The Integrated Environmental Control Model (IECM)

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Center for Energy and Environmental Studies
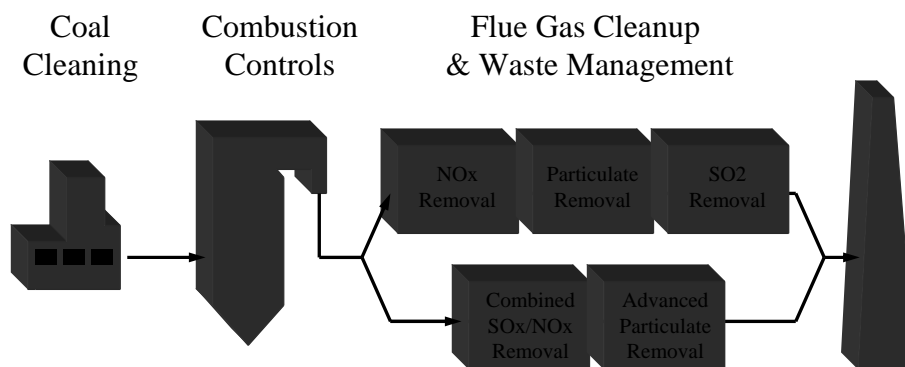Carnegie Mellon University

July 20, 1999

Objectives

- Develop reliable and easy-to-use models to estimate the environmental performance and cost of conventional and advanced technologies to produce electricity from coal

- Develop a framework for comparing alternative options on a systematic basis, including the effects of uncertainty

Approach

- Process Technology Models
- Engineering Economic Models
- Advanced Software Capabilities
- Systems Analysis Framework

Integrated Environmental Control Model (IECM)

Coal Cleaning   Combustion Controls   Flue Gas Cleanup & Waste Management

NOx Removal   Particulate Removal   SO2 Removal

Combined SOx/NOx Removal   Advanced Particulate Removal

Process Performance Models

- Employ detailed mass and energy balances
- Empirical relationships and models used for complex process chemistry
- Calculate component and system mass flows, energy flows, and efficiency
- Calculate multi-media environmental emissions
- Approximately 10-20 performance parameters for each process technology

Process Cost Models

- Direct cost models for each major process area (typically 5-10 areas per technology)
- Explicit links to process performance models
- Calculate total capital cost
- Calculate variable operating costs
- Calculate fixed operating costs
- Calculate annualized cost of electricity
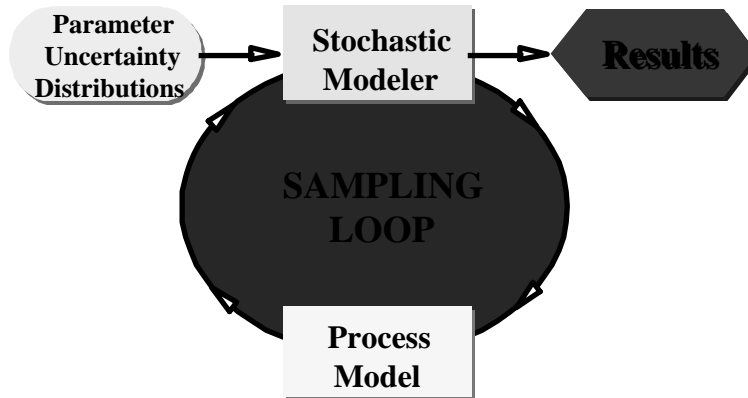- Approximately 20-30 cost parameters for each process technology

Conventional Process Modeling
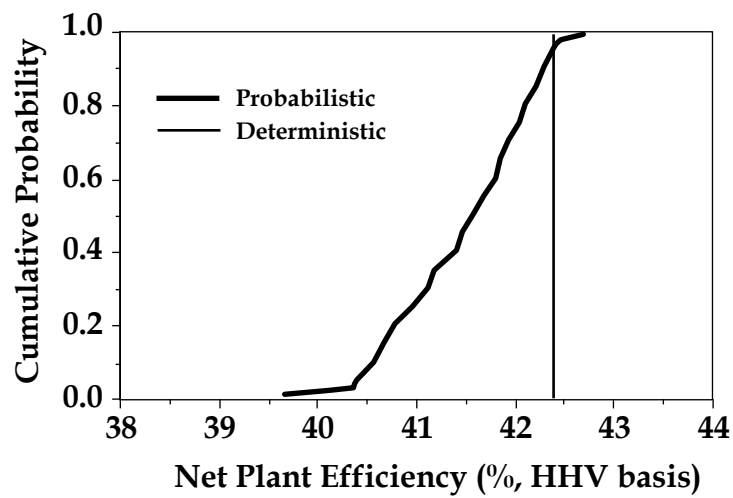## (Deterministic Simulation)

Parameter Values → Process Model → Results
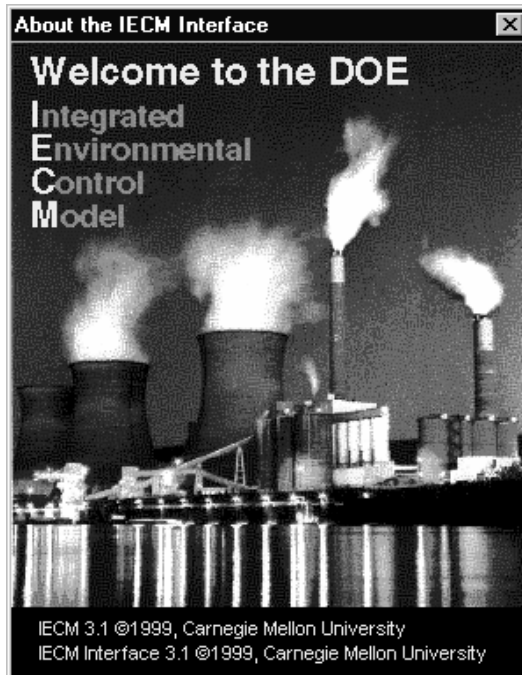
Parameter Uncertainty
Distributions

NORMAL   UNIFORM   LOGNORMAL

TRIANGULAR   BETA   FRACTILE

4
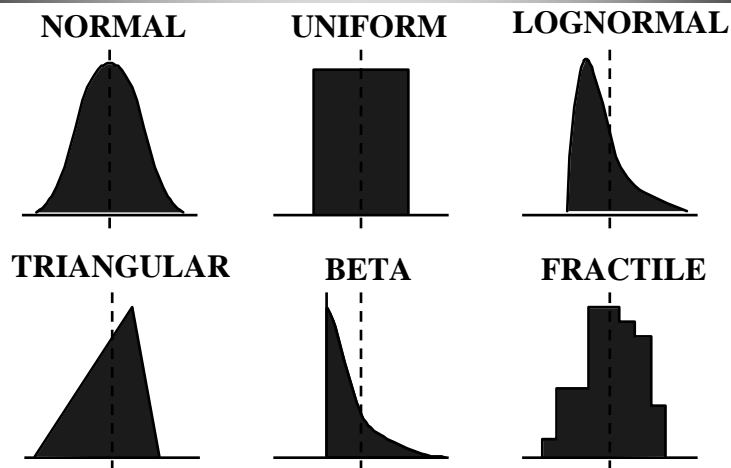
Stochastic Simulation

Calculated Plant Efficiency

Total Plant Capital Cost

Welcome to the DOE
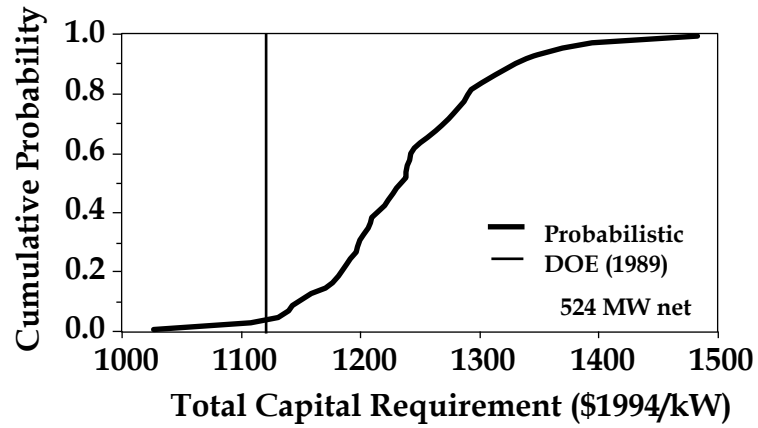
(live demo of the IECM)

The IECM is Now Available for Downloading by the Public

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

- **FTP Access:**
  - ftp.fetc.doe.gov/pub/IECM
    - anonymous login
    - any password

Additional Technology Options

- *Planned*
  - Combustion NO_x Controls
    - Selective Non-Catalytic Reduction (SNCR)
    - Low NOx Burners
    - Overfire air
    - Low Excess Air
    - Lean Gas Reburn
    - Burners Out of Service
    - Selected combinations of the above

- *Proposed*
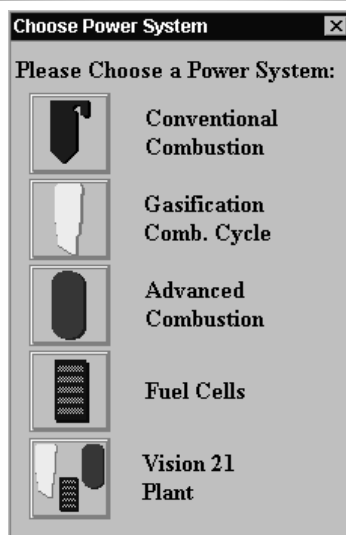 - Post-Combustion Controls
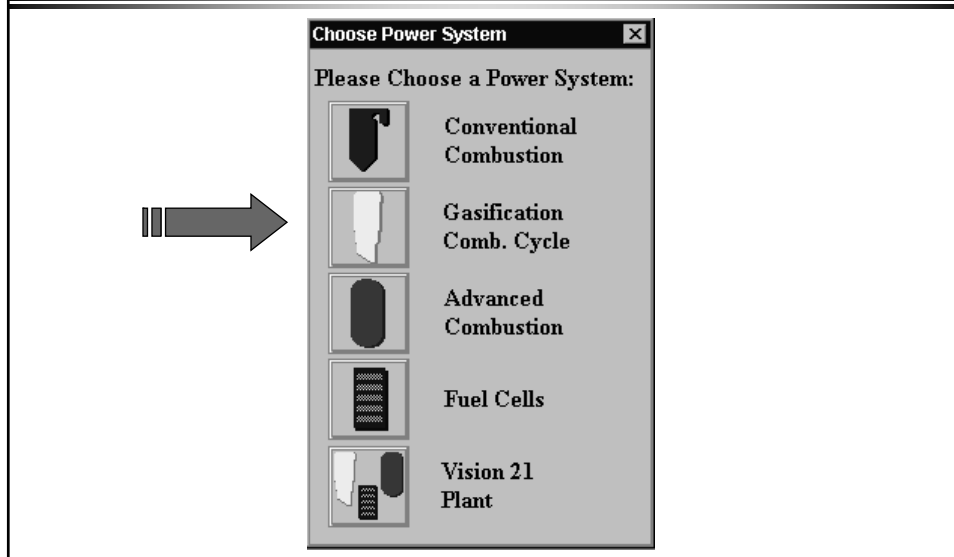   - Air Toxics (mercury)
  - Other Fuels
    - Natural Gas
    - Petroleum
    - Fuel Blending
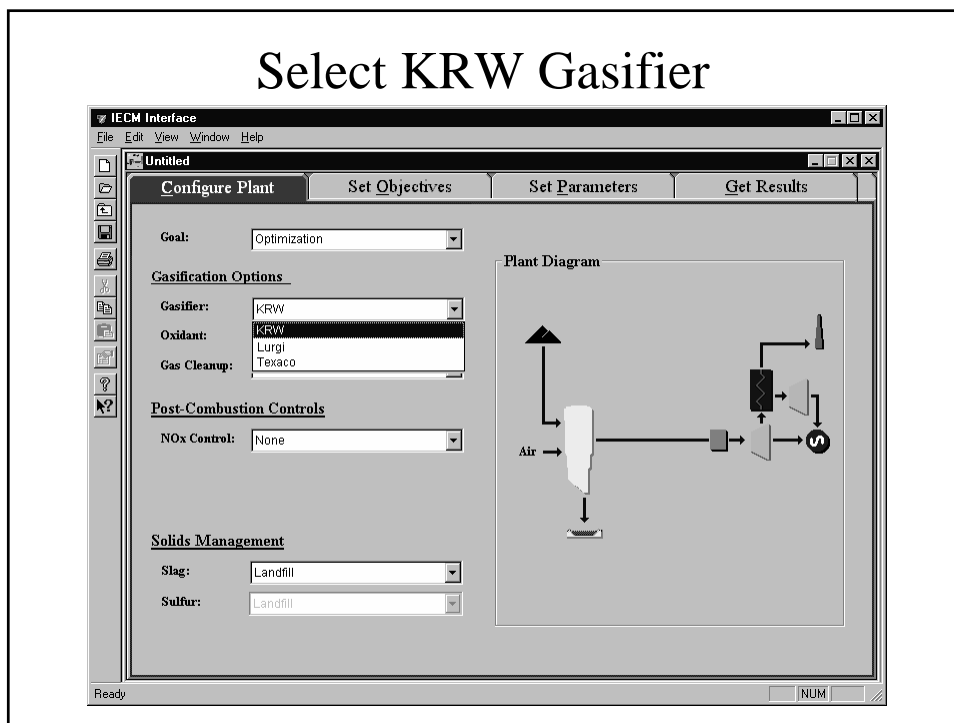 - Alternative Power Generation Systems
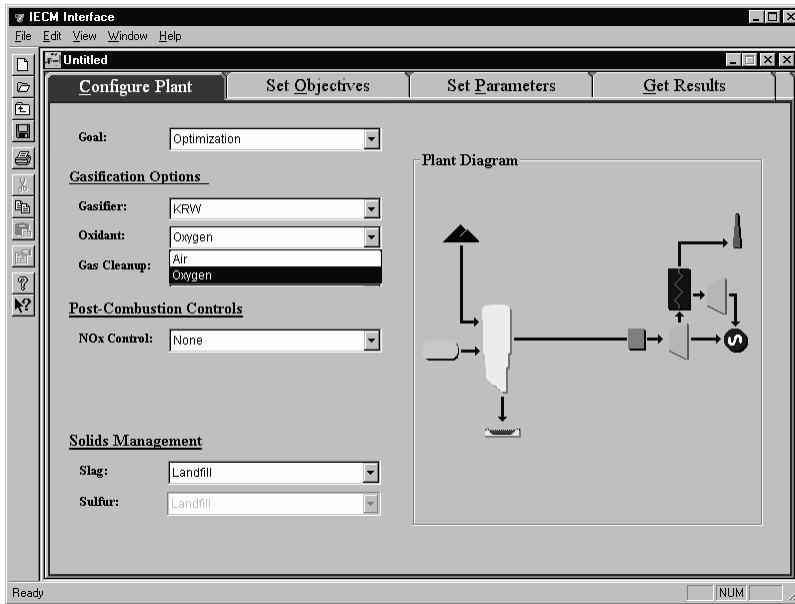
Future Development: A Menu of Technology Options
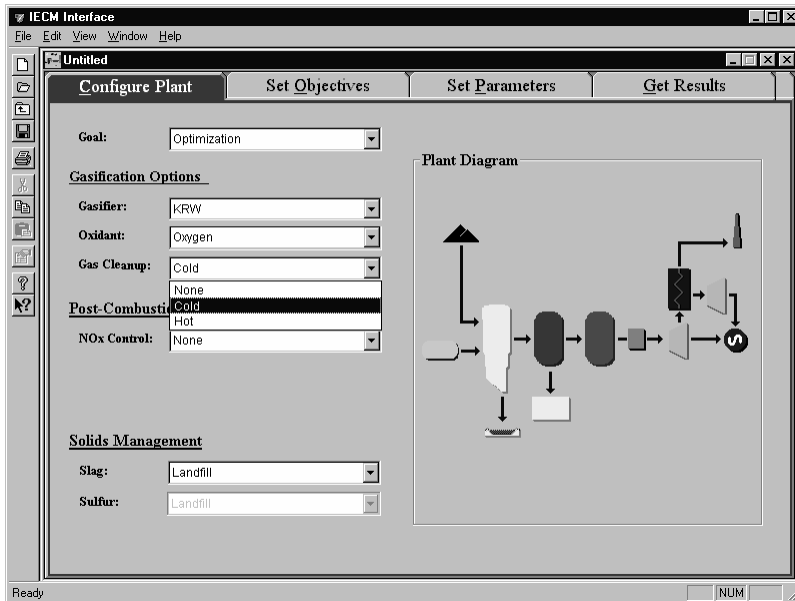
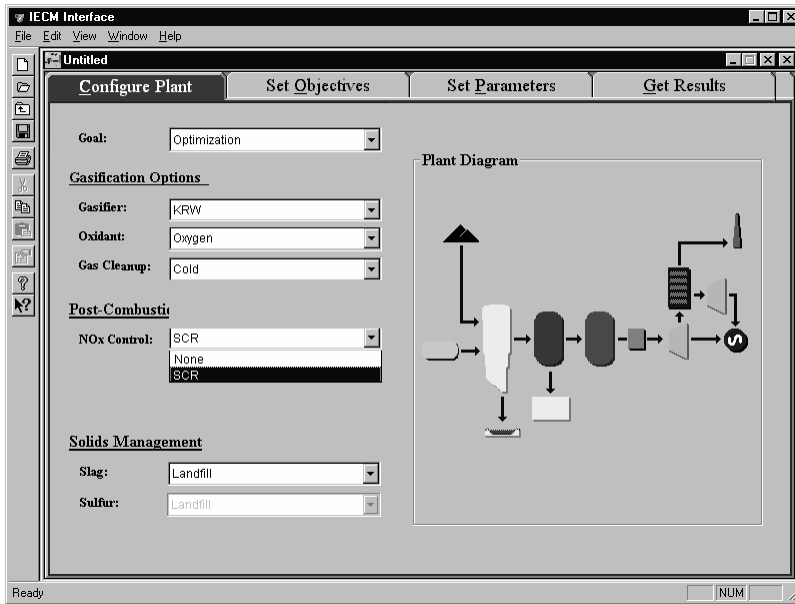# Select Gasification Combined Cycle (IGCC) Options

Select KRW Gasifier

Select Oxygen Plant

Select Cold Gas Cleanup

Select NO$_x$ Control

Select Byproduct Recovery

Set Process Parameters

IECM Interface

File Edit View Window Help

Untitled

| Configure Plant | Set Parameters | Get Results |

| Overall Plant | Coal Properties | IGCC | Furnace Factors | Emission Constraints | NOx Control | Particulate Control | SO2 Control | Solid Waste Mgmt |
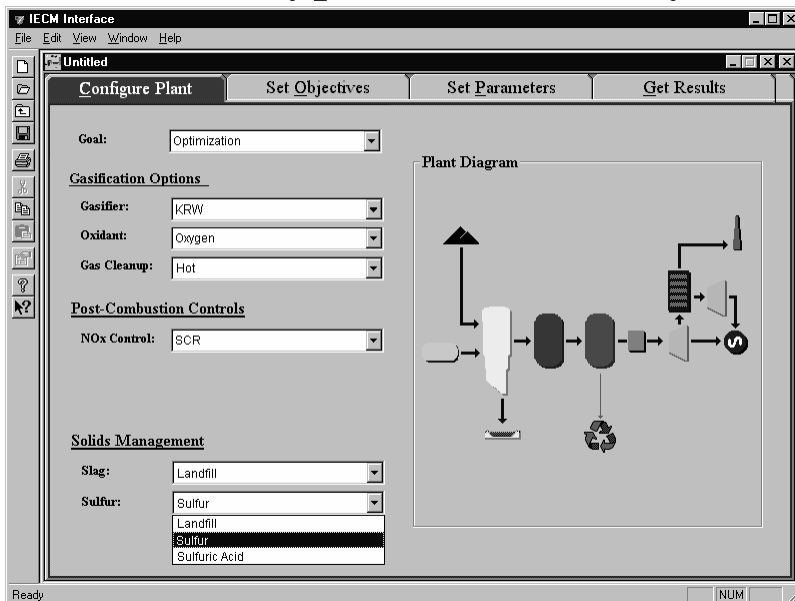
	Title	Units	Unc	Value	Calc	Min	Max	Default	DV
1	Gasifier Design								
2	Gasifier Carbon Conversion	%		95.0		90.0	98.0	95.0	
3	Gasifier Oxygen to Carbon Ratio	mol O2 / mol C		0.46		0.45	0.47	0.46	
4	Gasifier Steam to Carbon Ratio	mol H2O / mol C		0.46		0.445	0.455	0.46	
5	Coal-bound N Converted to NH3	%		10.0		5.0	15.0	10.0	
6	Sulfur Retained in Gasifier Bot Ash	%		90.0		80.0	95.0	90.0	
7									
8	Emissions Control								
9	Calcium to Sulfur Ratio	mol Ca / mol C		2.60		2.10	3.00	2.60	
10	Sulfation Unit Conversion	%		95.0		90.0	98.0	95.0	
11	NH3 Converted to NOx in Turbine	%		90.0		50.0	90.0	90.0	
12	SCR NOx Removal Efficiency	%		80.0		50.0	90.0	80.0	
13	SCR NH3 Slip	ppmw		10.0		5.0	20.0	10.0	
14									
15									
16									
17									
18									

1. Performance   2. Financing   3. Retrofit Cost   4. Capital Cost   5. O&M Cost   6. O&M Escalation

Open Vision 21 Plant Options

Choose Power System

Please Choose a Power System:

Conventional Combustion

Gasification Comb. Cycle

Advanced Combustion

Fuel Cells

Vision 21 Plant

Welcome to the
Vision 21
Planner

Select Existing Flowsheet - 1
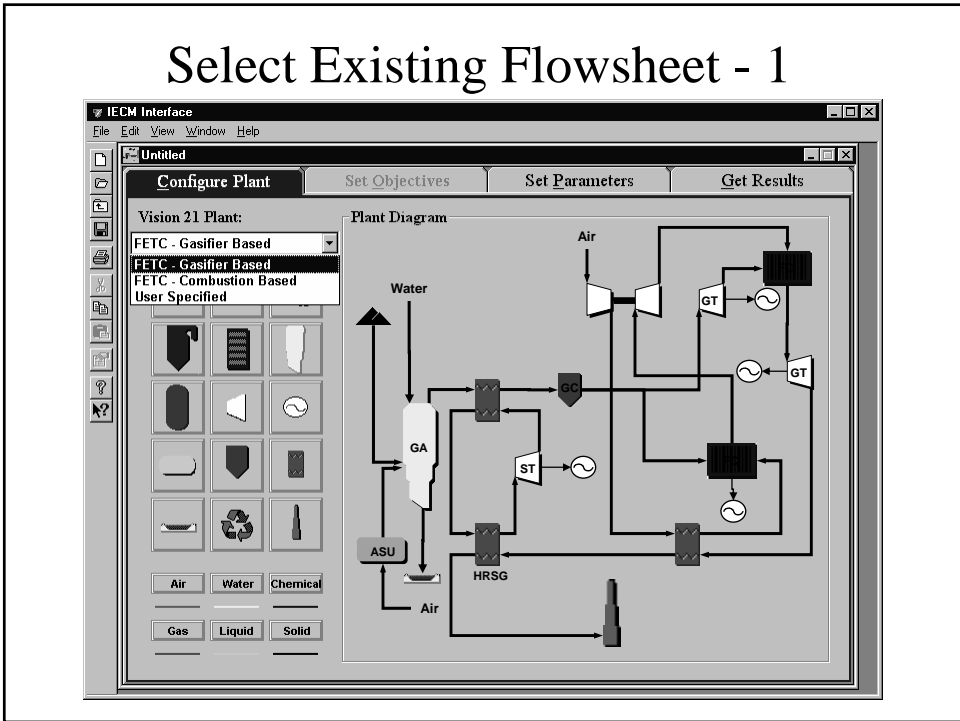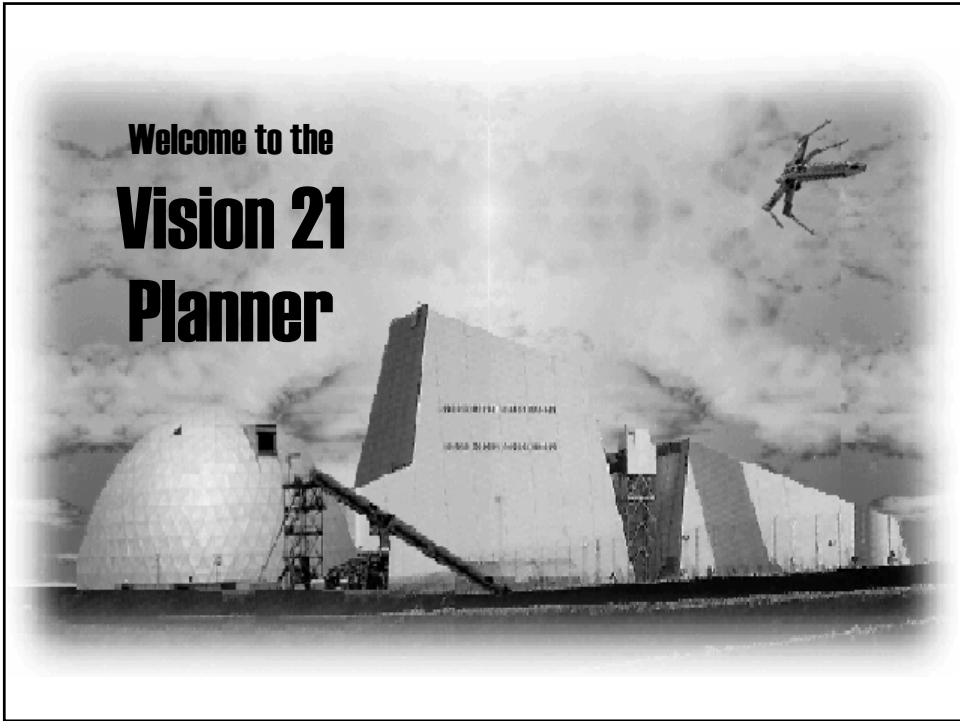
Select Existing Flowsheet - 2
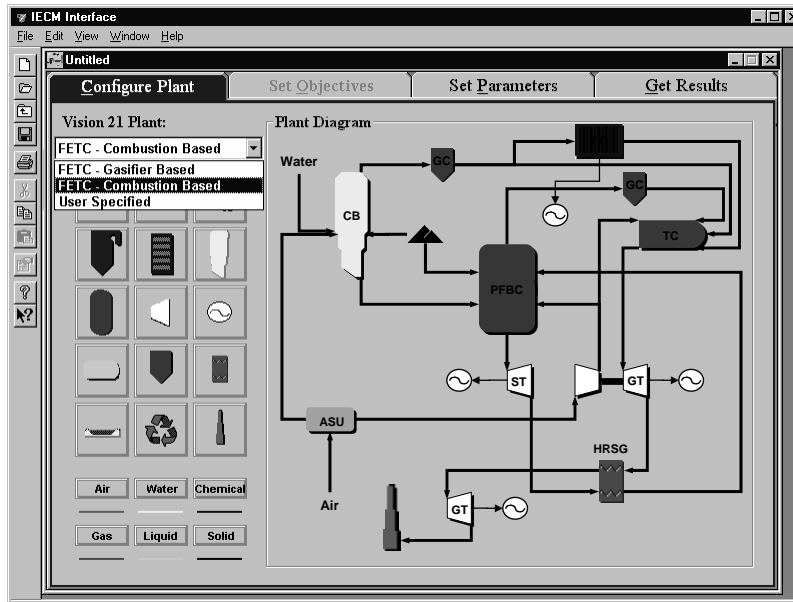
Vision 21 Workbench
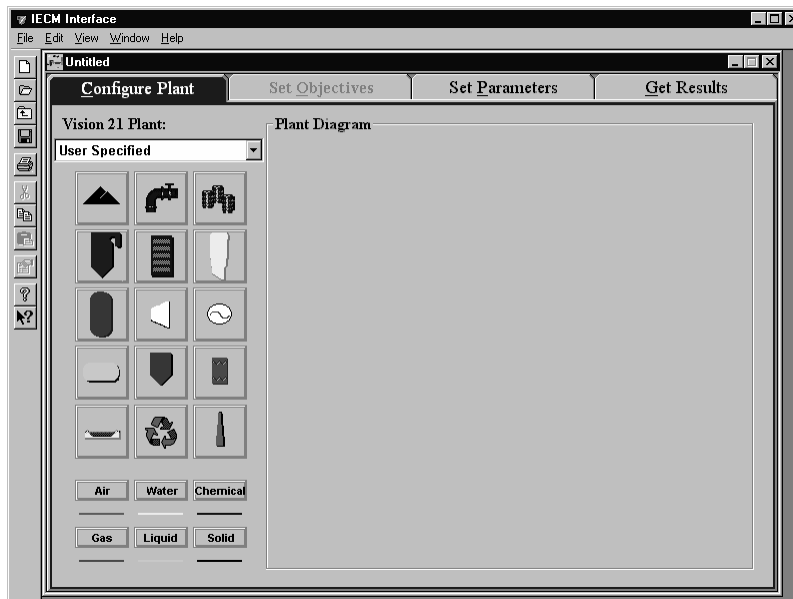
Configure a New System
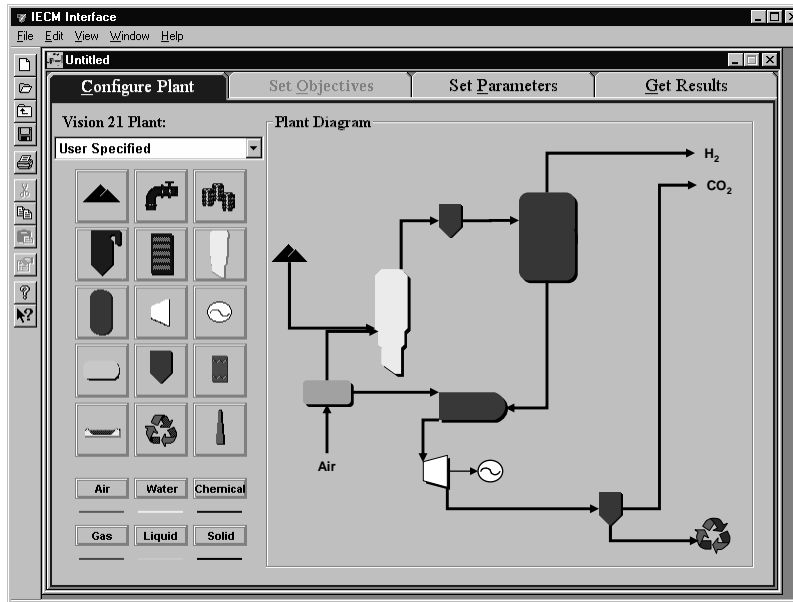
Potential New Software Options

- Process Optimization

- Process (Flowsheet) Synthesis

Advanced Design Capabilities:
Operation Overview

```
Open                                              Get
Session                                           Results

        ┌─→ Simulation ──→ Specify a ──→ Choose Process ──┘
        │                  Flowsheet     Parameters
        │                                      ↑
        │                              Set Decision
        │                               Variables
        │                                      ↑
        ├─→ Optimization ──→ Specify a ──→ Set Objective
        │                    Flowsheet     & Constraints
        │                          │              ↑
        └─→ Optimization/ ──→ Select Component ───┘
            Synthesis           Options
```
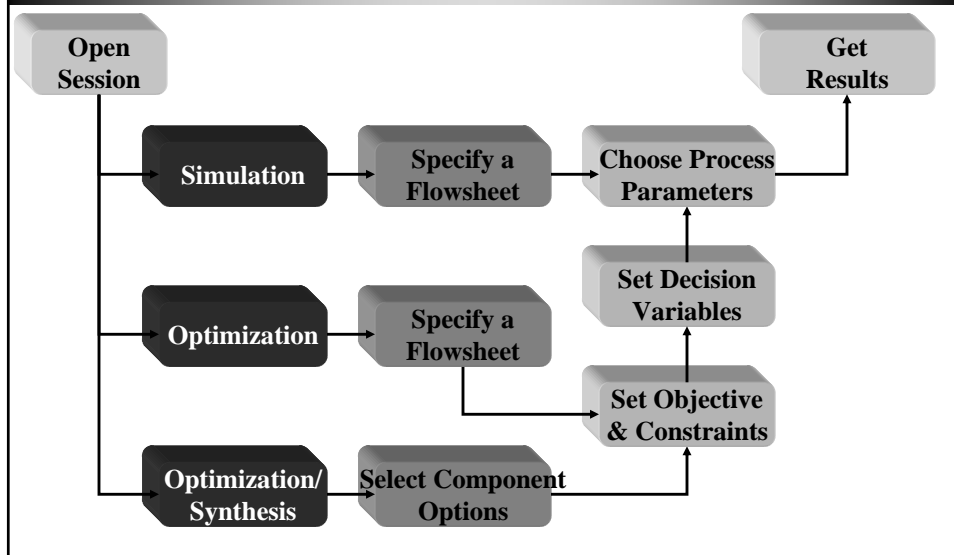
Select Optimization Mode
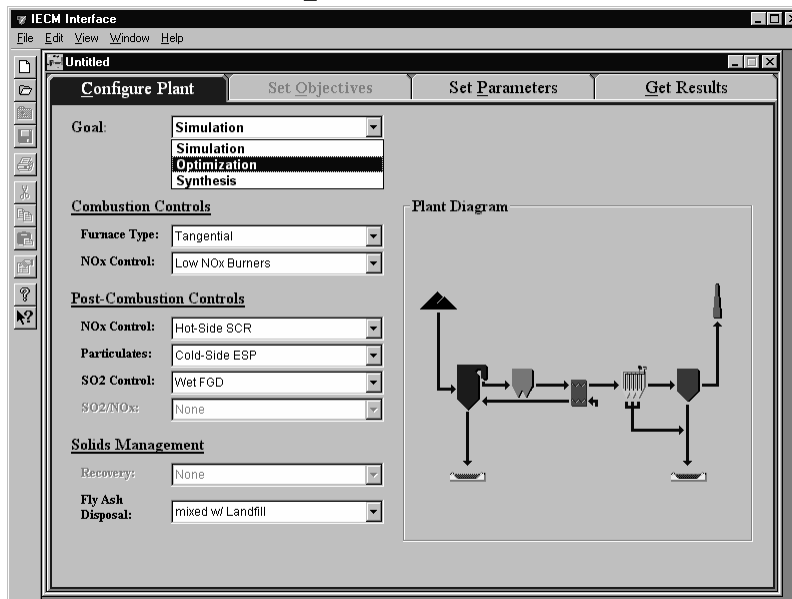
Set Objective and Constraints

IECM Interface

File Edit View Window Help

Untitled

| Configure Plant | Set Objectives | Set Parameters | Get Results |

Objective: Minimize Capital Cost

		Title	Units	CV	Min	Max
	1	Emissions (Final)				
	2	Particulates	lb/MBtu			
	3	Nitrogen Oxides	lb/MBtu	✓	0.06	0.6
	4	Sulfur Dioxide	lb/MBtu	✓	0.1	1.2
	5	Carbon Dioxide	lb/MBtu			
	6	Air Toxics	lb/MBtu			
	7	Solids Wastes	lb/MBtu			
	8					
	9	Net Thermal Efficiency	Btu/kWh			
	10					
	11	Overall Plant Costs				
	12	Capital Cost	M$			
	13	O&M Cost	M$/yr			
	14	Cost of Electricity	mills/kWh			
	15					
	16					
	17					
	18					

Set Parameter Values

IECM Interface

File Edit View Window Help

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| Configure Plant | Set Objectives | Set Parameters | Get Results |

| Overall Plant | Coal Properties | Base Plant | Furnace Factors | Emission Constraints | NOx Control | Particulate Control | SO2 Control | Solid Waste Mgmt |

Goal: Optimization

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

Select Decision Variables

IECM Interface

File Edit View Window Help

Untitled

| Configure Plant | Set Objectives | Set Parameters | Get Results |

| Overall Plant | Feedstocks | Fuel Upgrade | Energy Conversion | Gas Stream Cleanup | Process Options | Co-Products |

| IGCC | Conventional Boiler | Fuel Cell | PFBC |

	Title	Units	Unc	Value	Calc	Min	Max	Default	DV
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 |

Get Results (Run Model)

IECM Interface

File Edit View Window Help

Untitled

| Configure Plant | Set Objectives | Set Parameters | Get Results |

| Overall Plant | Fuel (Coal) | | Landfill | Stack |

Goal: Optim

IECM Analysis Progress

IECM Analysis Progress

Iteration	Obj. Function Value	Optimizer Error Value
6	90.345 %	1.4e-01
7	90.462 %	2.4e-02
8	90.523 %	9.5e-04
9	90.549 %	5.4e-05
10	90.563 %	4.0e-07
11	90.568 %	1.7e-07
12	90.570 %	3.3e-09
13	90.570 %	6.2e-11

Calculating New Decision Variables

Pause   Stop

Combustion Controls

Furnace Type: Tangen

NOx Control: Low N

Post-Combustion Cor

NOx Control: Hot-Si

Particulates: Cold-S

SO2 Control: Wet FG

SO2/NOx: None

Solids Management

Recovery: None

Fly Ash Disposal: mixed w/ Landfill

| 1. Diagram | 2. Perf. Summary | 3. Flow Summary | 4. Cost Summary |

View Results

Select Synthesis Mode

Select Possible Technologies

IECM Interface — File Edit View Window Help

Untitled

| Configure Plant | Set Objectives | Set Parameters | Get Results |

Goal: Optimization

Combustion Controls

Furnace Type:
- ☑ Tangential
- ☐ Wall
- ☐ Cyclone

NOx Control:
- ☑ Low Excess Air
- ☑ Burners out of Service
- ☑ Low NOx Burners (LNB)
- ☐ LNB + Overfire Air (OFA)
- ☑ Lean Gas Reburn
- ☐ Gas Reburn + OFA
- ☐ Coal Reburn
- ☑ None

Solids Management

Recovery:
- ☑ Gypsum
- ☑ Sulfur
- ☑ Sulfuric Acid
- ☑ None

Fly Ash Disposal:
- ☑ mixed w/ Bottom Ash
- ☑ mixed w/ Landfill
- ☑ None

Post-Combustion Controls

NOx Control:
- ☑ Hot-Side SCR
- ☐ None

Particulates:
- ☑ Cold-Side ESP
- ☑ Reverse Gas Fabric Filter
- ☑ Reverse Gas Sonic Fabric Filter
- ☑ Shake & Deflate Fabric Filter
- ☐ None

SO2 Control:
- ☑ Wet Lime FGD
- ☑ Wet Limestone FGD
- ☑ Wet Limestone w/ Additives FGD
- ☑ Spray Dryer
- ☐ None

SO2/NOx:
- ☑ Copper Oxide
- ☑ NOXSO
- ☐ None

Set Parameters

IECM Interface — File Edit View Window Help

Untitled

| Configure Plant | Set Objectives | Set Parameters | Get Results |

Overall Plant | Feedstocks | Fuel Upgrade | Energy Conversion | Gas Stream Cleanup | Process Options | Co-Products

IGCC | Conventional Boiler | Fuel Cell | PFBC

	Title	Units	Unc	Value	Calc	Min	Max	Default	DV
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

Get Results (Run Model)

IECM Interface
File Edit View Window Help

Untitled

| Configure Plant | Set Objectives | Set Parameters | Get Results |

| Overall Plant | Fuel (Coal) | Boiler | Air Preheater | NOx Control | Particulate Control | SO2 Control | Pond | Landfill | Stack |

Goal: Optim

Combustion Controls

Furnace Type: Tangen

NOx Control: Low NO

Post-Combustion Con

NOx Control: Hot-Sid

Particulates: Cold-S

SO2 Control: Wet FG

SO2/NOx: None

Solids Management

Recovery: None

Fly Ash Disposal: mixed w/ Landfill

IECM Analysis Progress

Iteration	Obj. Function Value	Optimizer Error Value
6	787.3	1.4e-01
7	702.0	2.4e-02
8	669.8	9.5e-04
9	619.3	5.4e-05
10	627.5	4.0e-07
11	580.5	1.7e-07
12	526.2	3.3e-09
13	526.2	6.2e-11

Calculating New Decision Variables

Pause   Stop

1. Diagram   2. Perf. Summary   3. Flow Summary   4. Cost Summary

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View Optimal Flowsheet

IECM Interface
File Edit View Window Help

Untitled

| Configure Plant | Set Objectives | Set Parameters | Get Results |

| Overall Plant | Fuel (Coal) | Boiler | Air Preheater | NOx Control | Particulate Control | SO2 Control | Pond | Landfill | Stack |

Goal: **Optimization**

Combustion Controls

Furnace Type: Tangential

NOx Control: Low NOx Burners

Post-Combustion Controls

NOx Control: Hot-Side SCR

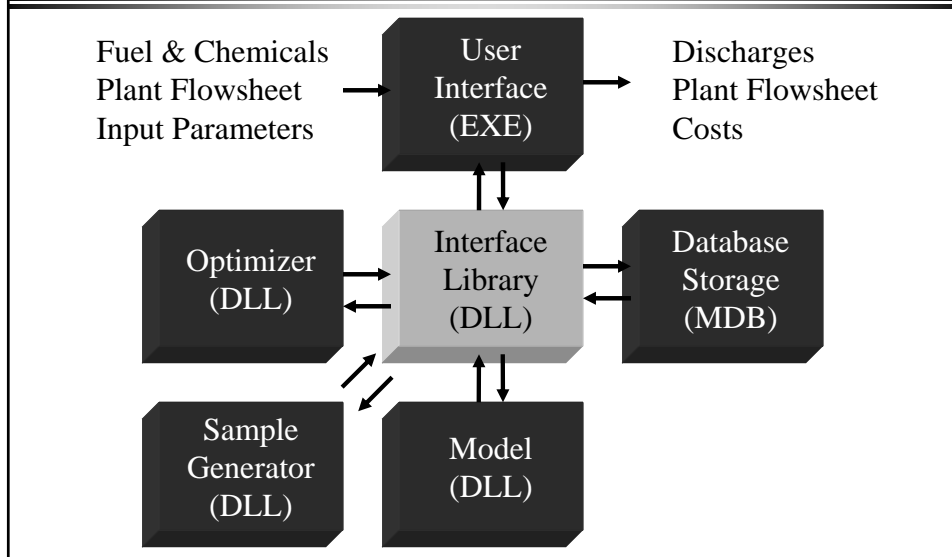Particulates: Cold-Side ESP

SO2 Control: Wet FGD

SO2/NOx: None

Solids Management

Recovery: None

Fly Ash Disposal: mixed w/ Landfill

Plant Diagram

1. Diagram   2. Perf. Summary   3. Flow Summary   4. Cost Summary

IECM Programming Module Structure

Fuel & Chemicals
Plant Flowsheet
Input Parameters
→
User Interface (EXE)
→
Discharges
Plant Flowsheet
Costs

Optimizer (DLL)
→
←
Interface Library (DLL)
→
←
Database Storage (MDB)

Sample Generator (DLL)
Model (DLL)

Model Applications

- Process design
- Technology evaluation
- Cost estimation
- R&D management

- Risk analysis
- Environmental compliance
- Marketing studies
- Strategic planning

Please let us know what you think

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