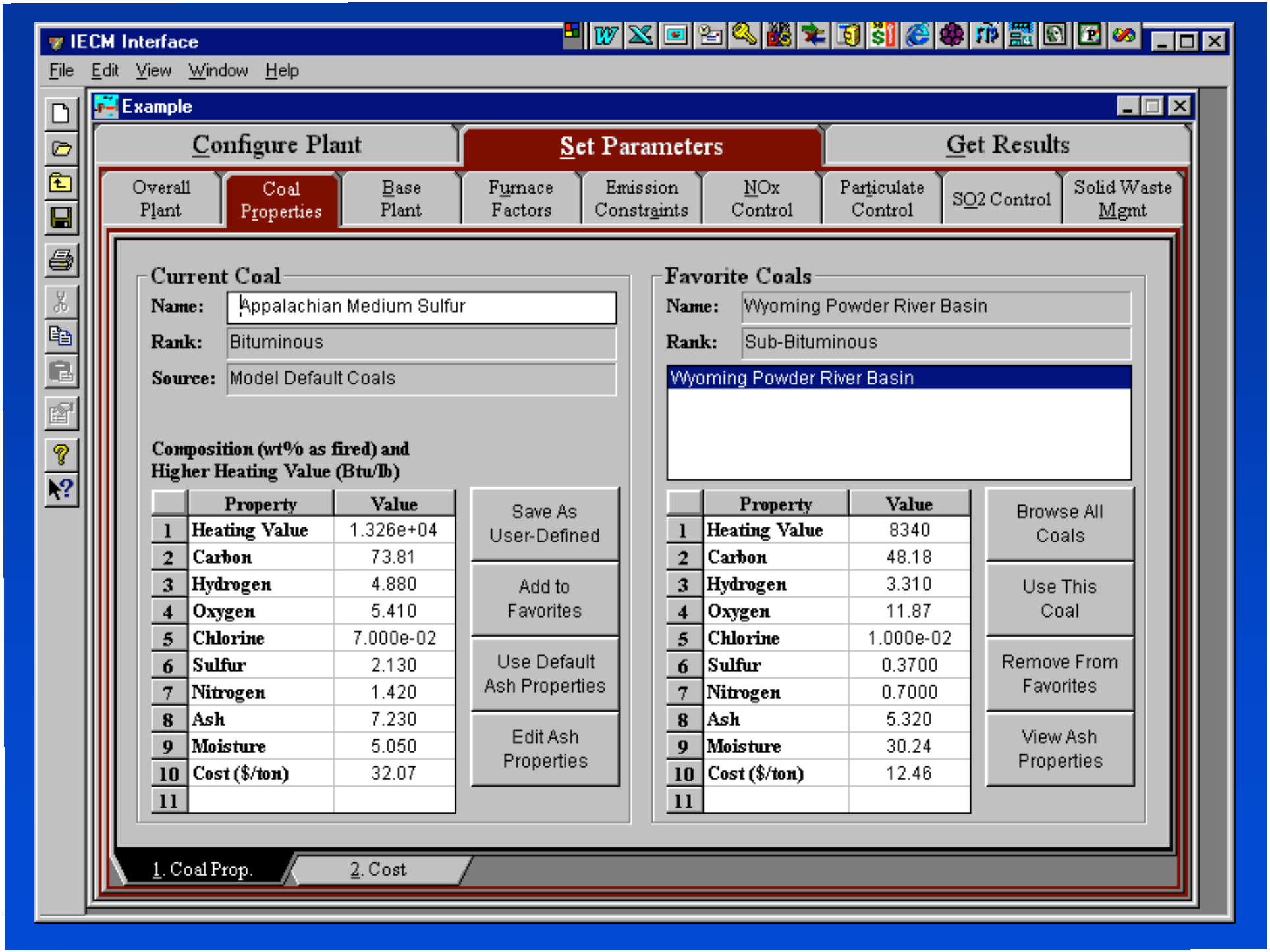
Recovery: None

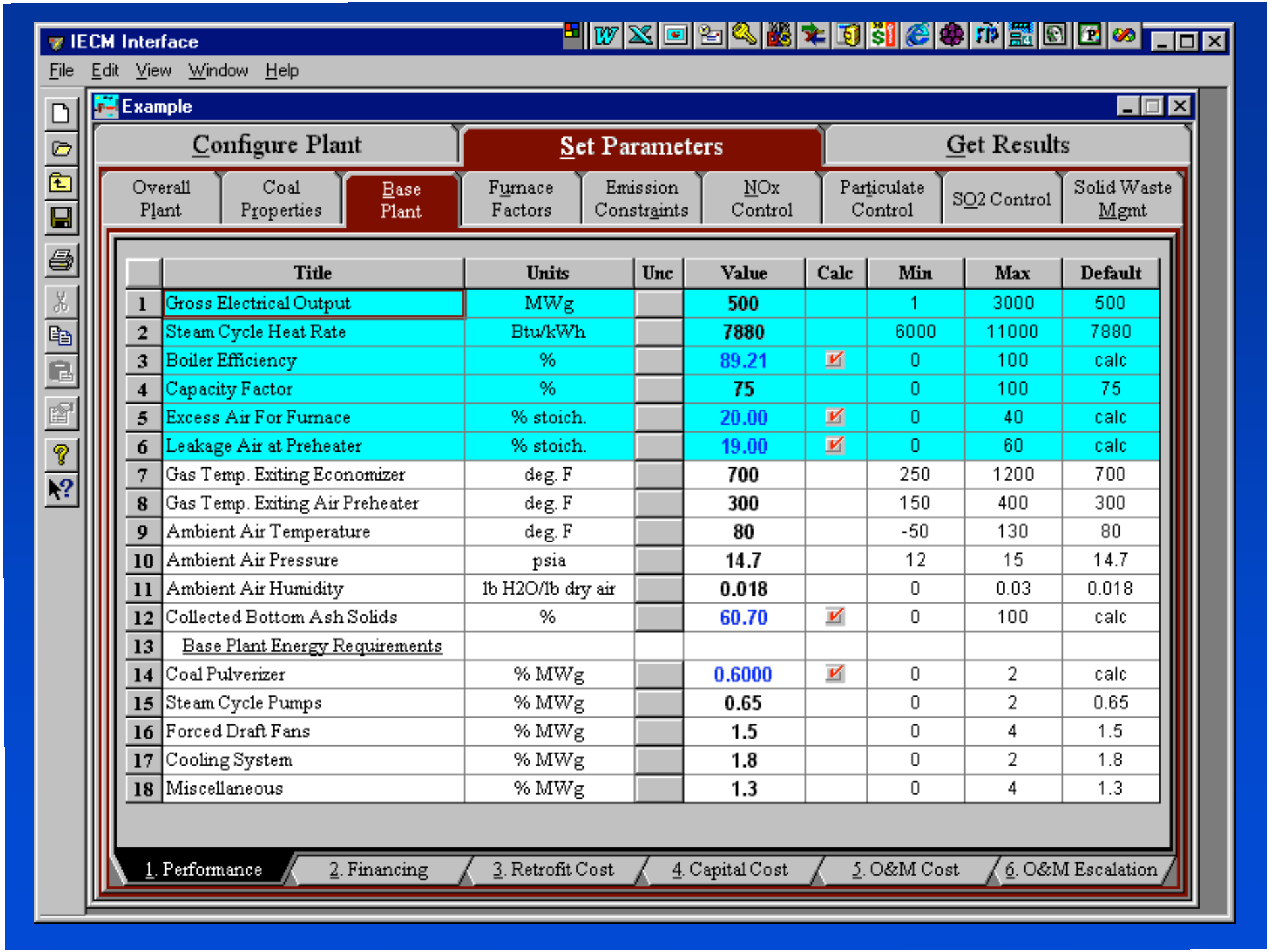
Fly Ash Disposal: mixed w/ Landfill

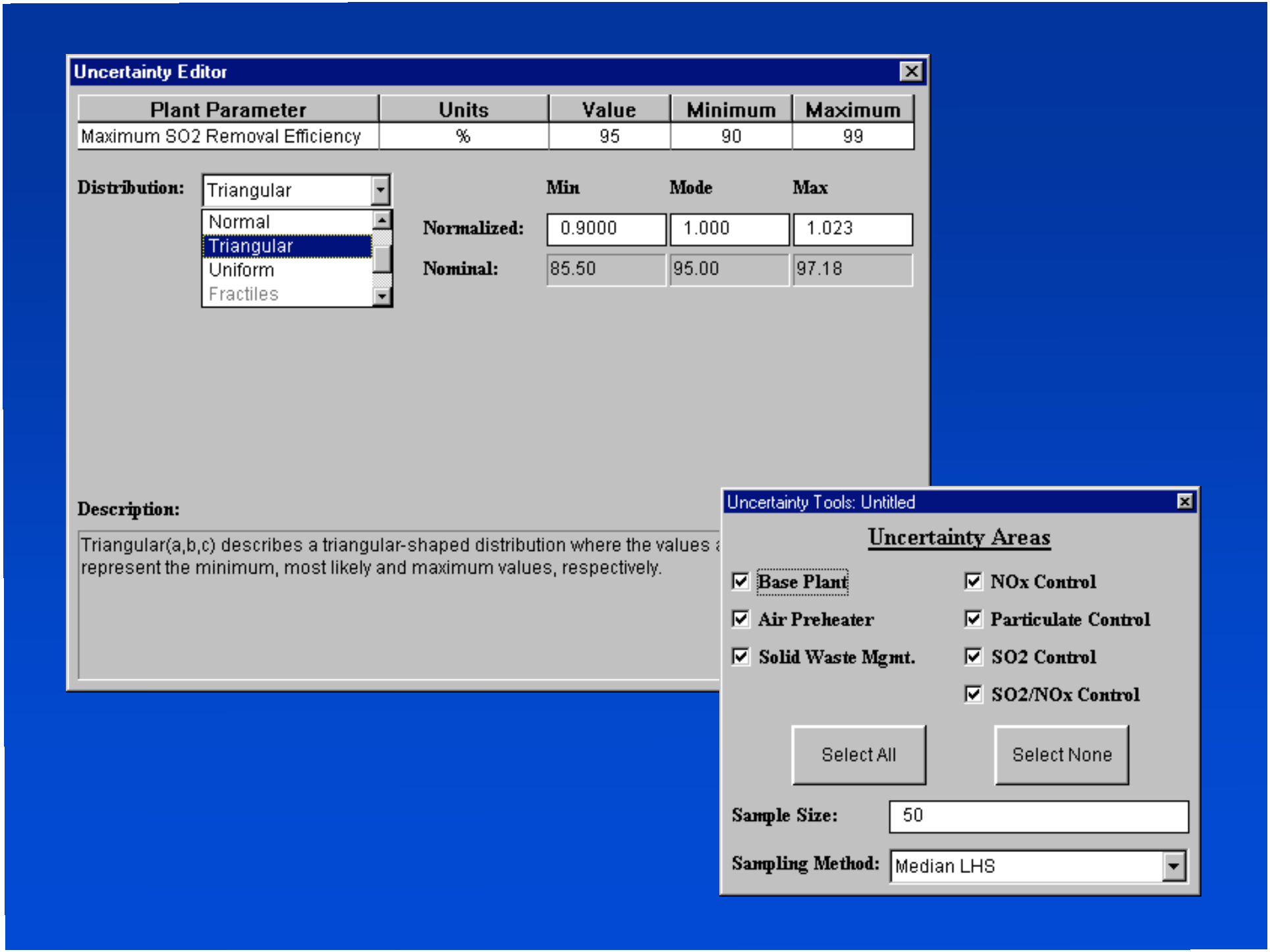
CO2 Storage: Depleted Oil Wells

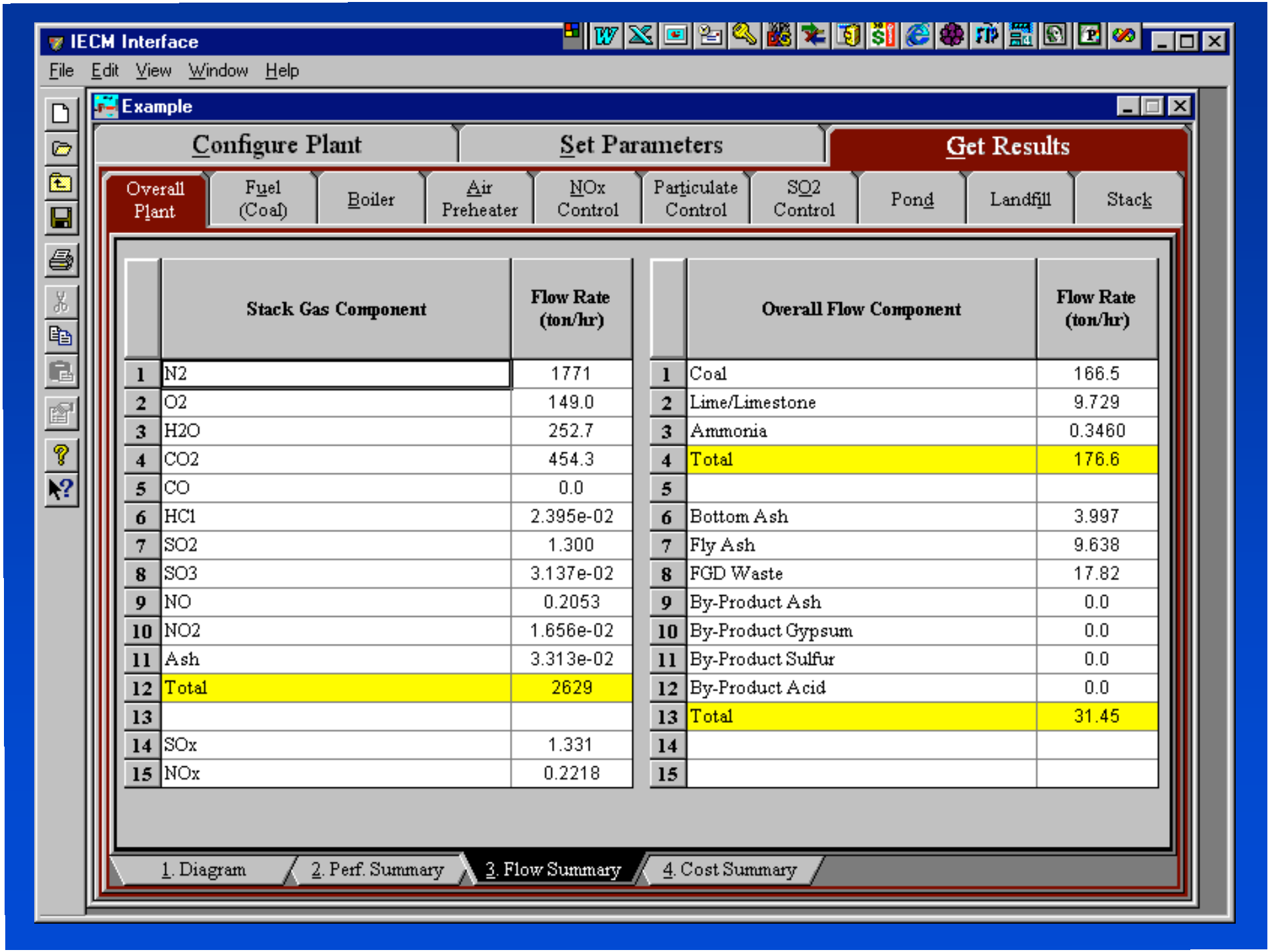
Plant Diagram




IECM Interface
File Edit View Window Help
Example
Configure Plant
Set Parameters
Get Results
Overall Plant
Coal Properties
Base Plant
Furnace Factors
Emission Constraints
NOx Control
Particulate Control
SO2 Control
Solid Waste Mgmt
Current Coal
Name: Appalachian Medium Sulfur
Rank: Bituminous
Source: Model Default Coals
Composition (wt% as fired) and Higher Heating Value (Btu/lb)
Property Value
1 Heating Value 1.326e+04
2 Carbon 73.81
3 Hydrogen 4.880
4 Oxygen 5.410
5 Chlorine 7.000e-02
6 Sulfur 2.130
7 Nitrogen 1.420
8 Ash 7.230
9 Moisture 5.050
10 Cost ($/ton) 32.07
11
Save As User-Defined
Add to Favorites
Use Default Ash Properties
Edit Ash Properties
Favorite Coals
Name: Wyoming Powder River Basin
Rank: Sub-Bituminous
Wyoming Powder River Basin
Property Value
1 Heating Value 8340
2 Carbon 48.18
3 Hydrogen 3.310
4 Oxygen 11.87
5 Chlorine 1.000e-02
6 Sulfur 0.3700
7 Nitrogen 0.7000
8 Ash 5.320
9 Moisture 30.24
10 Cost ($/ton) 12.46
11
Browse All Coals
Use This Coal
Remove From Favorites
View Ash Properties
1. Coal Prop.
2. Cost

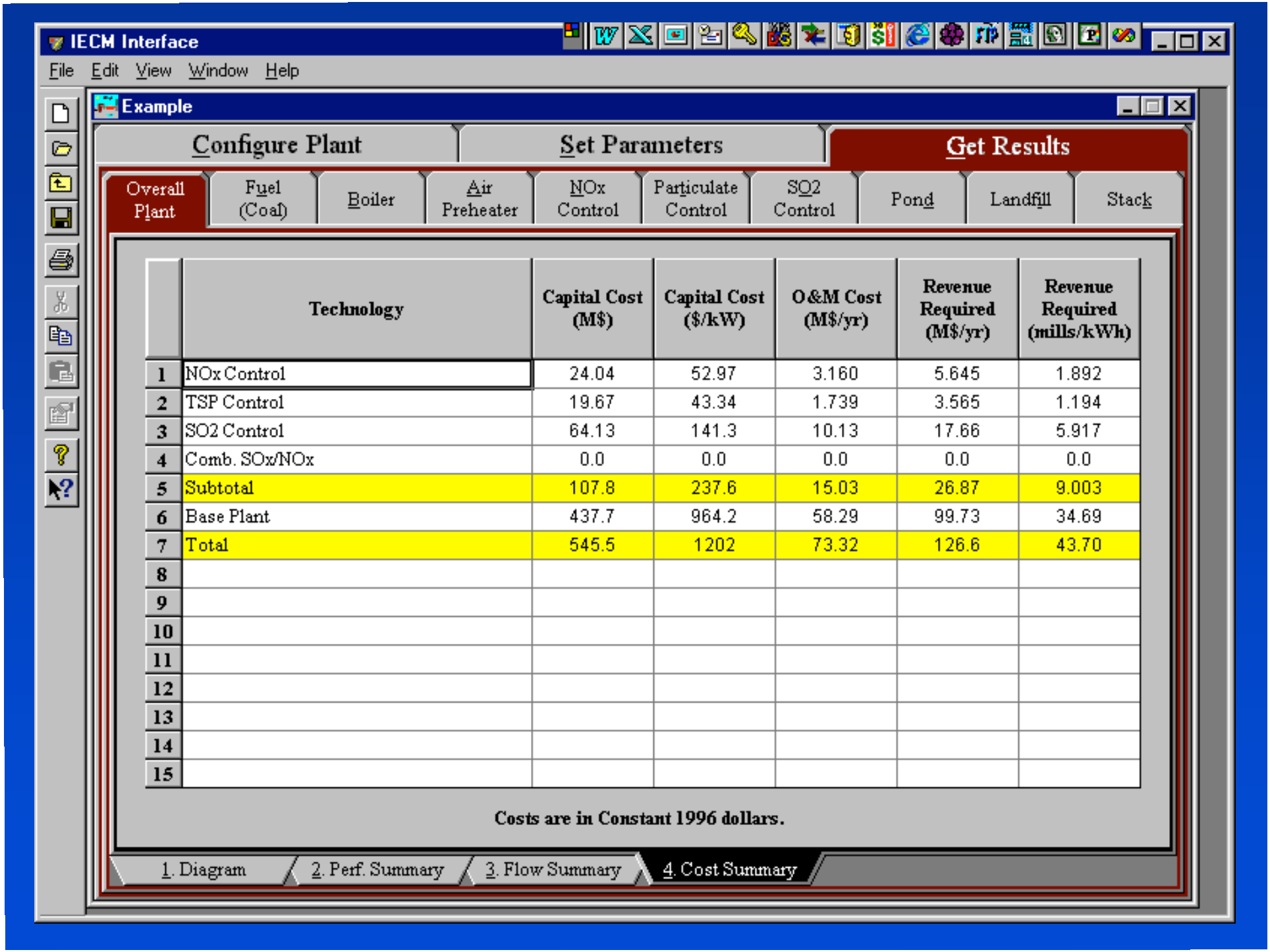

IECM Interface
File Edit View Window Help
Example
Configure Plant
Set Parameters
Get Results
Overall Plant
Coal Properties
Base Plant
Furnace Factors
Emission Constraints
NOx Control
Particulate Control
SO2 Control
Solid Waste Mgmt
Title
Units
Unc
Value
Calc
Min
Max
Default
1 Gross Electrical Output MWg 500 1 3000 500
2 Steam Cycle Heat Rate Btu/kWh 7880 6000 11000 7880
3 Boiler Efficiency % 89.21 0 100 calc
4 Capacity Factor % 75 0 100 75
5 Excess Air For Furnace % stoich. 20.00 0 40 calc
6 Leakage Air at Preheater % stoich. 19.00 0 60 calc
7 Gas Temp. Exiting Economizer deg. F 700 250 1200 700
8 Gas Temp. Exiting Air Preheater deg. F 300 150 400 300
9 Ambient Air Temperature deg. F 80 -50 130 80
10 Ambient Air Pressure psia 14.7 12 15 14.7
11 Ambient Air Humidity lb H2O/lb dry air 0.018 0 0.03 0.018
12 Collected Bottom Ash Solids % 60.70 0 100 calc
13 Base Plant Energy Requirements
14 Coal Pulverizer % MWg 0.6000 0 2 calc
15 Steam Cycle Pumps % MWg 0.65 0 2 0.65
16 Forced Draft Fans % MWg 1.5 0 4 1.5
17 Cooling System % MWg 1.8 0 2 1.8
18 Miscellaneous % MWg 1.3 0 4 1.3
1. Performance
2. Financing
3. Retrofit Cost
4. Capital Cost
5. O&M Cost
6. O&M Escalation


Uncertainty Editor
Plant Parameter
Units
Value
Minimum
Maximum
Maximum SO2 Removal Efficiency
%
95
90
99
Distribution:
Triangular
Normal
Triangular
Uniform
Fractiles
Min
Mode
Max
Normalized:
0.9000
1.000
1.023
Nominal:
85.50
95.00
97.18
Description:
Triangular(a,b,c) describes a triangular-shaped distribution where the values a
represent the minimum, most likely and maximum values, respectively.
Uncertainty Tools: Untitled
Uncertainty Areas
Base Plant
Air Preheater
Solid Waste Mgmt.
NOx Control
Particulate Control
SO2 Control
SO2/NOx Control
Select All
Select None
Sample Size:
50
Sampling Method:
Median LHS

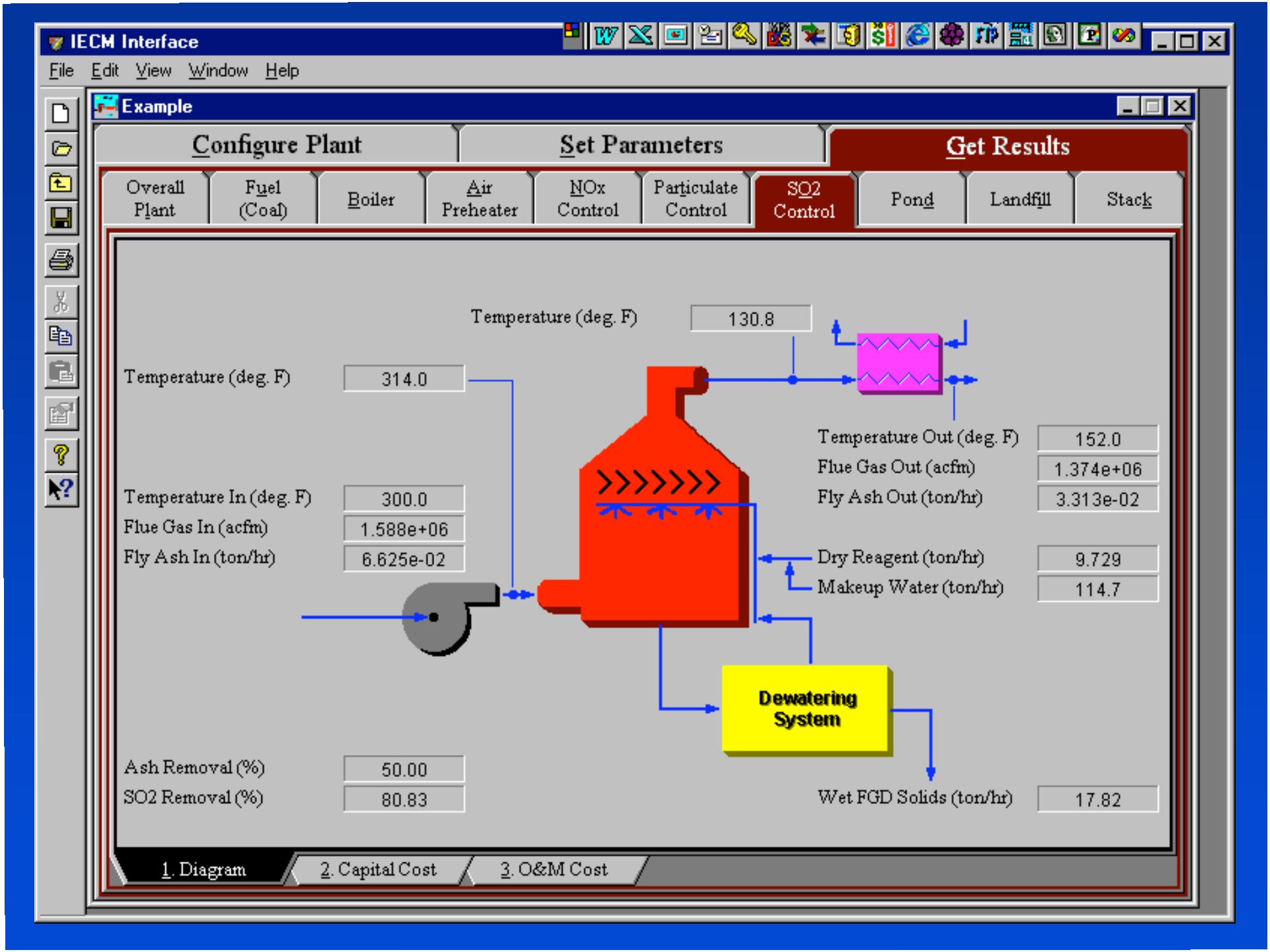


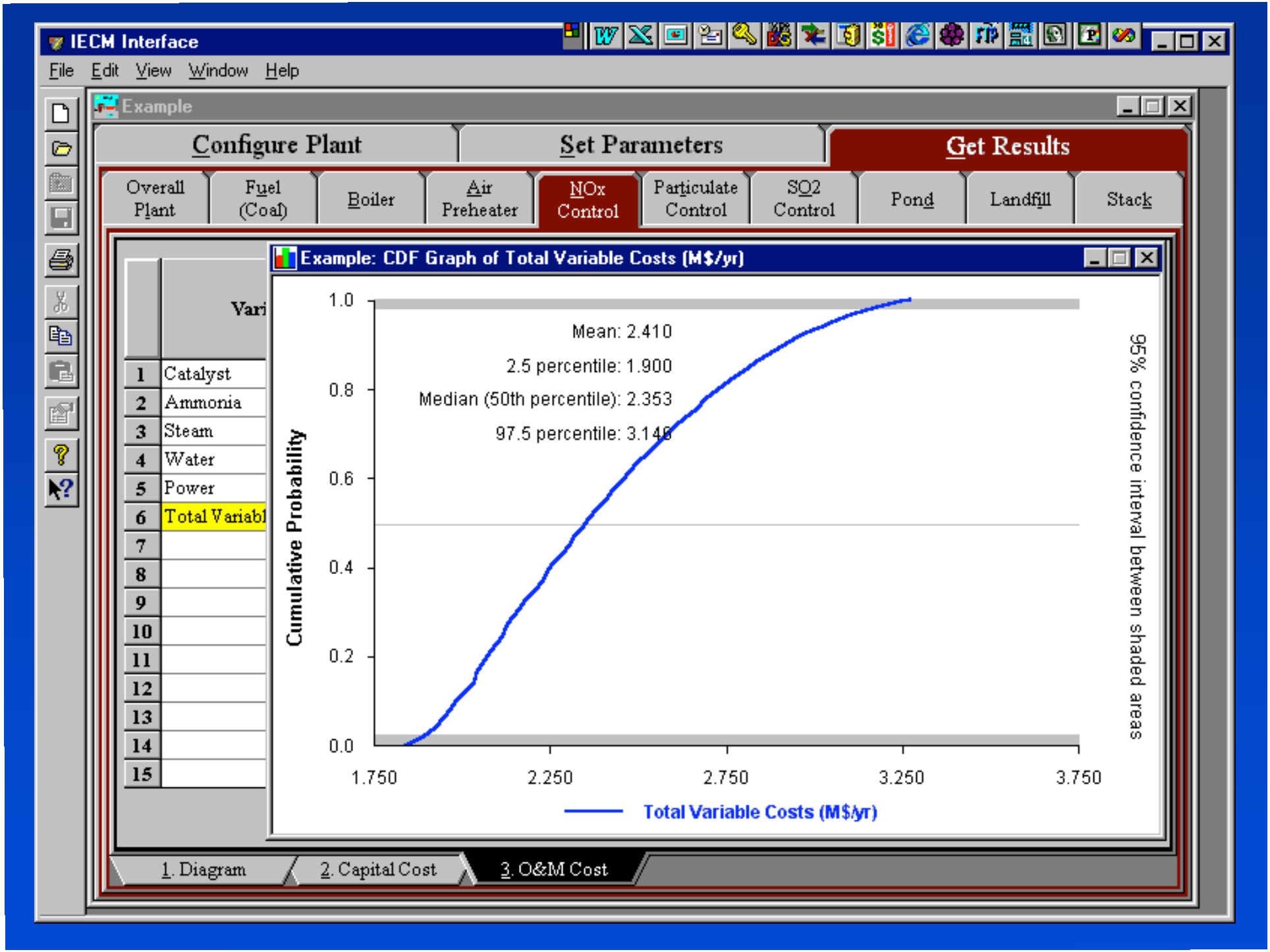
	Stack Gas Component	Flow Rate (ton/hr)
1	N2	1771
2	O2	149.0
3	H2O	252.7
4	CO2	454.3
5	CO	0.0
6	HCl	2.395e-02
7	SO2	1.300
8	SO3	3.137e-02
9	NO	0.2053
10	NO2	1.656e-02
11	Ash	3.313e-02
12	Total	2629
13		
14	SOx	1.331
15	NOx	0.2218

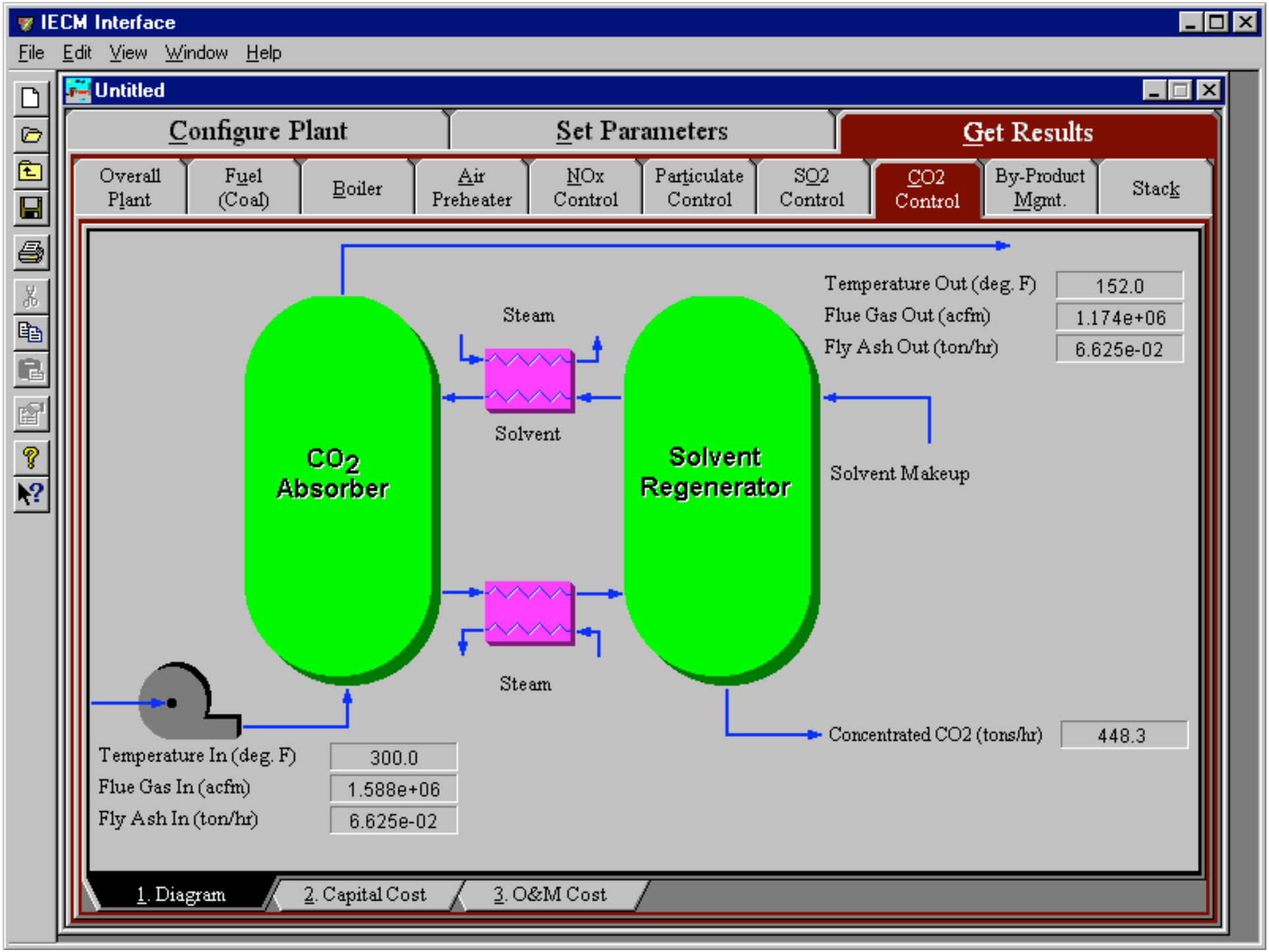
	Overall Flow Component	Flow Rate (ton/hr)
1	Coal	166.5
2	Lime/Limestone	9.729
3	Ammonia	0.3460
4	Total	176.6
5		
6	Bottom Ash	3.997
7	Fly Ash	9.638
8	FGD Waste	17.82
9	By-Product Ash	0.0
10	By-Product Gypsum	0.0
11	By-Product Sulfur	0.0
12	By-Product Acid	0.0
13	Total	31.45
14		
15		

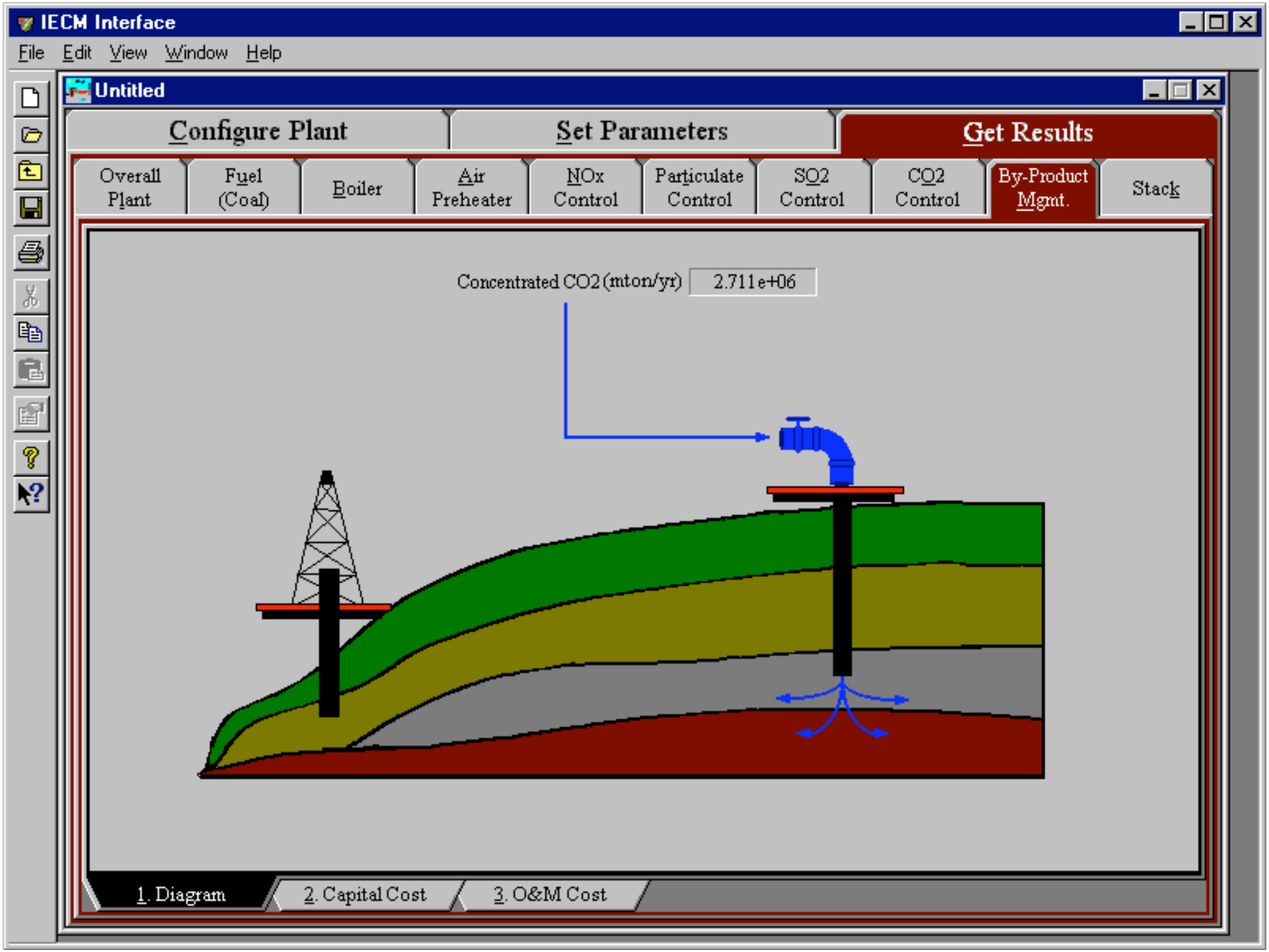


	Technology	Capital Cost (M$)	Capital Cost ($/kW)	O&M Cost (M$/yr)	Revenue Required (M$/yr)	Revenue Required (mills/kWh)
1	NOx Control	24.04	52.97	3.160	5.645	1.892
2	TSP Control	19.67	43.34	1.739	3.565	1.194
3	SO2 Control	64.13	141.3	10.13	17.66	5.917
4	Comb. SOx/NOx	0.0	0.0	0.0	0.0	0.0
5	Subtotal	107.8	237.6	15.03	26.87	9.003
6	Base Plant	437.7	964.2	58.29	99.73	34.69
7	Total	545.5	1202	73.32	126.6	43.70
8						
9						
10						
11						
12						
13						
14						
15						


IECM Interface
File Edit View Window Help
Example
Configure Plant
Set Parameters
Get Results
Overall Plant
Fuel (Coal)
Boiler
Air Preheater
NOx Control
Particulate Control
SO2 Control
Pond
Landfill
Stack
Temperature (deg. F)
130.8
Temperature (deg. F)
314.0
Temperature Out (deg. F)
152.0
Flue Gas Out (acfm)
1.374e+06
Fly Ash Out (ton/hr)
3.313e-02
Temperature In (deg. F)
300.0
Flue Gas In (acfm)
1.588e+06
Fly Ash In (ton/hr)
6.625e-02
Dry Reagent (ton/hr)
9.729
Makeup Water (ton/hr)
114.7
Dewatering System
Ash Removal (%)
50.00
SO2 Removal (%)
80.83
Wet FGD Solids (ton/hr)
17.82
1. Diagram
2. Capital Cost
3. O&M Cost


IECM Interface
File Edit View Window Help
Example
Configure Plant
Set Parameters
Get Results
Overall Plant
Fuel (Coal)
Boiler
Air Preheater
NOx Control
Particulate Control
SO2 Control
Pond
Landfill
Stack
Vari
1 Catalyst
2 Ammonia
3 Steam
4 Water
5 Power
6 Total Variabl
7
8
9
10
11
12
13
14
15
Example: CDF Graph of Total Variable Costs (M$/yr)
Mean: 2.410
2.5 percentile: 1.900
Median (50th percentile): 2.353
97.5 percentile: 3.148
Cumulative Probability
1.0
0.8
0.6
0.4
0.2
0.0
1.750
2.250
2.750
3.250
3.750
95% confidence interval between shaded areas
Total Variable Costs (M$/yr)
1. Diagram
2. Capital Cost
3. O&M Cost


IECM Interface
File Edit View Window Help
Untitled
Configure Plant
Set Parameters
Get Results
Overall Plant
Fuel (Coal)
Boiler
Air Preheater
NOx Control
Particulate Control
SO2 Control
CO2 Control
By-Product Mgmt.
Stack
Temperature Out (deg. F) 152.0
Flue Gas Out (acfm) 1.174e+06
Fly Ash Out (ton/hr) 6.625e-02
Steam
Solvent
CO2 Absorber
Solvent Regenerator
Solvent Makeup
Steam
Concentrated CO2 (tons/hr) 448.3
Temperature In (deg. F) 300.0
Flue Gas In (acfm) 1.588e+06
Fly Ash In (ton/hr) 6.625e-02
1. Diagram
2. Capital Cost
3. O&M Cost


IECM Interface
File Edit View Window Help
Untitled
Configure Plant
Set Parameters
Get Results
Overall Plant
Fuel (Coal)
Boiler
Air Preheater
NOx Control
Particulate Control
SO2 Control
CO2 Control
By-Product Mgmt.
Stack
Concentrated CO2 (mton/yr)
2.711e+06
1. Diagram
2. Capital Cost
3. O&M Cost

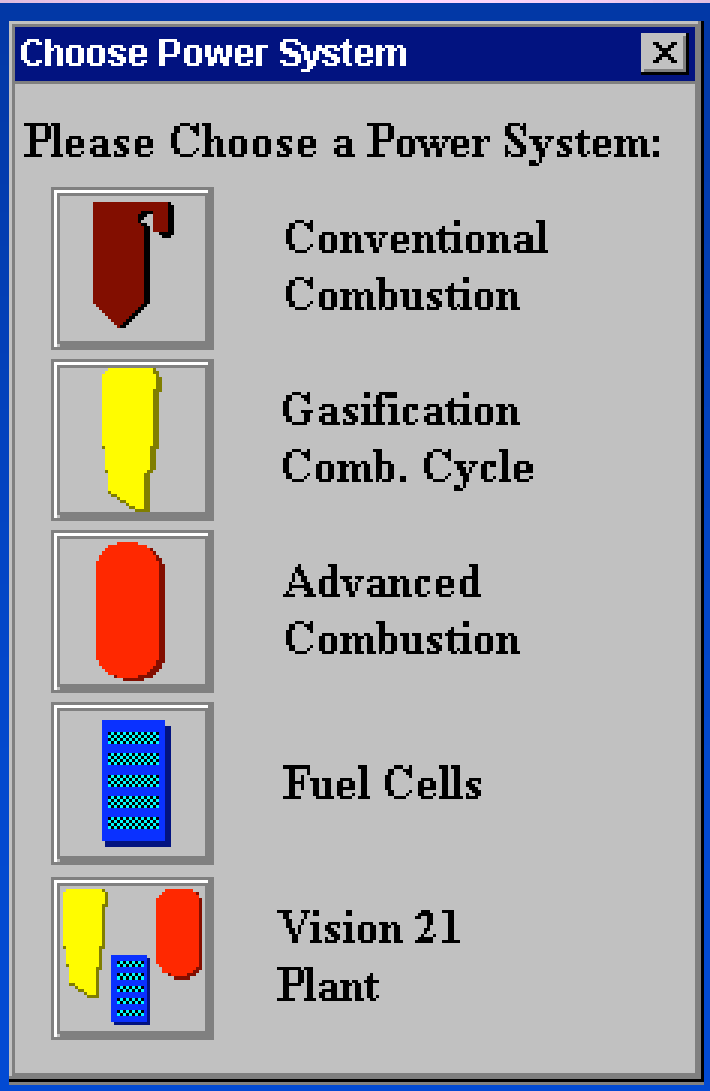
CO_2 Module Results

- Flue gas (out) composition
- CO_2 emission level (kg CO_2/hr)
- Amount of CO_2 product (ton/hr)
- Purity of CO_2 product (%)
- Solvent circulation rate (m3/hr)
- Make-up solvent rate (kg MEA/hr)
- Make-up rate relative to the circulation rate (%)
- Waste generation rate (kg/hr)
- Energy penalty (% of MWg)
- Net power generation
- Cost of CO_2 captured ($/ ton$CO_2$ captured)
- Cost increase in electricity (cents/kWh)
- Cost of CO_2 avoided ($/ ton$CO_2$ avoided)

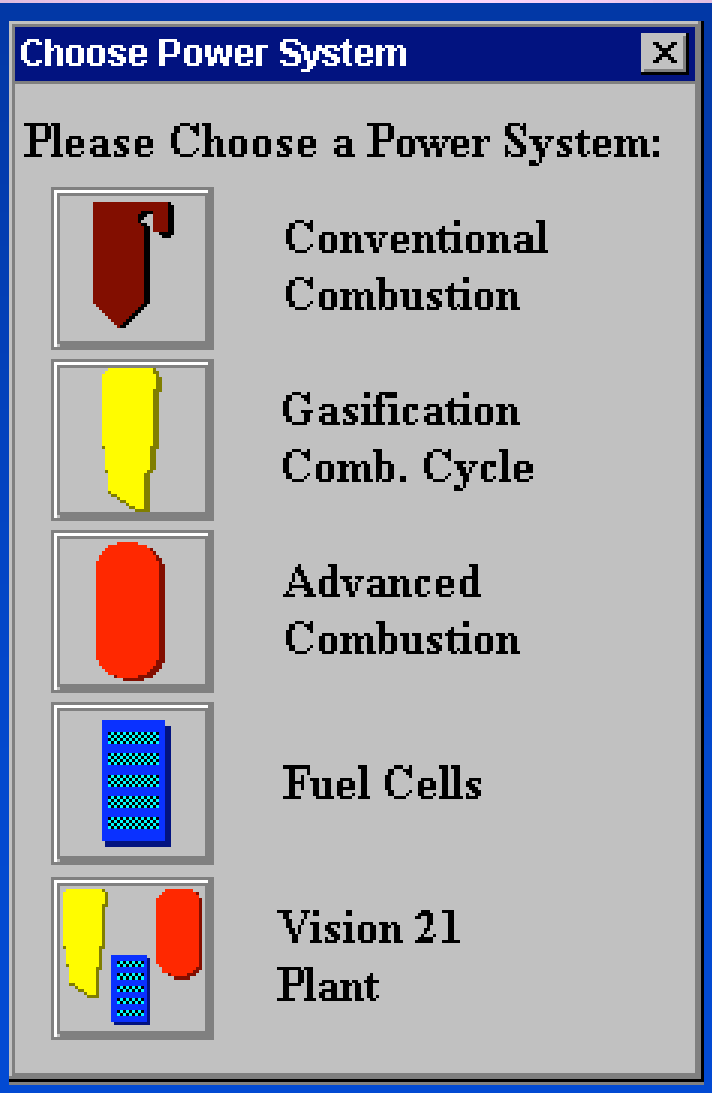
Additional Technology Options

- ***Just Completed***
  - Combustion NO_x Controls
    - Selective Non-Catalytic Reduction (SNCR)
    - Low NO_x Burners (LNB)
    - LNB + Overfire air
    - LNB + SNCR
    - Natural Gas Reburn
    - Tangential, Wall & Cyclone Firing
- ***Just Started***
  - Post-Combustion Controls
    - Air Toxics (mercury)
  - Other Fossil Fuels
  - Alternative Power Generation Systems
  - CO2 Sequestration Options

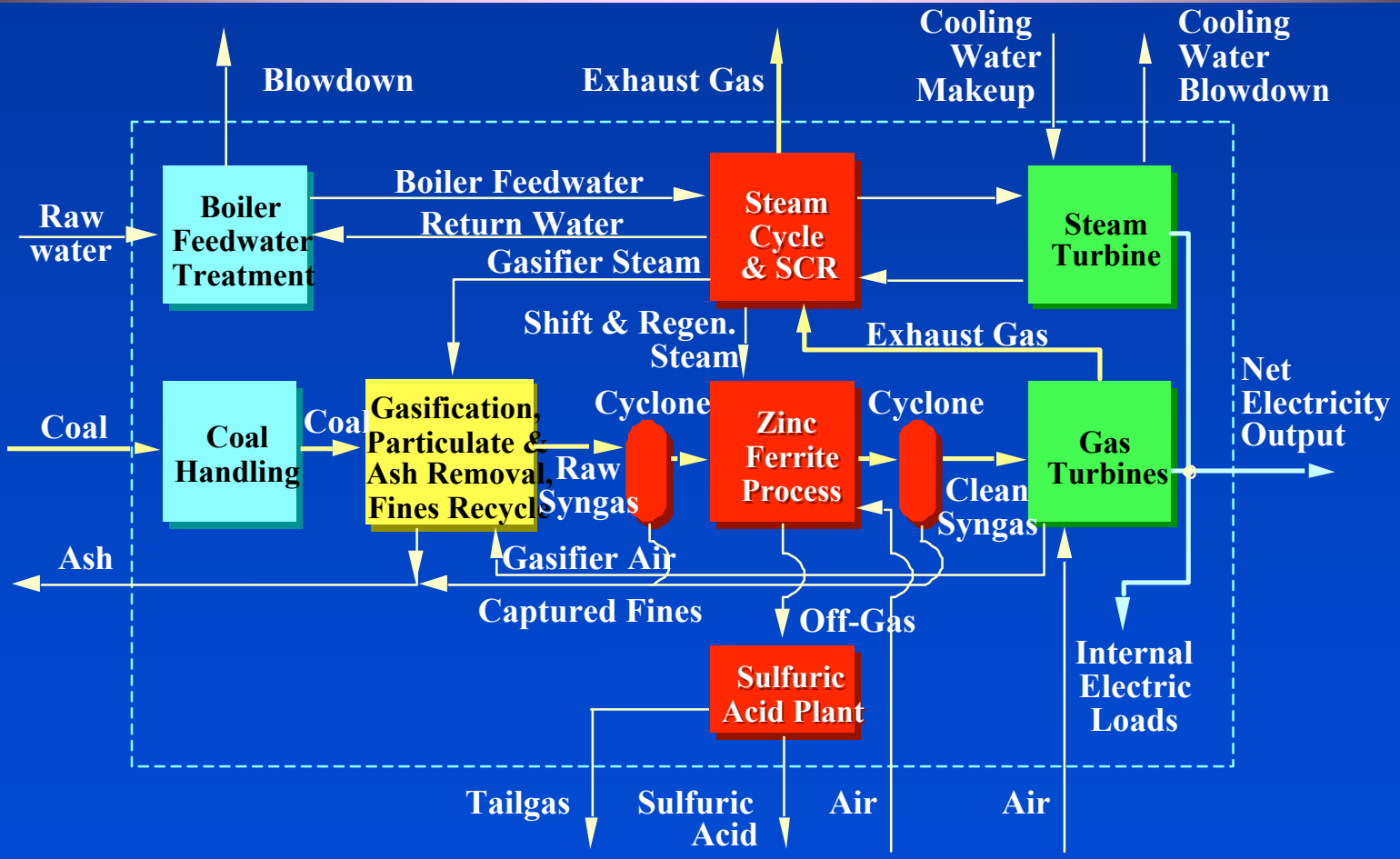
Future Developments: A Menu of Technology Options



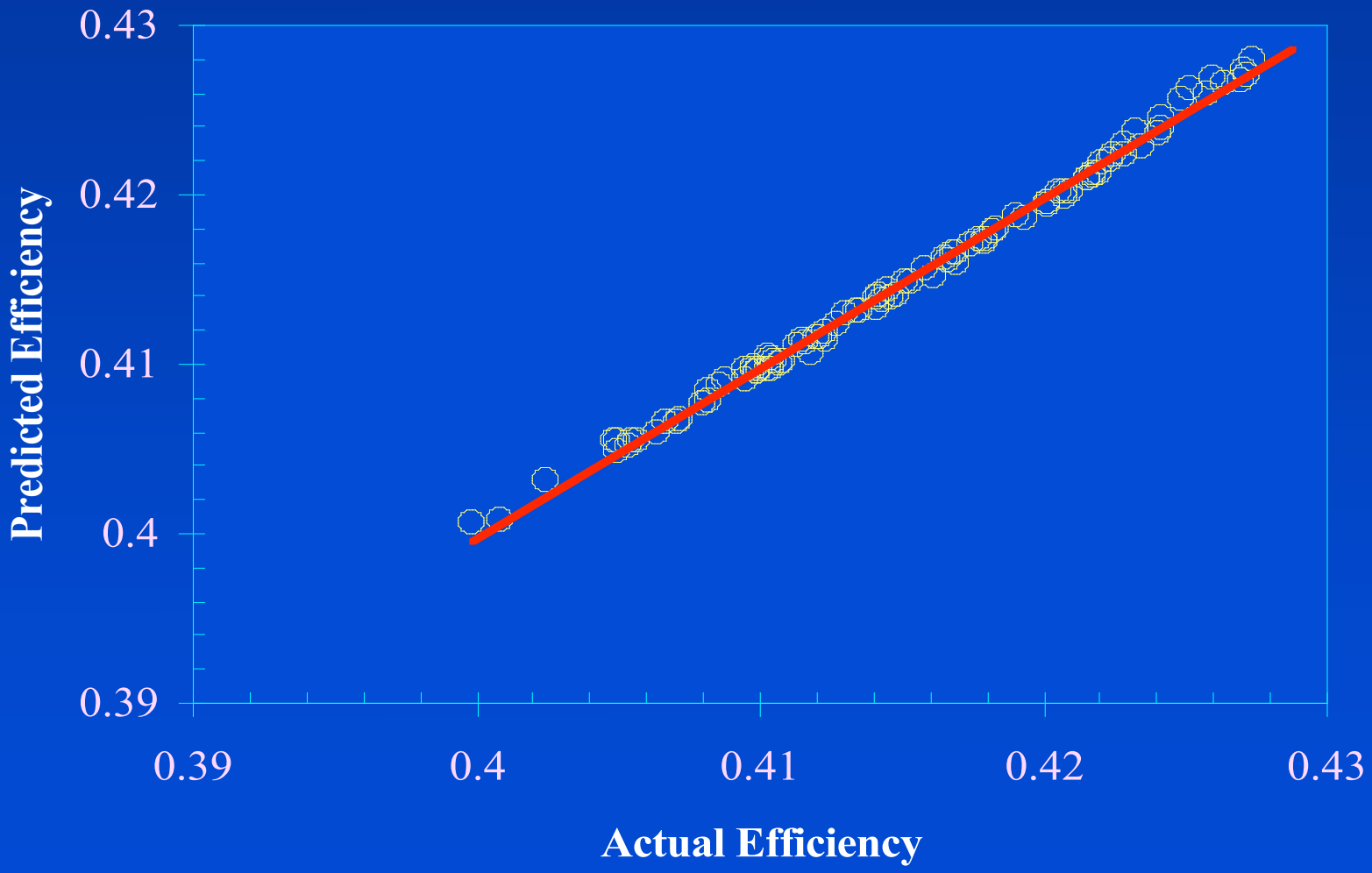
Select Gasification Combined Cycle (IGCC) Options



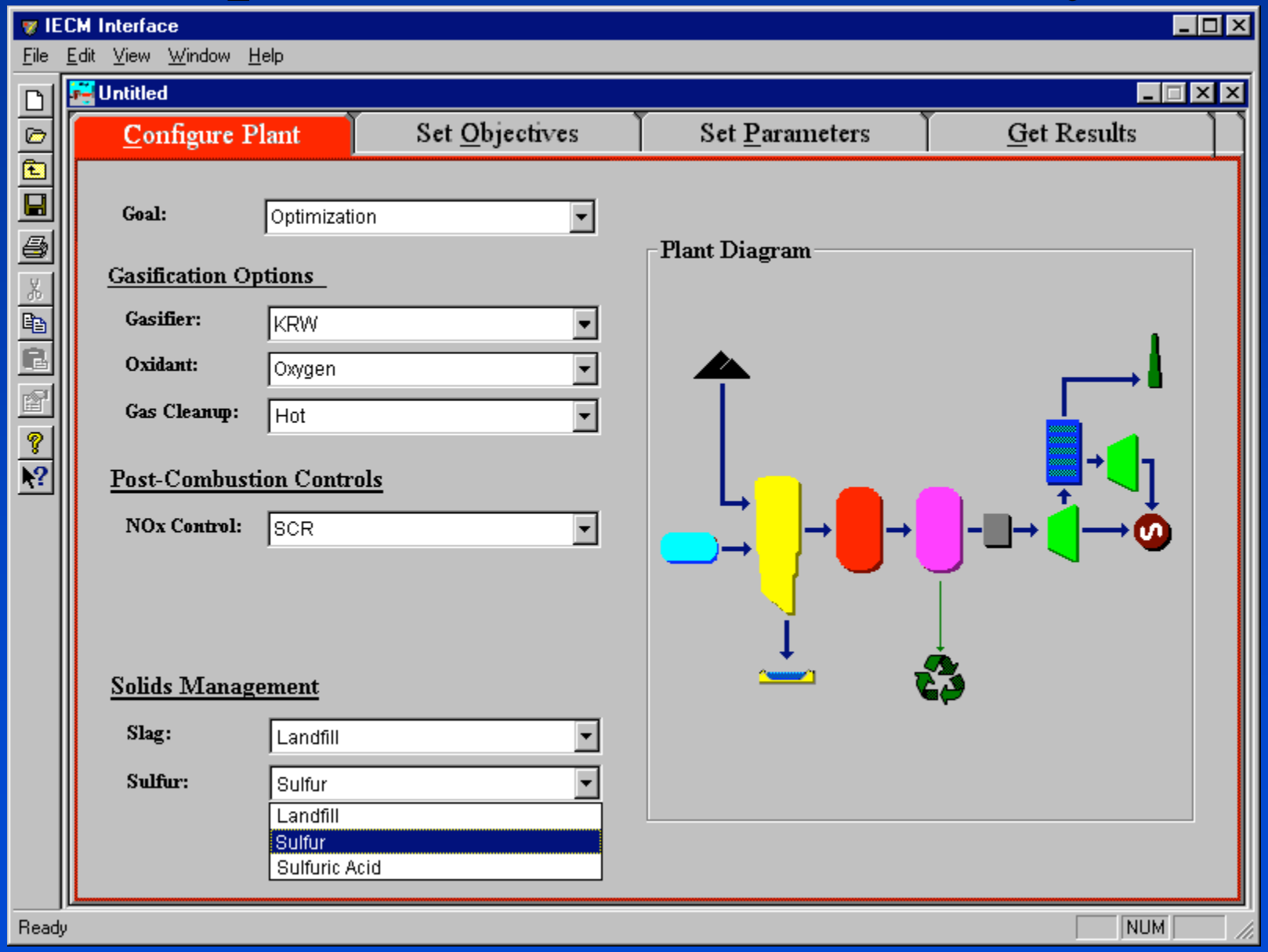
ASPEN Model of an IGCC System



Response Surface Model for an IGCC System



Desktop Model of an IGCC System



Model Applications

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

A Hierarchy of Process Models