

Conceptual Design of a Vision 21 Planning Model

Ed Rubin, Mike Berkenpas,
Urmila Diwekar and Karen Kietzke

Center for Energy and Environmental Studies
Carnegie Mellon University

July 19, 1999

Objectives

- Develop a flexible and easy-to-use modeling system to estimate the performance, environmental emissions and cost of a preliminary Vision 21 plant design
- Develop a framework for comparing alternative options and on a systematic basis, including effects of uncertainty

Current FETC Projects

Development of the Integrated Environmental Control Model (IECM)

Duration: September 1992 - April 1999
Amount: \$1.3 million
COR: Gerst Gibbon

Development and Application of Optimal Design Capability for Coal Gasification Systems

Duration: September 1992 - February 2000
Amount: \$1.5 million
COR: Gerst Gibbon

Advanced Design and Analysis Methods are Needed

- Increasing complexity of advanced processes
- Multiple options for component design & selection
- Strong interactions among system components
- Significant uncertainties in the performance and cost of new technologies

Approach

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

Technologies Modeled and Evaluated

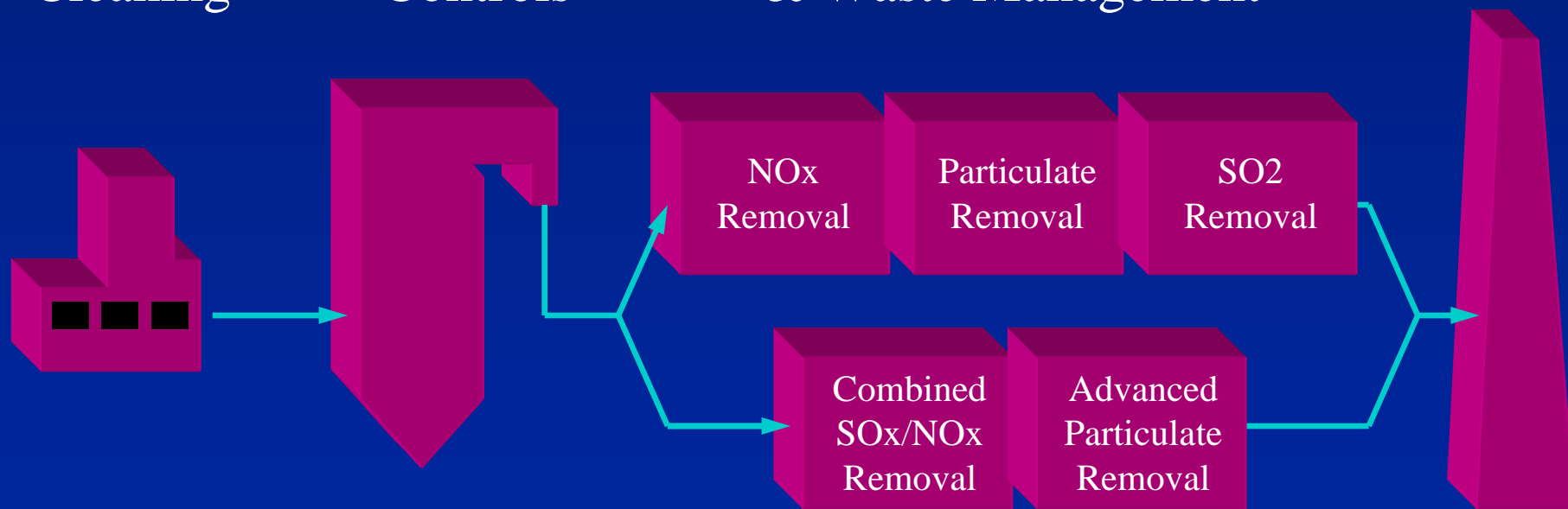
- Pulverized Coal Combustion Plants
 - Selective catalytic reduction (SCR)
 - Wet lime/limestone FGD
 - Lime spray dryer
 - Electrostatic precipitators
 - Fabric filters
- Advanced Environmental Control Systems
 - Combined SO₂/NO_x removal
- Coal Beneficiation Processes

Integrated Environmental Control Model (IECM)

Coal
Cleaning

Combustion
Controls

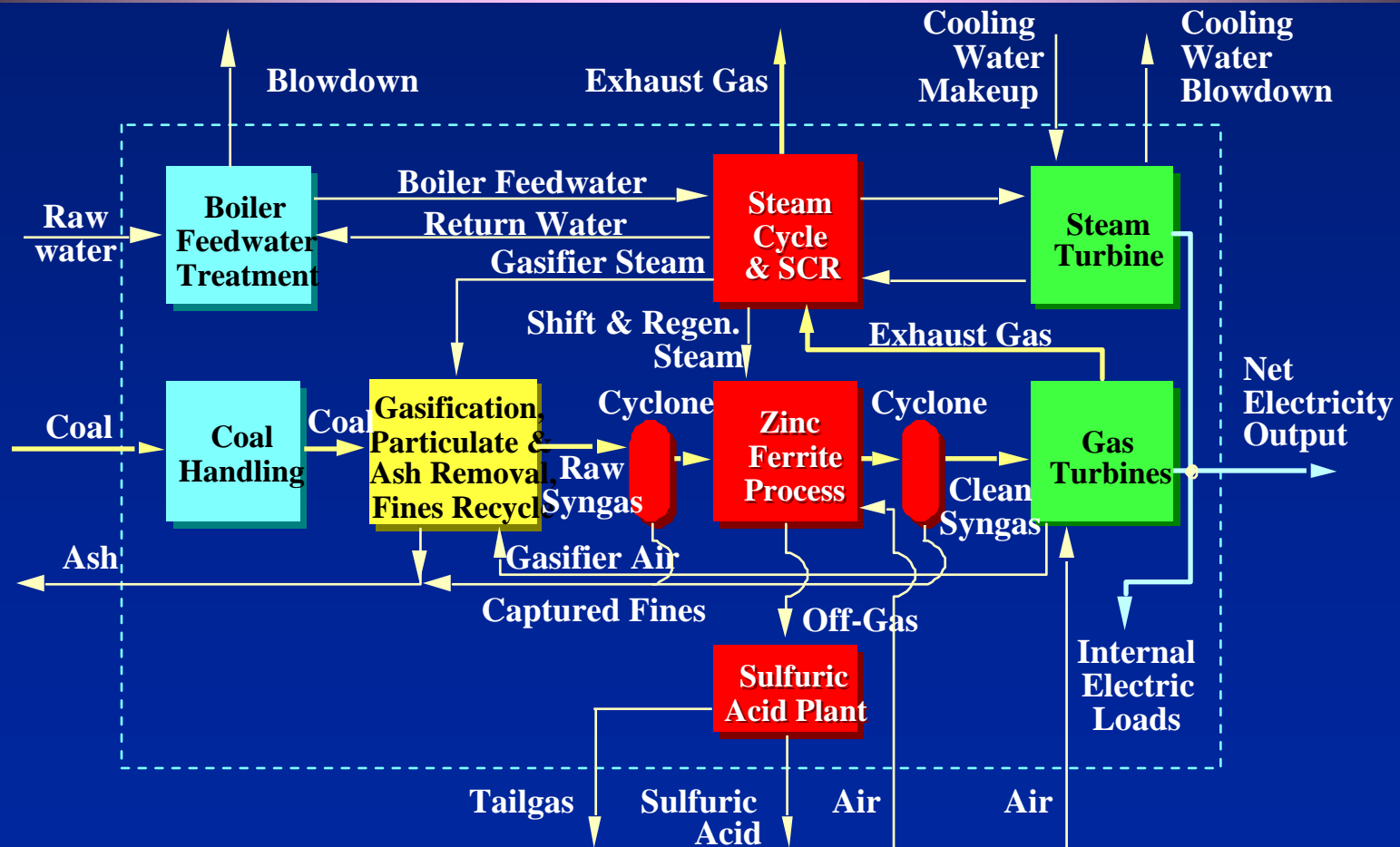
Flue Gas Cleanup
& Waste Management



Technologies Modeled (con't)

- Integrated Gasification Combined Cycles (IGCC)
 - Air and oxygen blown gasifiers
 - Fixed bed and fluidized bed gasifiers
 - Hot gas and cold gas cleanup systems
 - Byproduct recovery options (e.g., sulfuric acid, Claus plant, direct sulfur reduction process)
 - Other environmental controls (e.g., SCR)
- Pressurized Fluidized Bed Combustion (PFBC)
- Externally-Fired Combined Cycle (EFCC)

ASPEN Model of an IGCC System



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

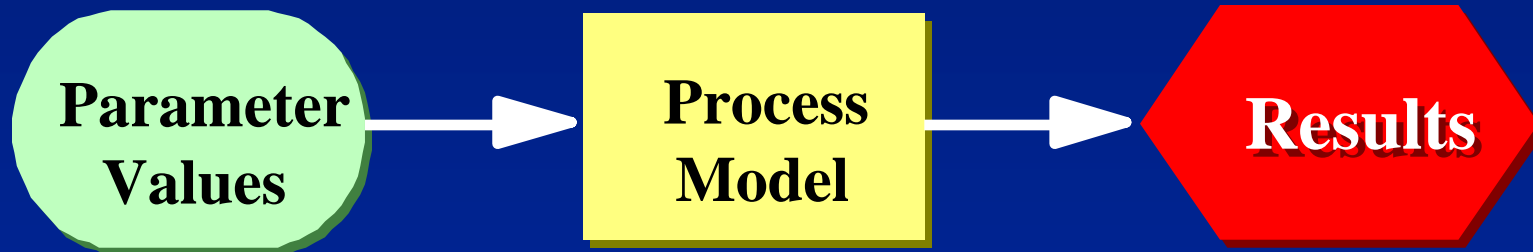
Process Cost Models

- 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

New Modeling Capabilities

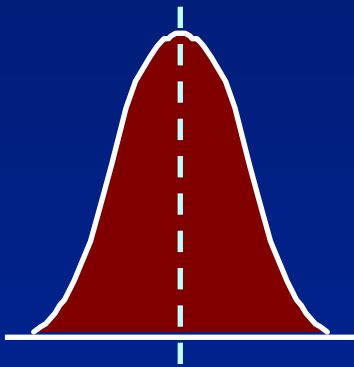
System	Deterministic	Stochastic
Simulation	✓	✓
Optimization	✓	✓
Synthesis	✓	✓

Conventional Process Modeling (Deterministic Simulation)

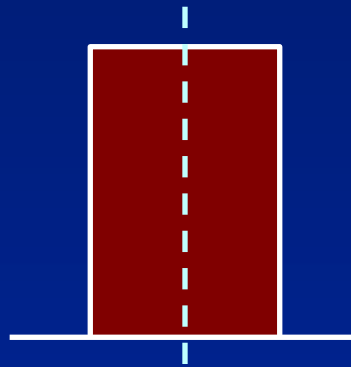


Parameter Uncertainty Distributions

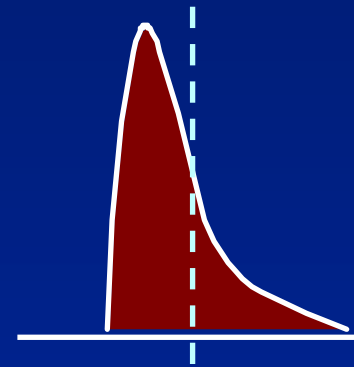
NORMAL



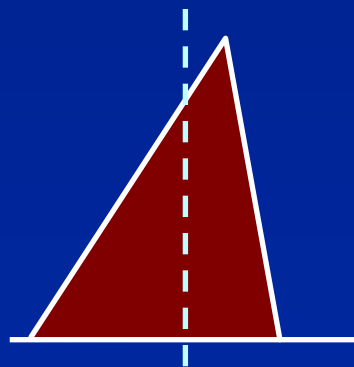
UNIFORM



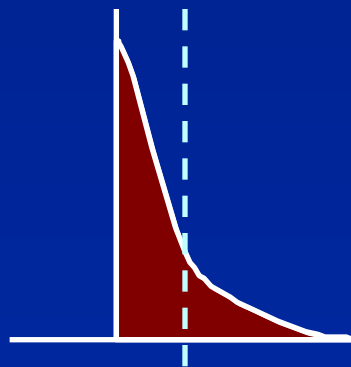
LOGNORMAL



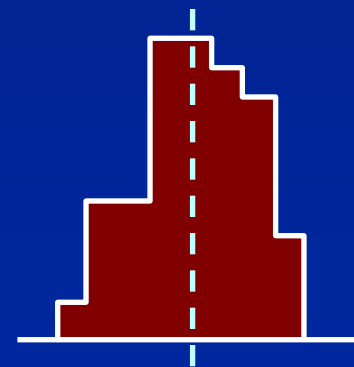
TRIANGULAR



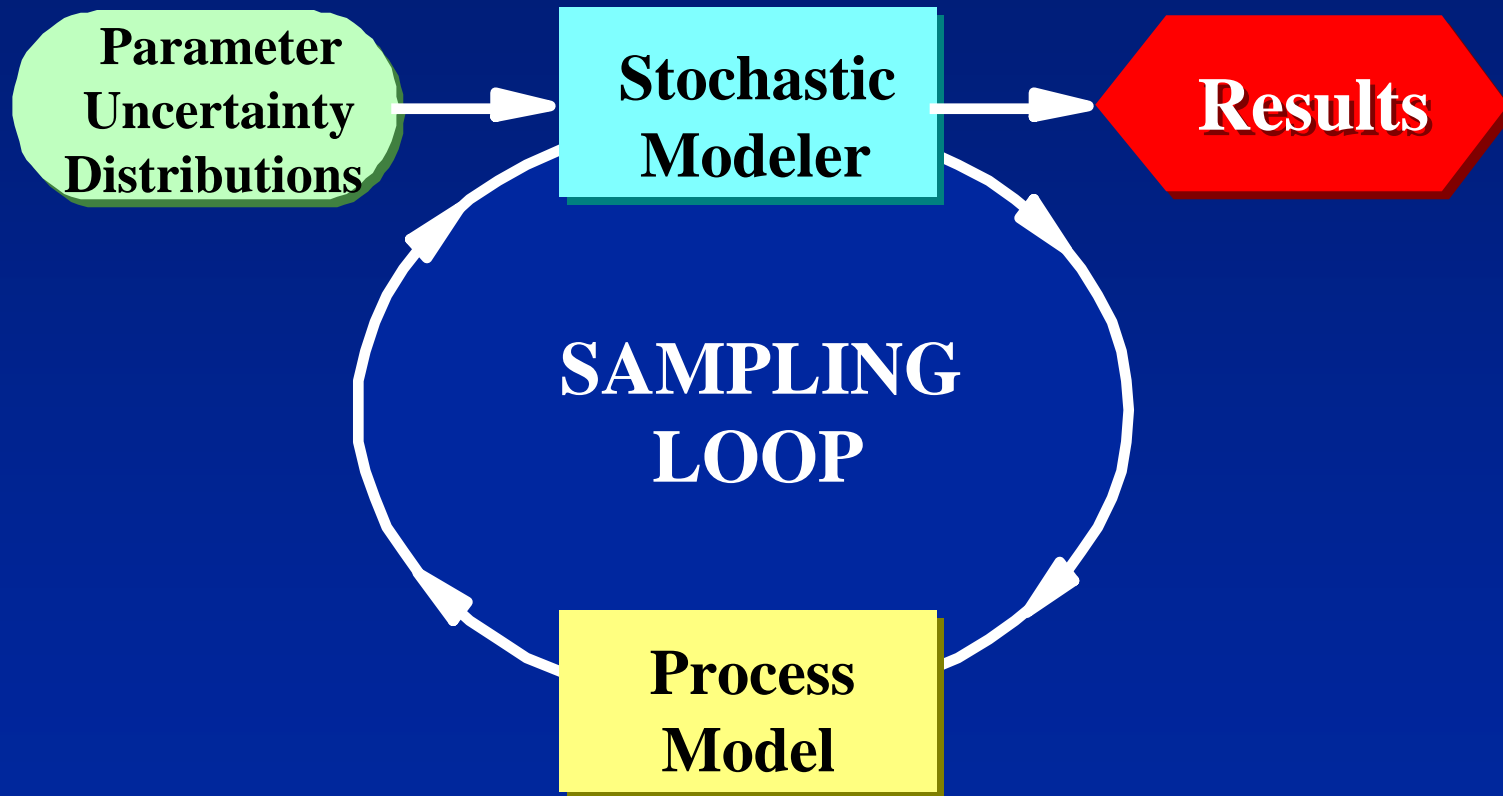
BETA



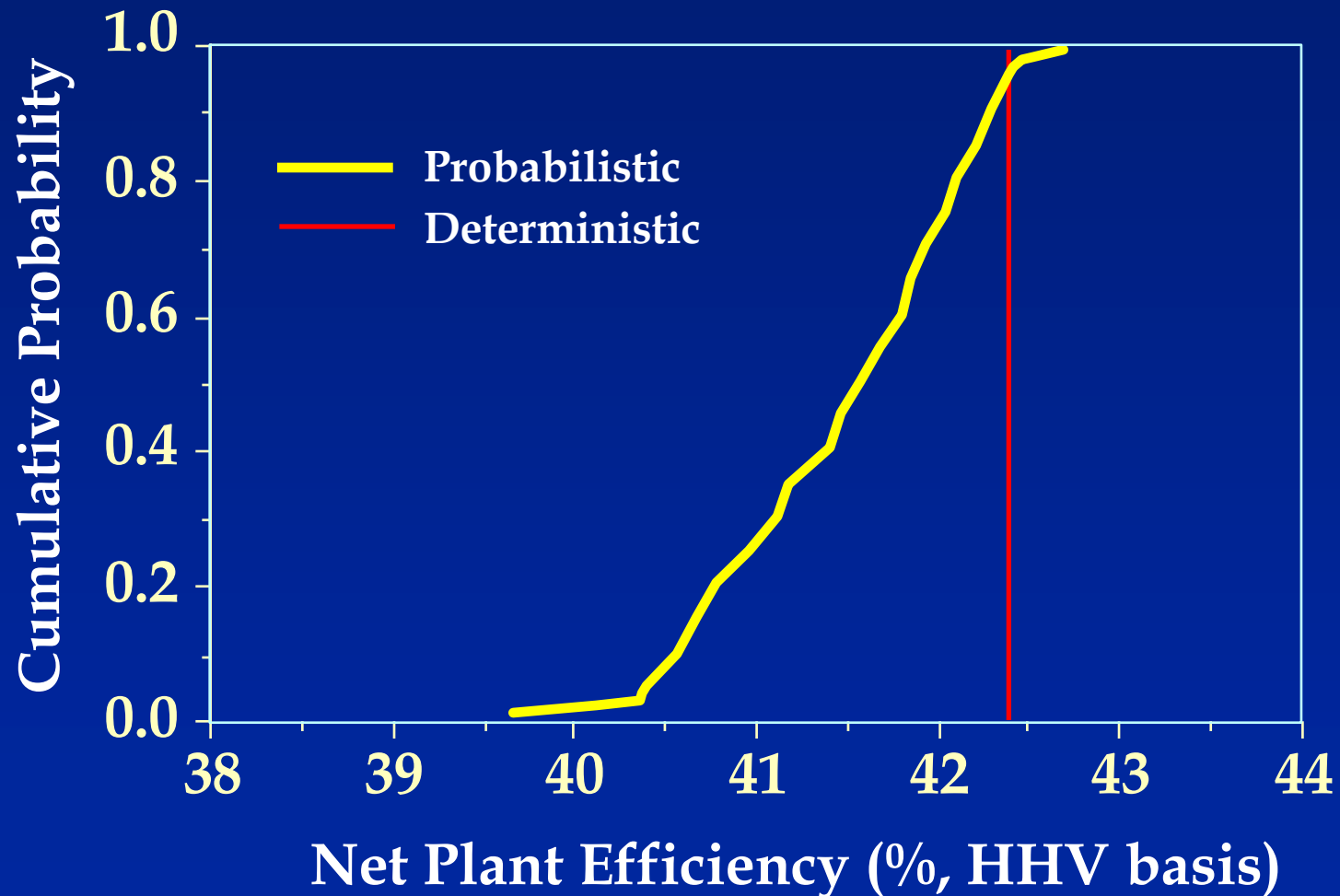
FRACTILE



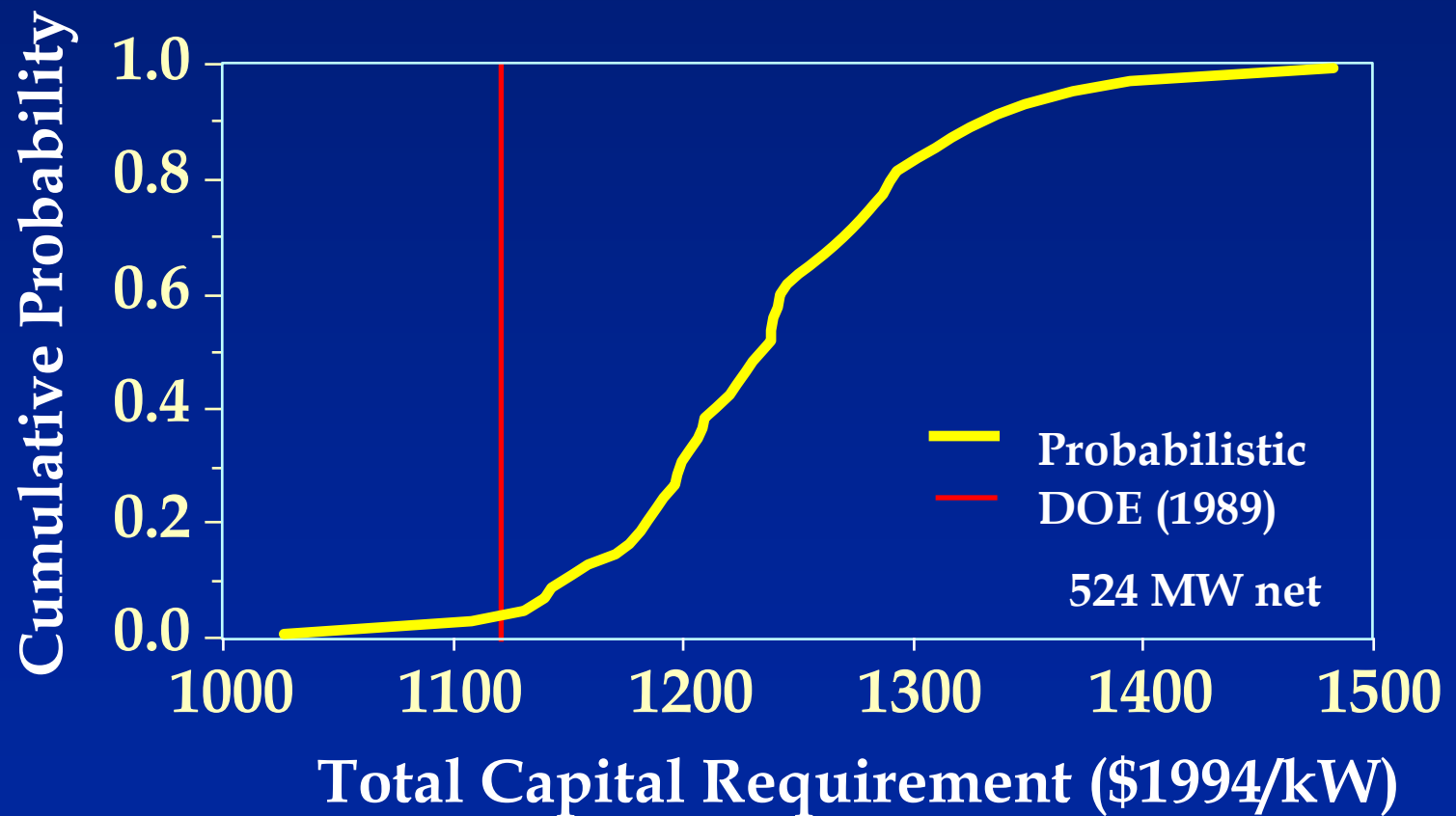
Stochastic Simulation



Externally-Fired Combined Cycle (EFCC) Plant Efficiency



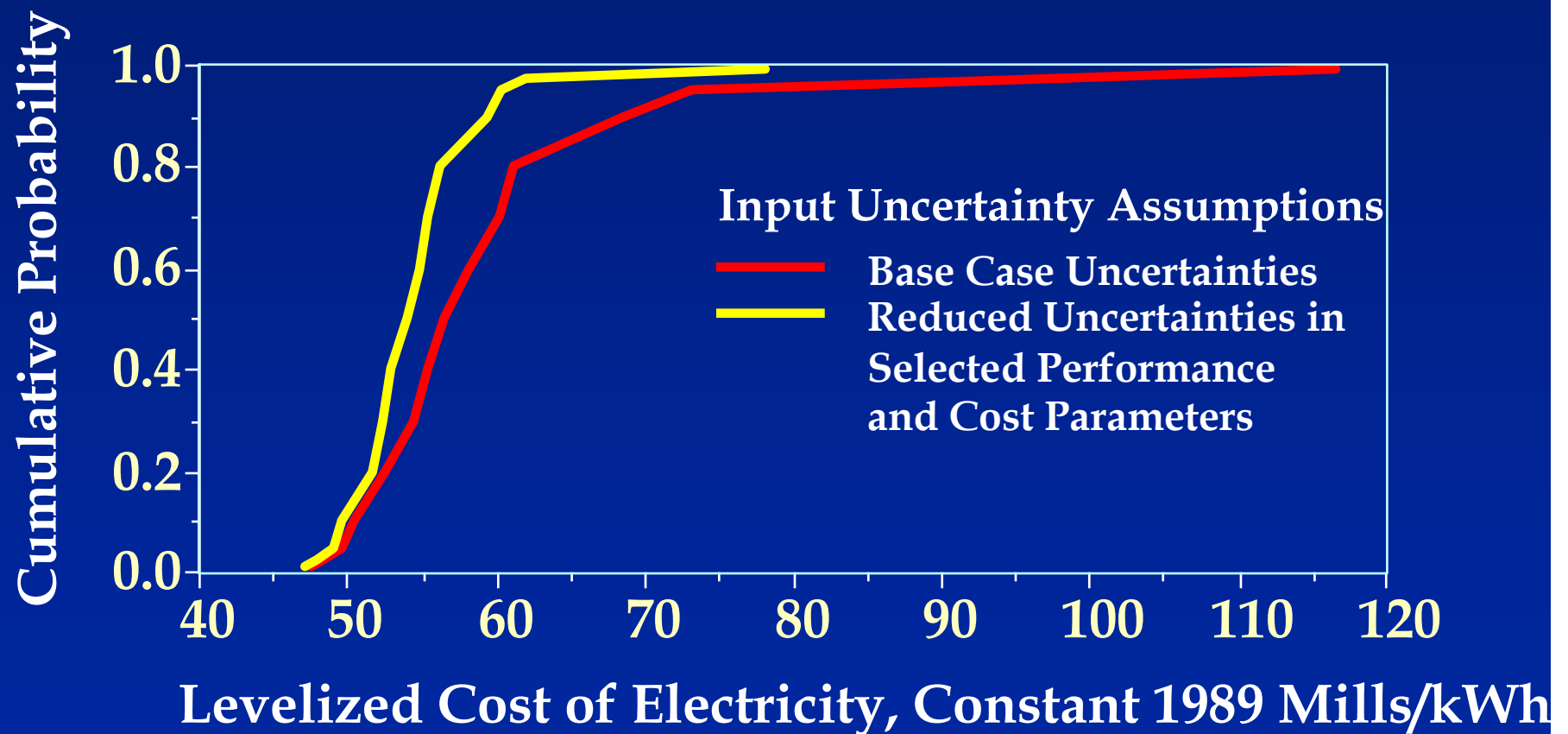
Second Generation PFBC System Total Capital Cost



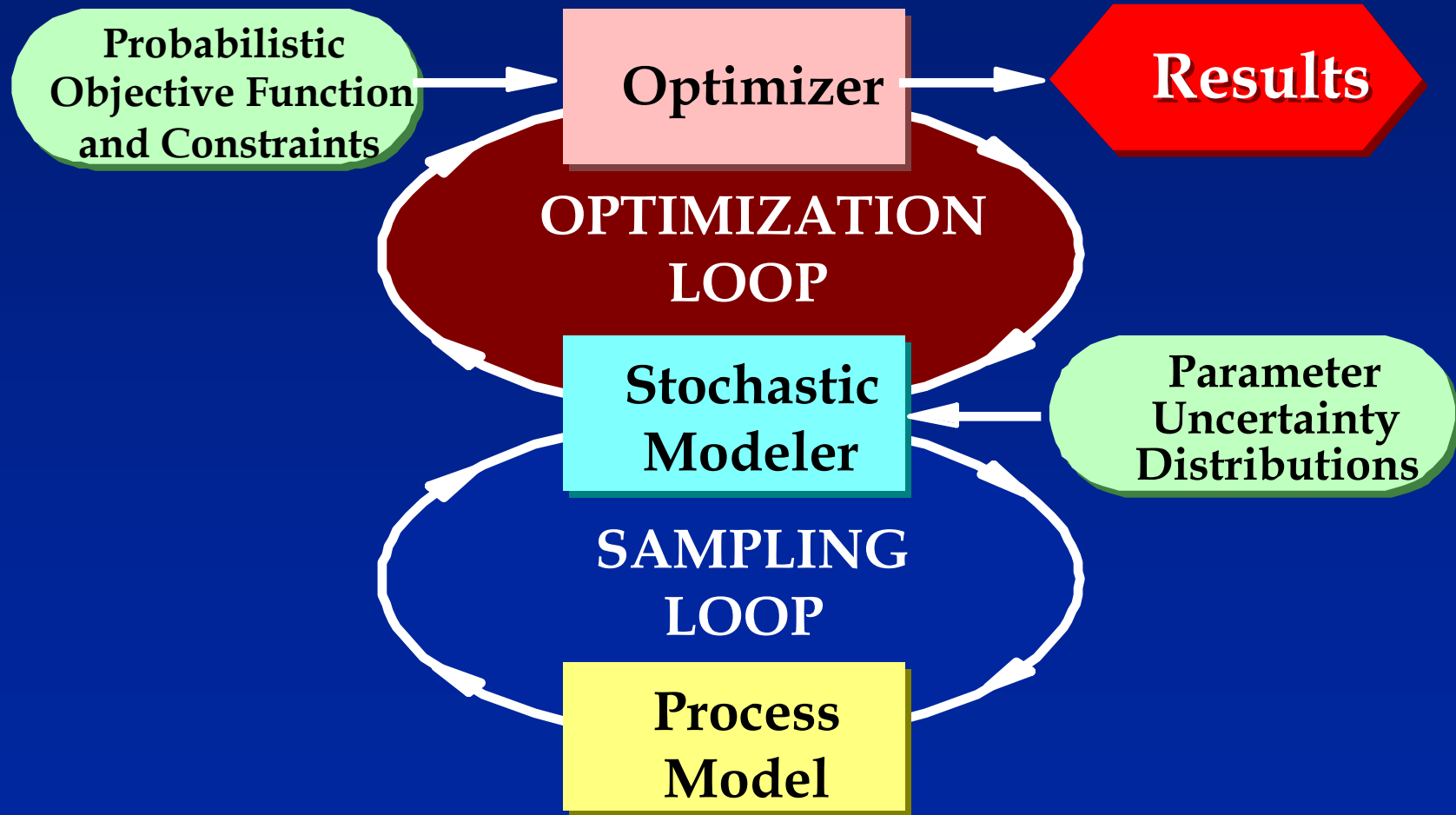
Some Questions Addressed by Stochastic Simulation

- What performance, emissions and cost can we expect given current uncertainties?
- What is the likelihood of performance shortfalls? Of cost overruns?
- What factors or process parameters contribute most to the overall uncertainty in performance and cost?
- How does this system or process compare to other competing technologies?
- What is the potential payoff of R&D to reduce the key uncertainties and risks?

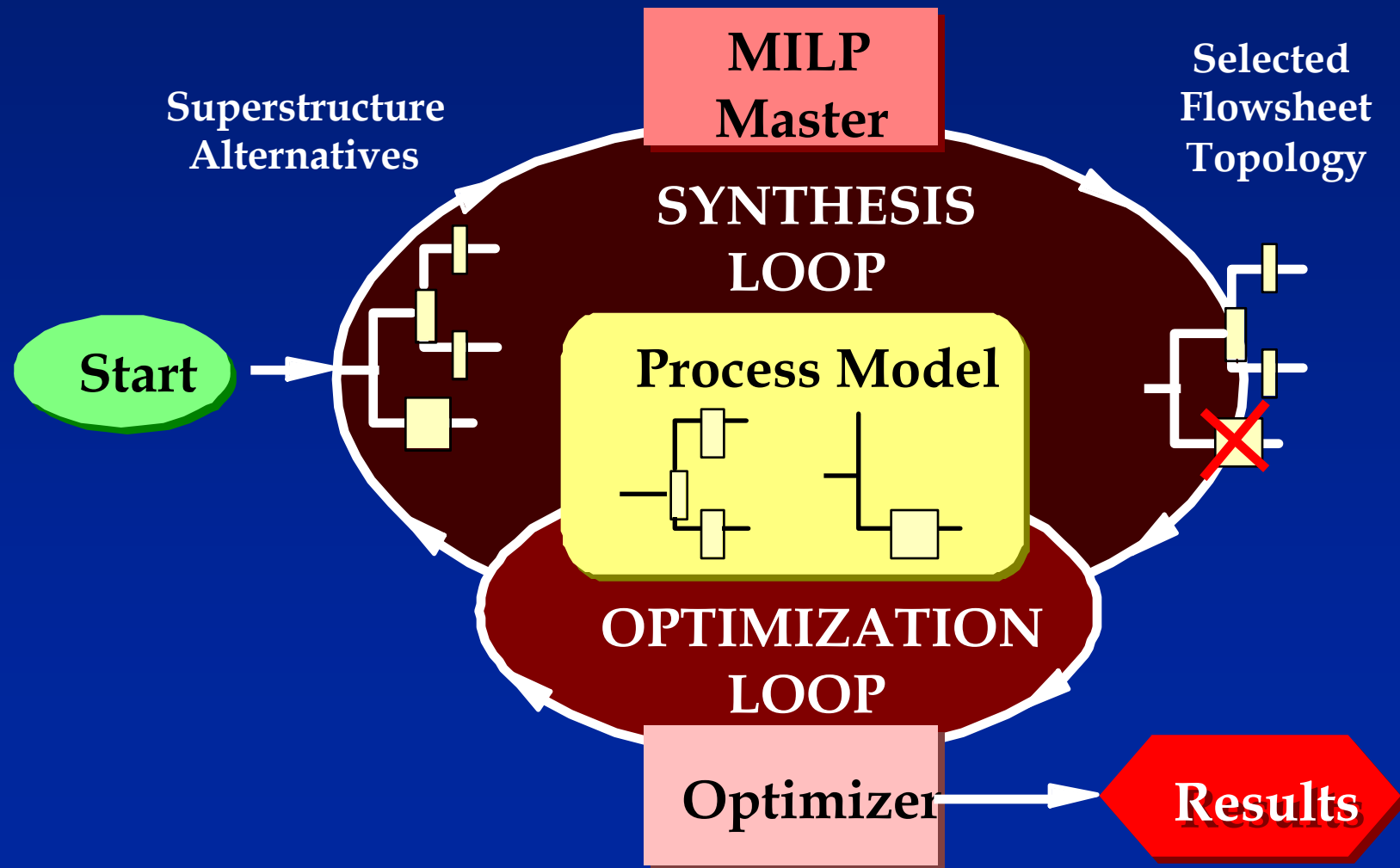
Value of Targeted Research in Reducing the Cost of an IGCC System



Stochastic Optimization



Process Synthesis



Some Questions Addressed by Optimization Capabilities

- Is there a better choice of parameter values for this process to improve its performance? To lower its cost?
- What levels of performance, emissions and cost can we expect from an optimized design?
- How do uncertainties in process performance and cost parameters affect the optimal design?
- What design choices will minimize the risk of a performance shortfall? Or the risk of a cost overrun?

Some Questions Addressed by Process Synthesis Capabilities

- How should the flowsheet be configured to achieve performance goals at lowest cost?
- What are the feasible flowsheet options to meet specified goals and constraints? Which options are not feasible?
- What are the cost savings (or performance and environmental gains) from moving to a more optimal design?

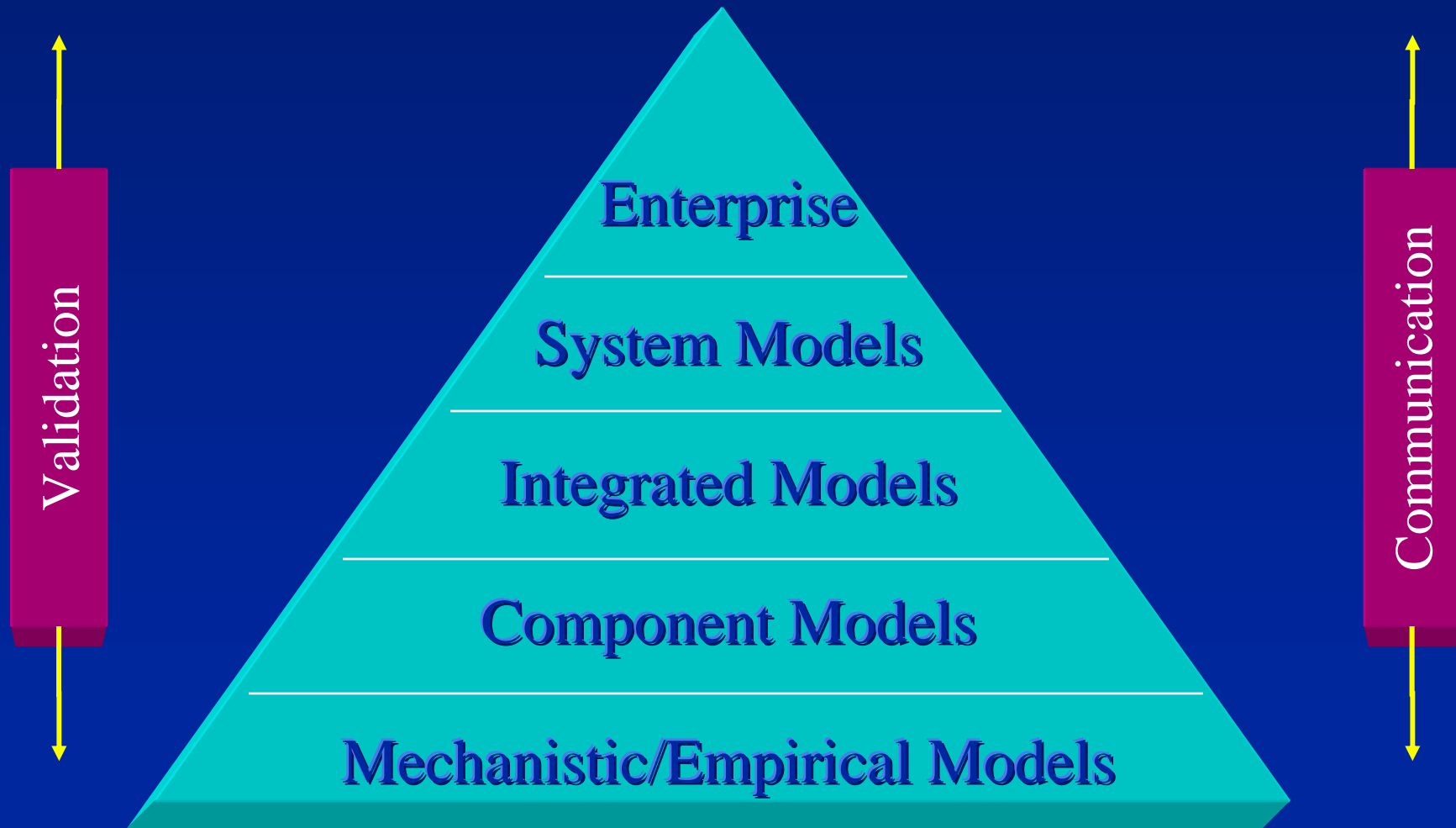
New Work in Progress

- Expansion of IECM modules
- Vision 21 systems analysis framework
(The Vision 21 Planner)

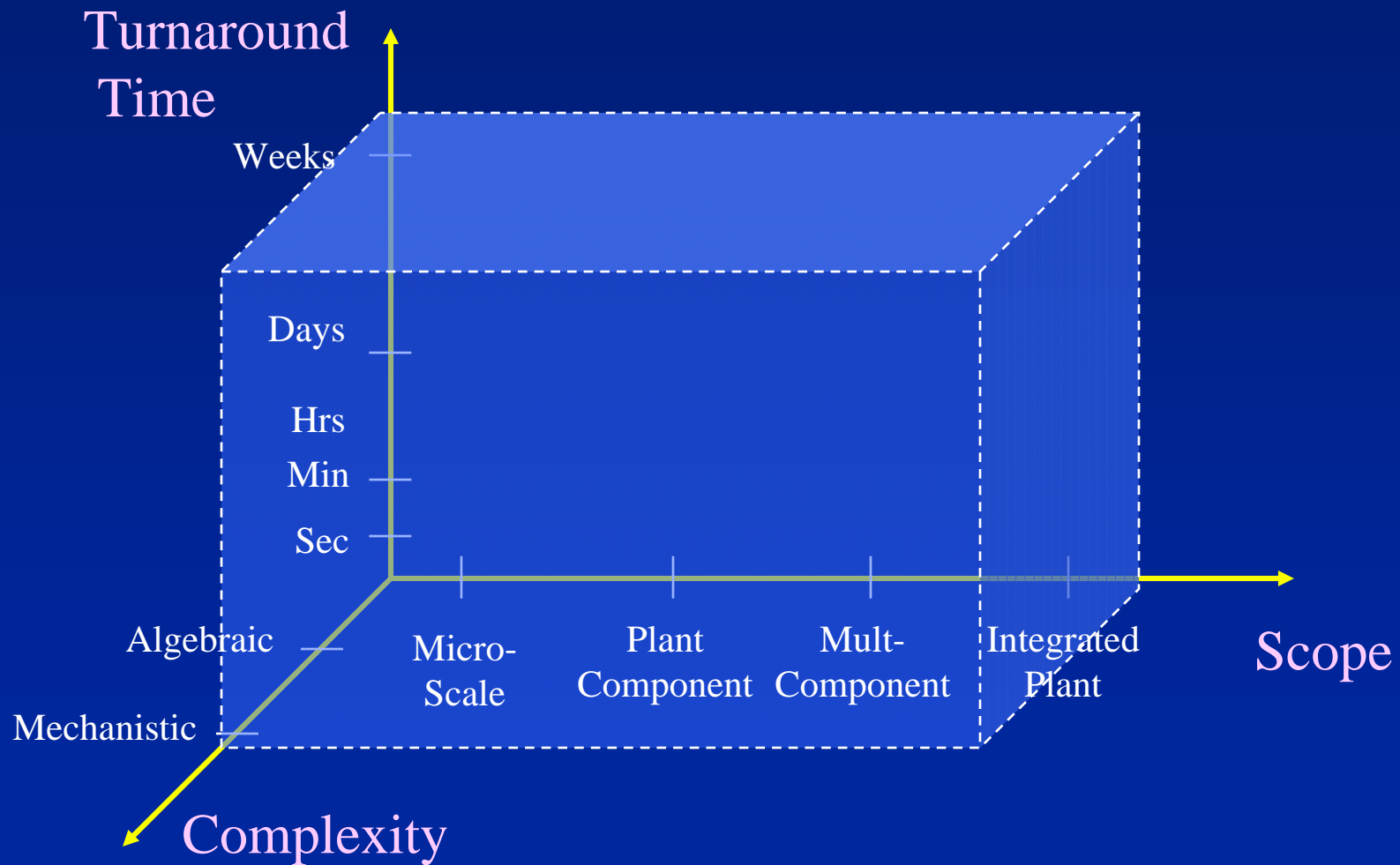
The Vision 21 Planner Would . . .

- Bring together a spectrum of performance and cost models for plant components and integrated systems, suitable for preliminary design and analysis
- Run quickly and easily on a desktop or laptop computer
- Use publically available software
- Allow new process concepts to be easily modeled
- Allow uncertainties to be characterized explicitly
- Facilitate selection of optimal (most promising) designs

A Hierarchy of Process Models



Attributes of Process Models

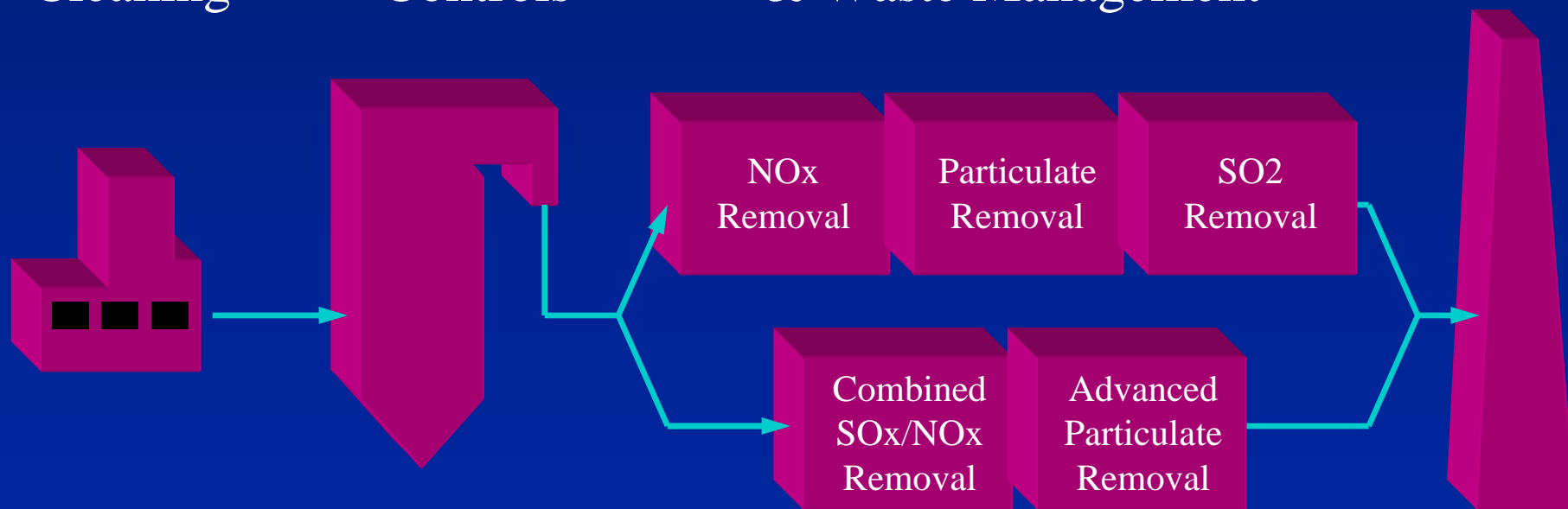


Integrated Environmental Control Model (IECM)

Coal
Cleaning

Combustion
Controls

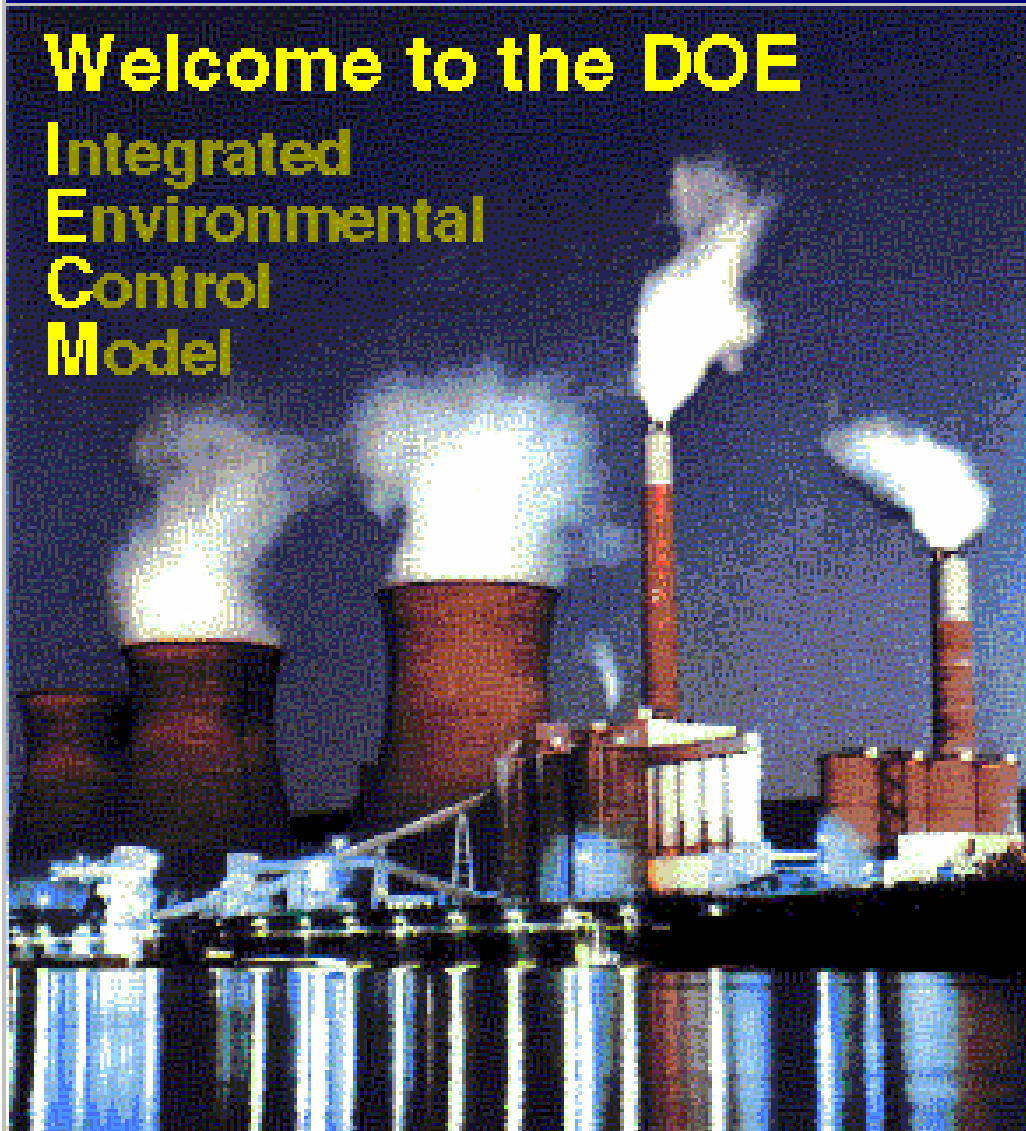
Flue Gas Cleanup
& Waste Management



About the IECM Interface



Welcome to the DOE Integrated Environmental Control Model

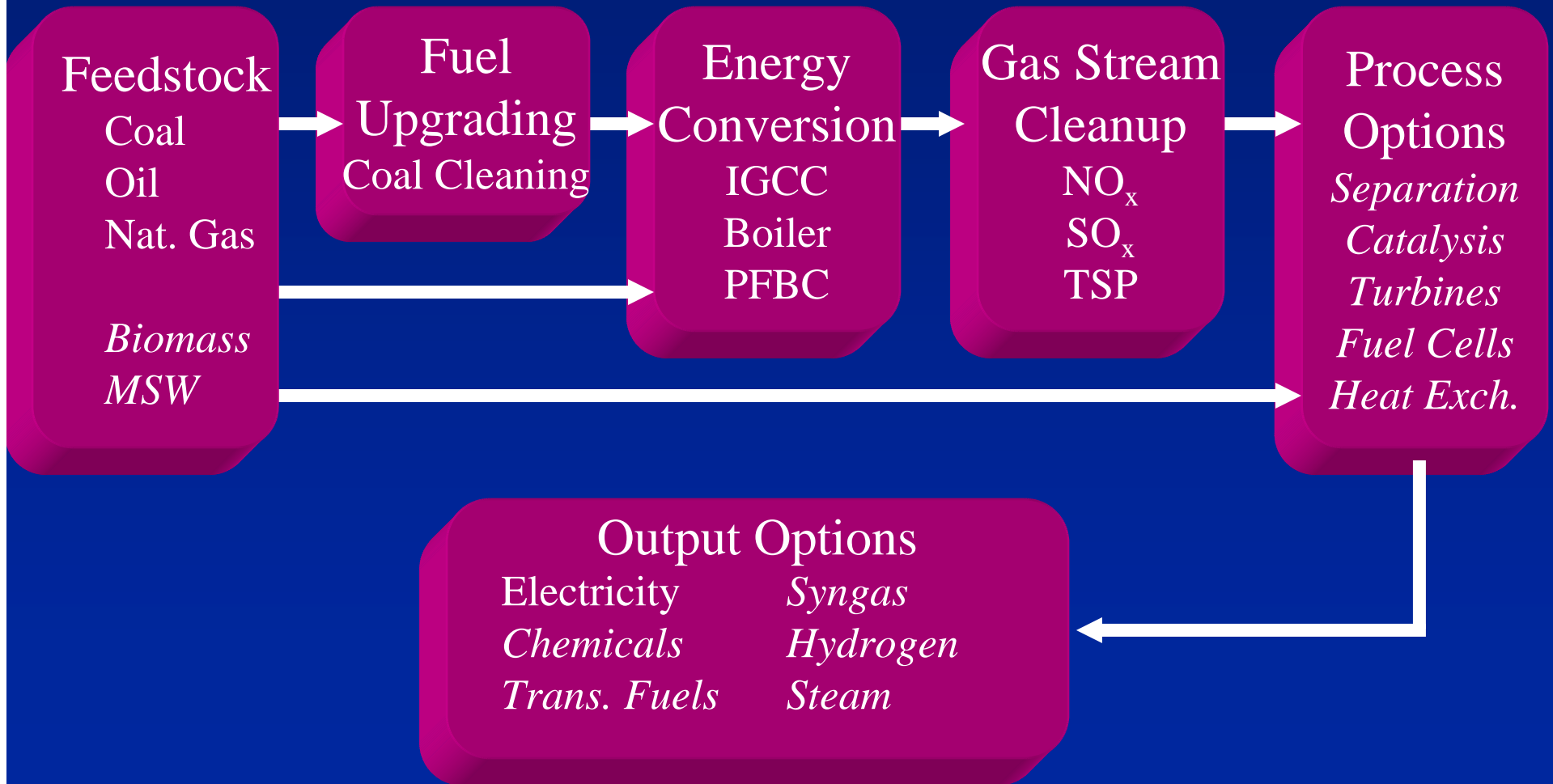


IECM 3.1 ©1999, Carnegie Mellon University

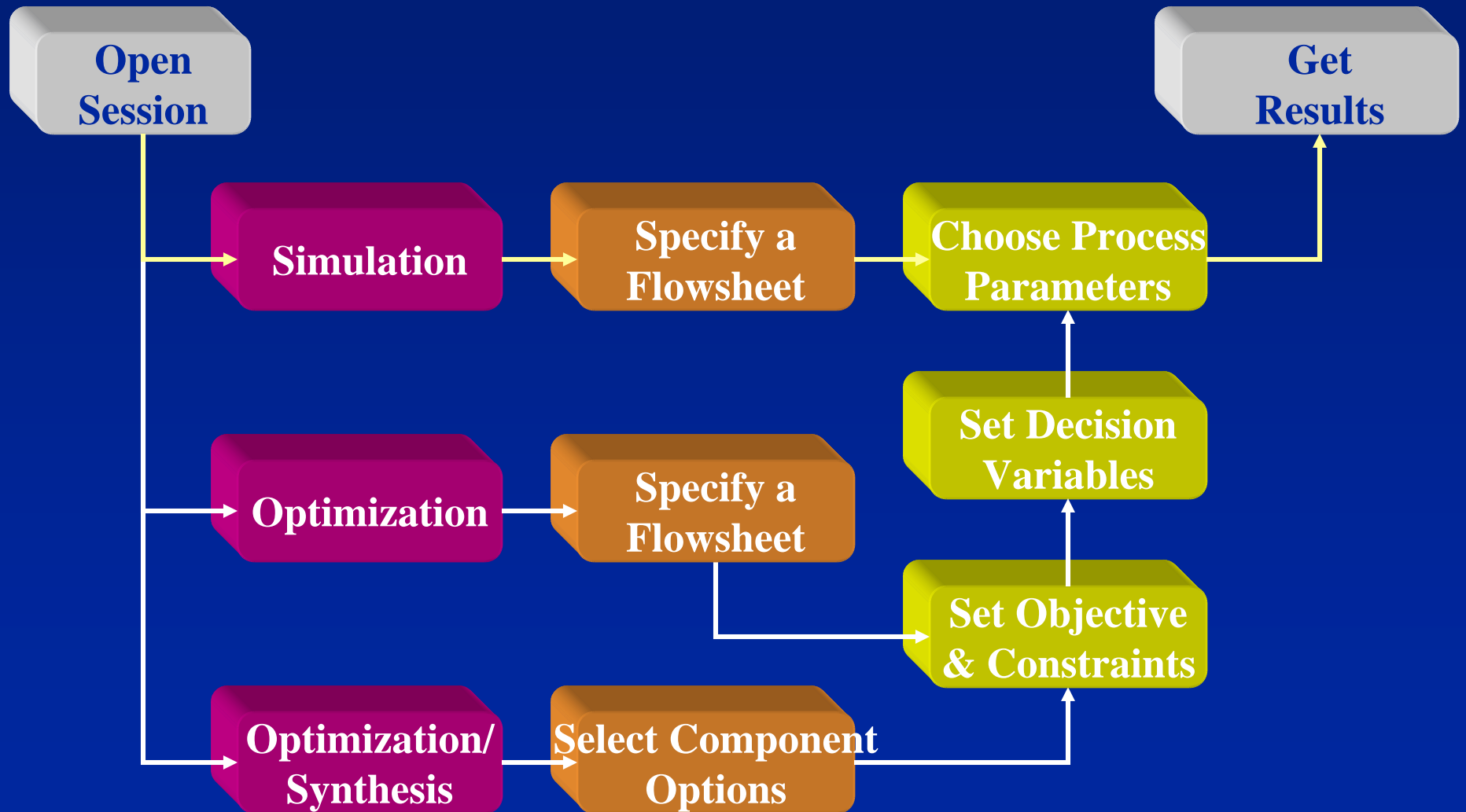
IECM Interface 3.1 ©1999, Carnegie Mellon University

(live demo of the IECM)

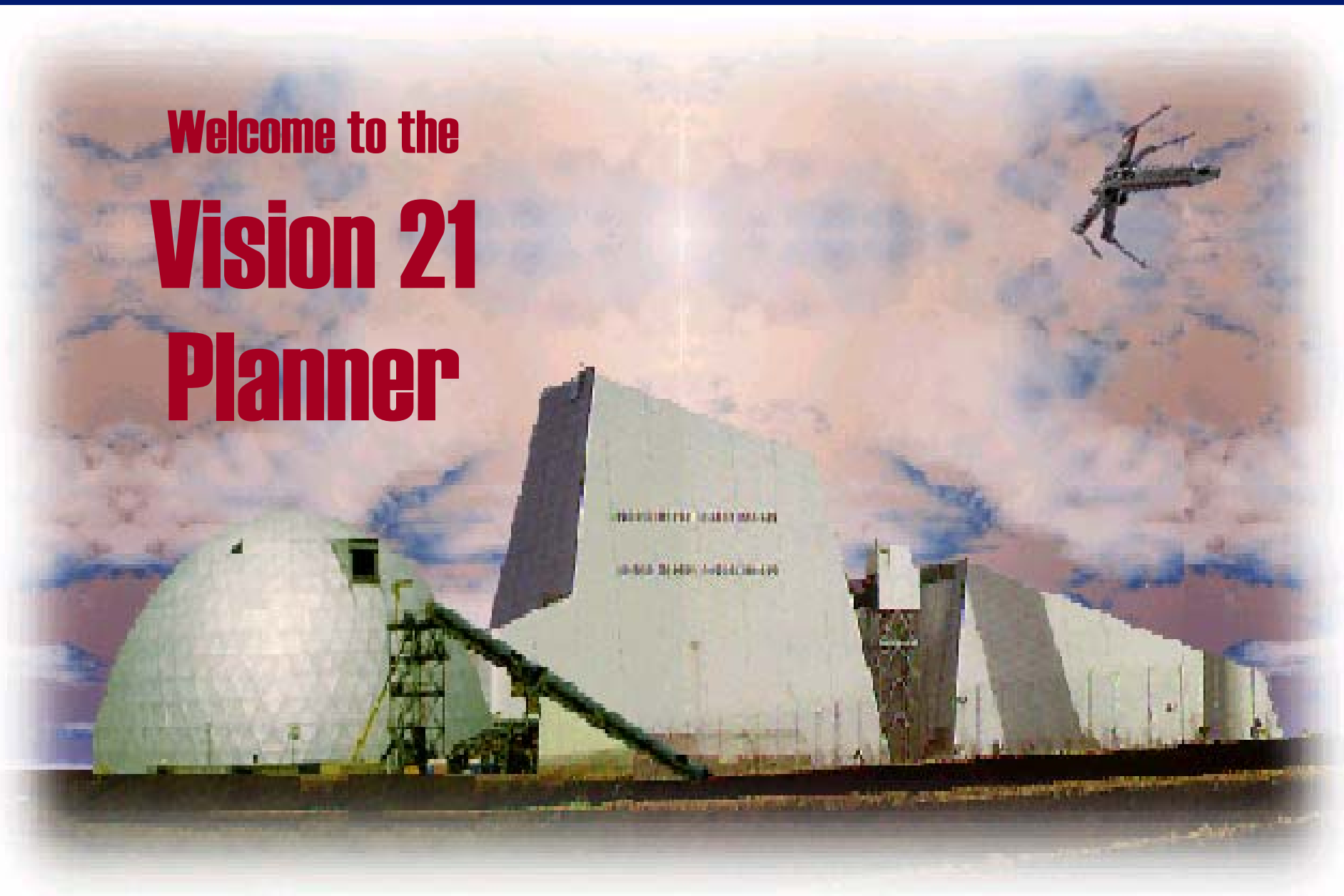
Schematic of the Proposed Vision 21 Planner



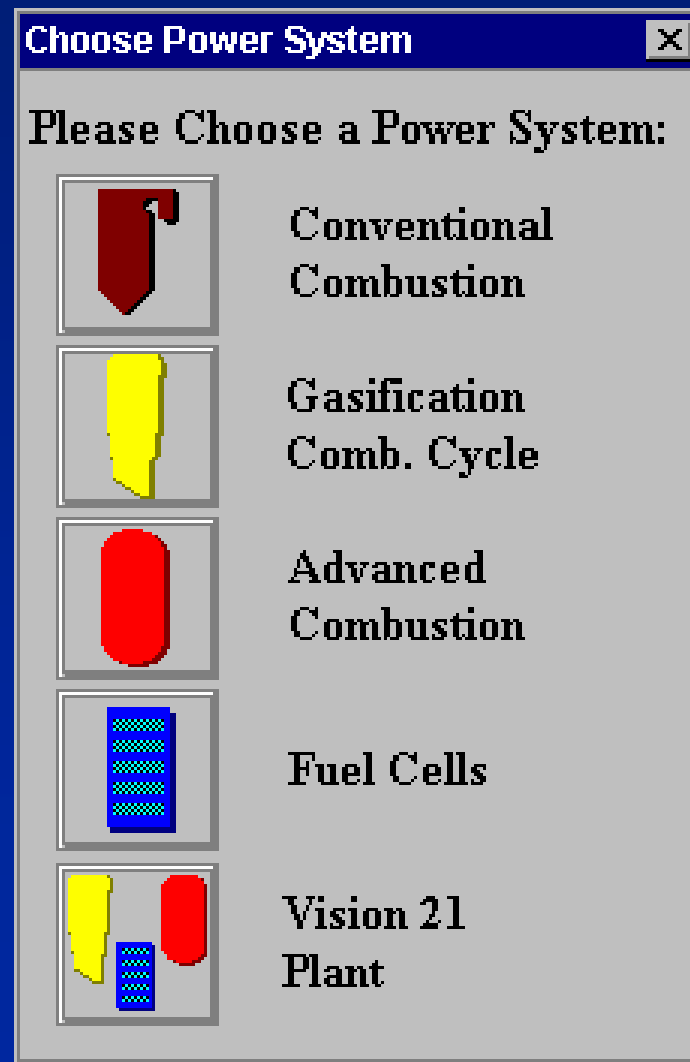
Vision 21 Planner: Operation Overview



Welcome to the
**Vision 21
Planner**



Opening Screen: A Menu of Technology Options

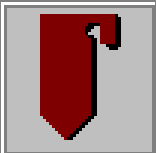
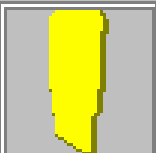
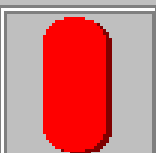
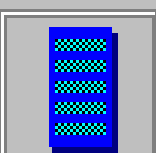
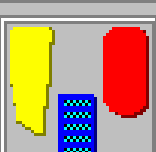


Select Gasification Combined Cycle (IGCC) Options



Choose Power System [X]

Please Choose a Power System:

	Conventional Combustion
	Gasification Comb. Cycle
	Advanced Combustion
	Fuel Cells
	Vision 21 Plant

Select KRW Gasifier

IECM Interface

File Edit View Window Help

Untitled

Configure Plant Set Objectives Set Parameters Get Results

Goal: Optimization

Gasification Options

Gasifier: KRW

Oxidant: KRW

Gas Cleanup: Lurgi
Texaco

Post-Combustion Controls

NOx Control: None

Solids Management

Slag: Landfill

Sulfur: Landfill

Plant Diagram

Ready NUM

Select Oxygen Plant

IECM Interface

File Edit View Window Help

Untitled

Configure Plant Set Objectives Set Parameters Get Results

Goal: Optimization

Gasification Options

Gasifier: KRW

Oxidant: Oxygen

Gas Cleanup: Air
Oxygen

Post-Combustion Controls

NOx Control: None

Solids Management

Slag: Landfill

Sulfur: Landfill

Plant Diagram

Ready NUM

Select Cold Gas Cleanup

IECM Interface

File Edit View Window Help

Untitled

Configure Plant Set Objectives Set Parameters Get Results

Goal: Optimization

Gasification Options

Gasifier: KRW

Oxidant: Oxygen

Gas Cleanup: Cold

Post-Combustion: Cold

NOx Control: None

Solids Management

Slag: Landfill

Sulfur: Landfill

Plant Diagram

The plant diagram illustrates a gasification process. It starts with a feed stream entering a gasifier (yellow vertical cylinder). From the gasifier, a gas stream goes to a gas cleanup unit (red horizontal cylinder), and a solid stream goes to a slag handling unit (yellow horizontal cylinder). The cleaned gas then passes through a post-combustion unit (pink horizontal cylinder). The gas then goes to a heat exchanger (blue vertical cylinder with a zigzag line), which preheats the feed gas. The gas then goes to a turbine (green trapezoid) and a compressor (green trapezoid). The final gas product is shown as a green gas stream entering a storage tank (green cylinder). The compressor output goes to a sulfur recovery unit (red circle with an 'S').

Ready NUM

Select NO_x Control

IECM Interface

File Edit View Window Help

Untitled

Configure Plant Set Objectives Set Parameters Get Results

Goal: Optimization

Gasification Options

Gasifier: KRW

Oxidant: Oxygen

Gas Cleanup: Cold

Post-Combustion

NO_x Control: SCR
None
SCR

Solids Management

Slag: Landfill

Sulfur: Landfill

Plant Diagram

The plant diagram illustrates a gasification process. It starts with a feed stream entering a yellow gasifier. From the gasifier, a gas stream goes to a red gas cleanup unit, and a solid stream goes to a yellow slag handling unit. The cleaned gas then passes through a pink combustion chamber. The combustion chamber output goes to a blue heat exchanger, which preheats the feed. The cooled gas then goes to a green turbine, which produces power (indicated by a green lightning bolt). The turbine exhausts gas to a green scrubber, which produces a sulfur stream (indicated by a red 'S' in a circle) and a final gas stream (indicated by a green lightning bolt).

Ready NUM

Select Byproduct Recovery

IECM Interface

File Edit View Window Help

Untitled

Configure Plant Set Objectives Set Parameters Get Results

Goal: Optimization

Gasification Options

Gasifier: KRW

Oxidant: Oxygen

Gas Cleanup: Hot

Post-Combustion Controls

NOx Control: SCR

Solids Management

Slag: Landfill

Sulfur: Sulfur
Landfill
Sulfur
Sulfuric Acid

Plant Diagram

The plant diagram illustrates a gasification process. It starts with a blue gasifier on the left, which feeds into a yellow gasifier. The output of the yellow gasifier goes to a red scrubber. From the scrubber, the gas goes to a pink sulfur recovery unit. The sulfur recovery unit has a green recycling symbol below it, indicating a byproduct recovery stream. The gas then goes to a blue scrubber, which feeds into a green sulfur recovery unit. The final product is a red circle with a white 'S', representing sulfur. There are also arrows pointing to a black triangle (top) and a green bottle (right).

Ready NUM

Set Process Parameters

IECM Interface

File Edit View Window Help

Untitled

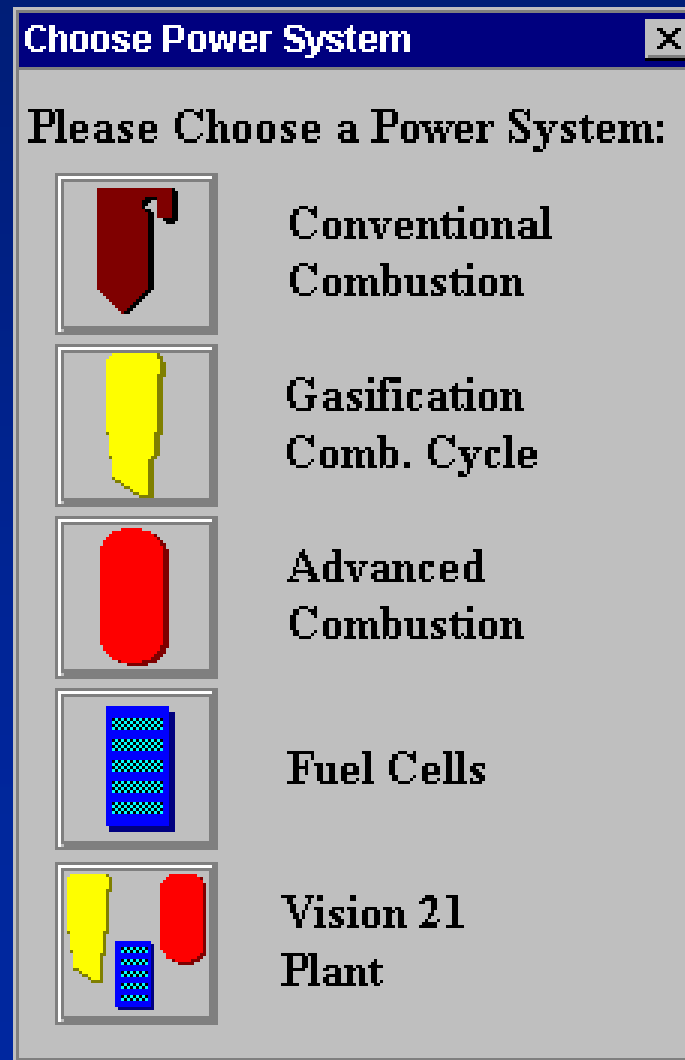
Configure Plant **Set Parameters** Get Results

Overall Plant Coal Properties **IGCC** Furnace Factors Emission Constraints NOx Control Particulate Control SO2 Control Solid Waste Mgmt

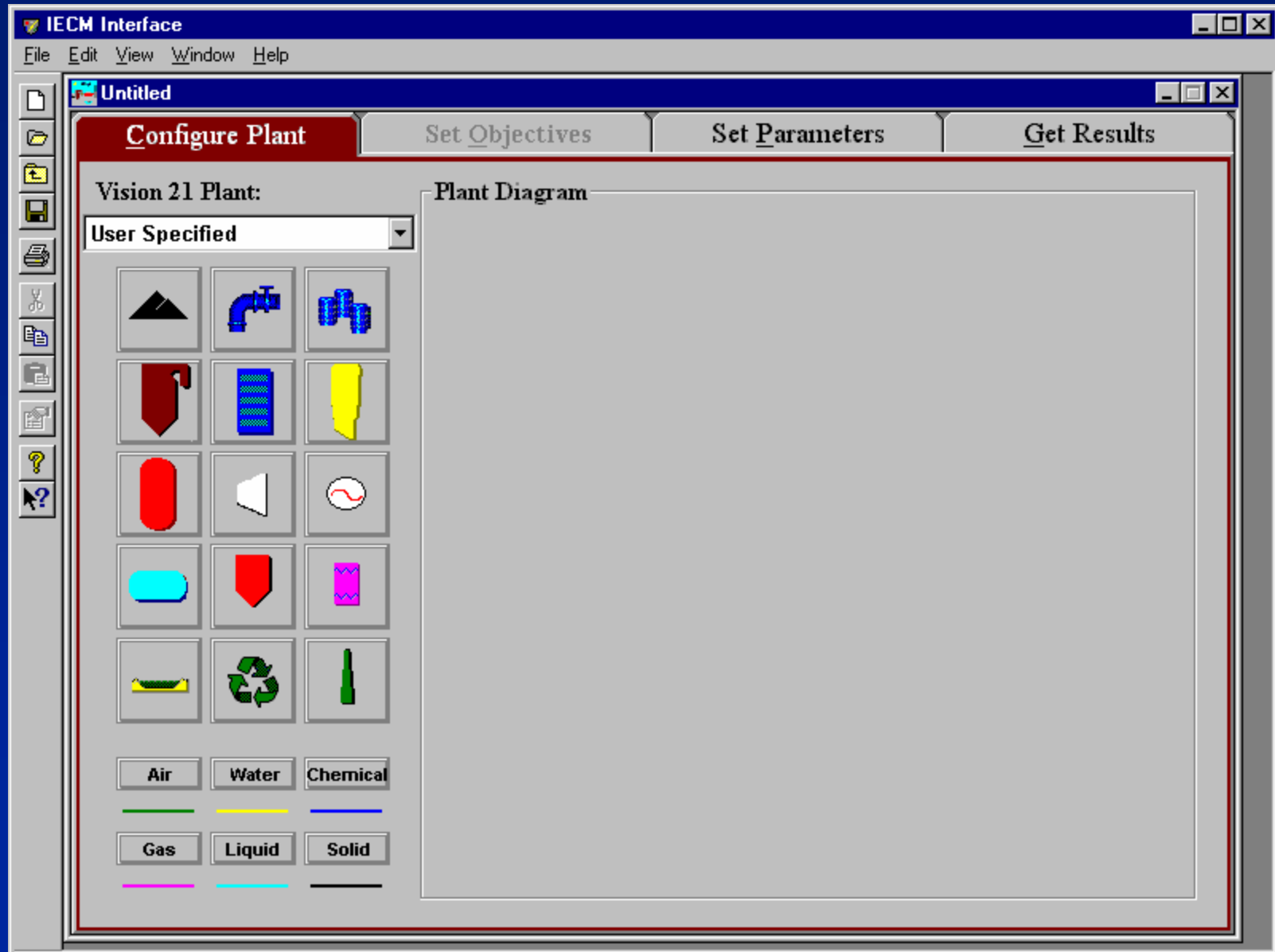
	Title	Units	Unc	Value	Calc	Min	Max	Default	DV
1	<u>Gasifier Design</u>								
2	Gasifier Carbon Conversion	%		95.0		90.0	98.0	95.0	
3	Gasifier Oxygen to Carbon Ratio	mol O2 / mol C		0.46		0.45	0.47	0.46	
4	Gasifier Steam to Carbon Ratio	mol H2O / mol C		0.46		0.445	0.455	0.46	
5	Coal-bound N Converted 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	<u>Emissions Control</u>								
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

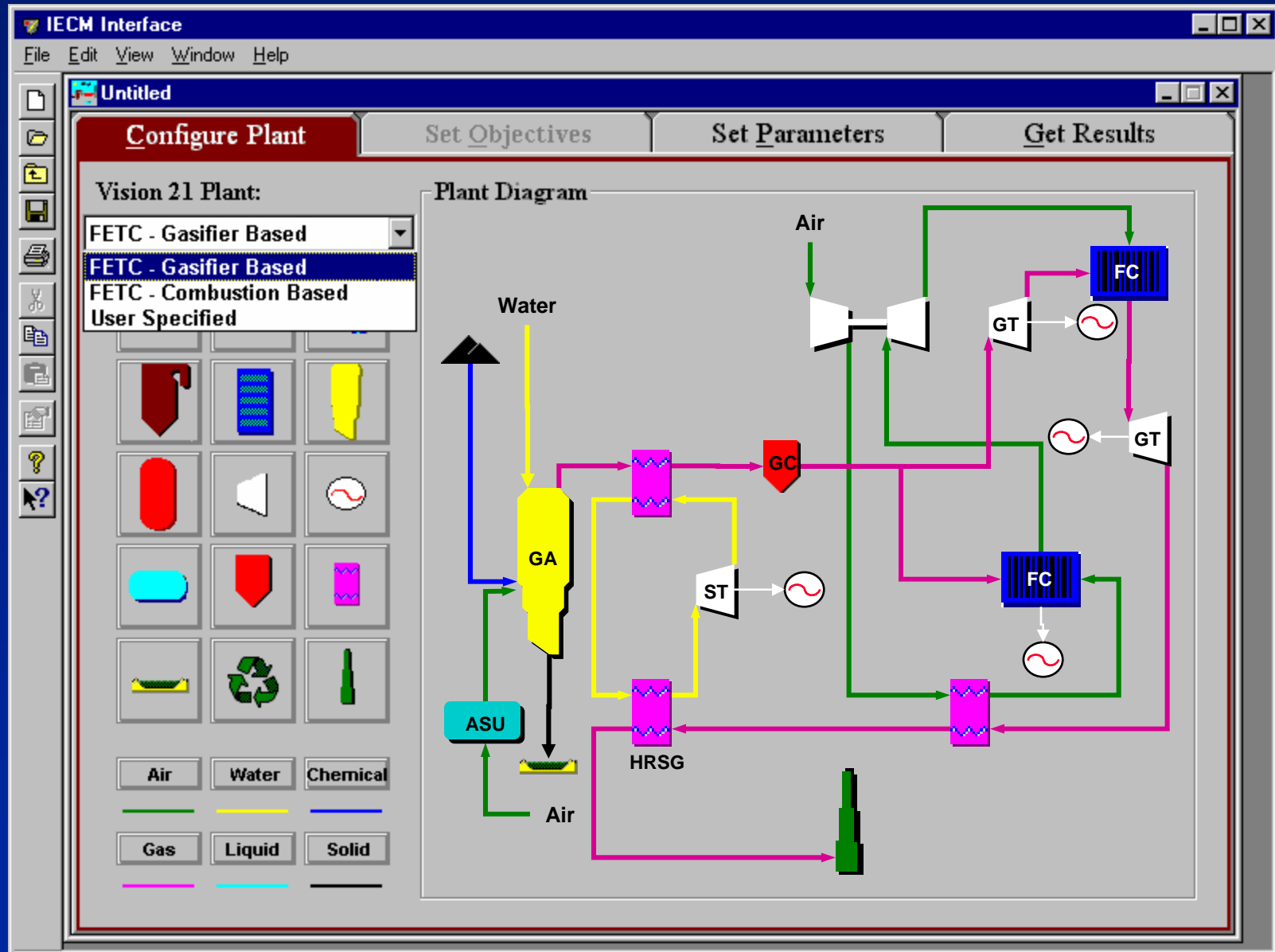
Open Vision 21 Plant Options



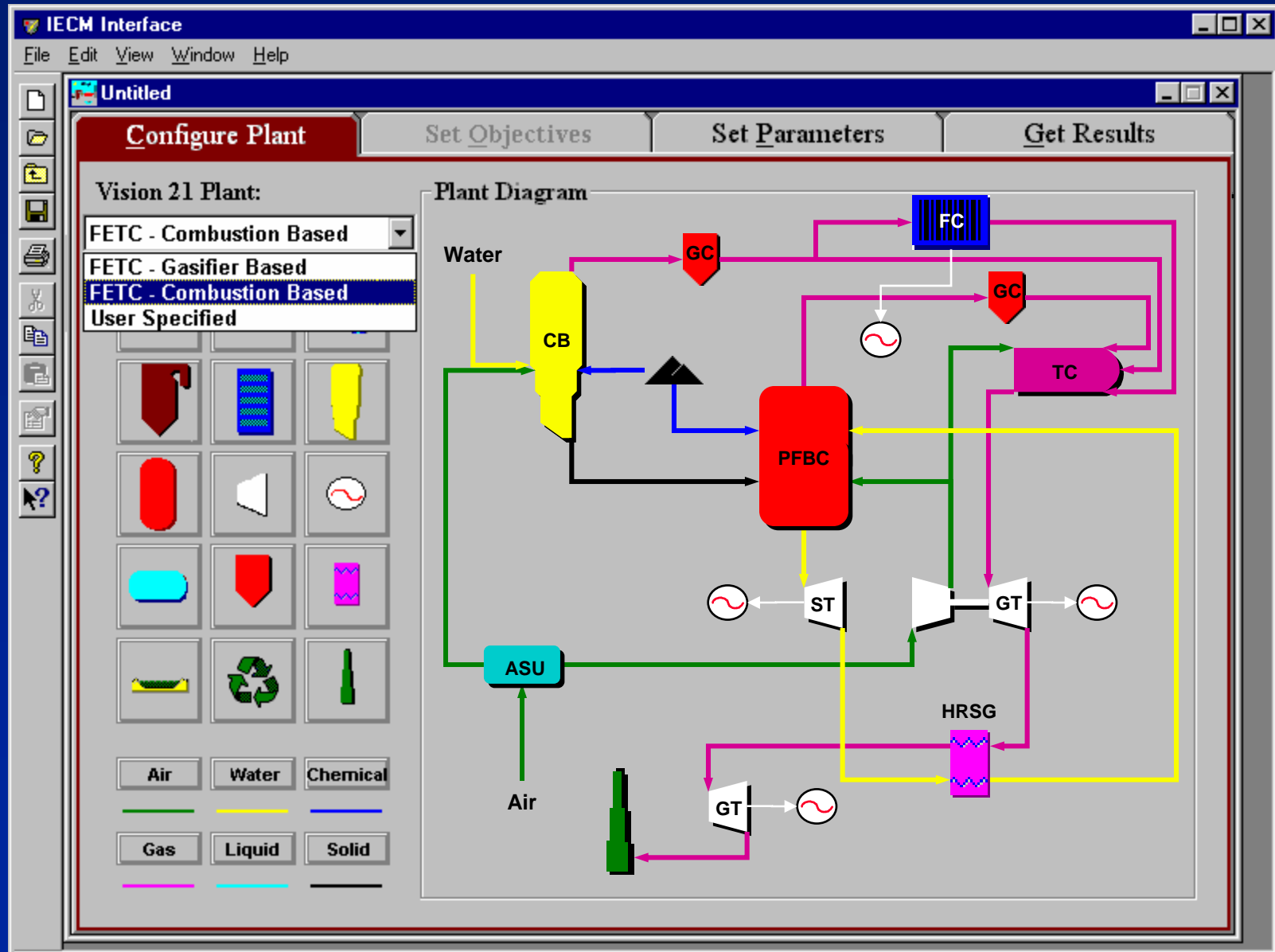
Vision 21 Workbench



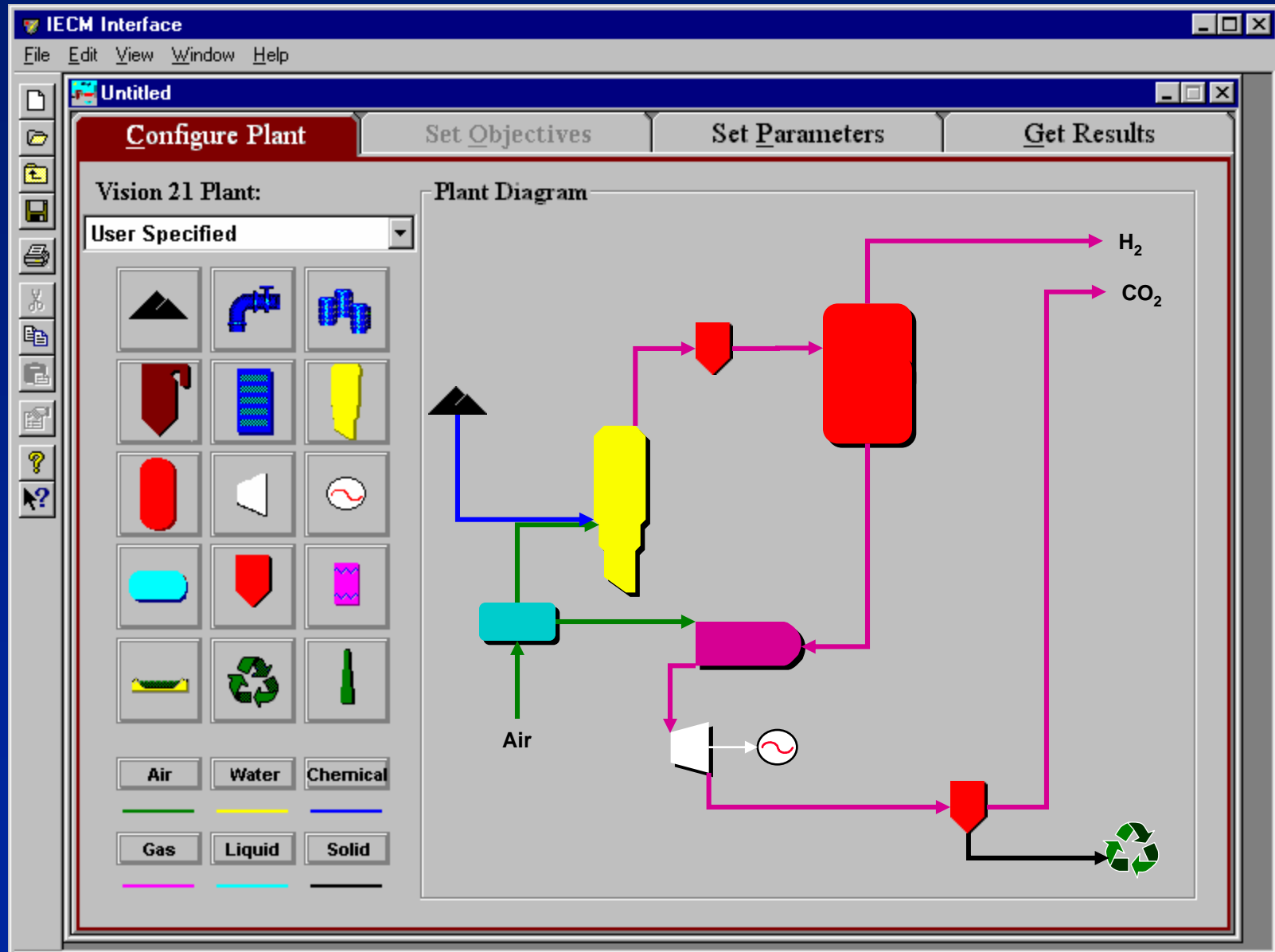
Select Existing Flowsheet - 1



Select Existing Flowsheet - 2



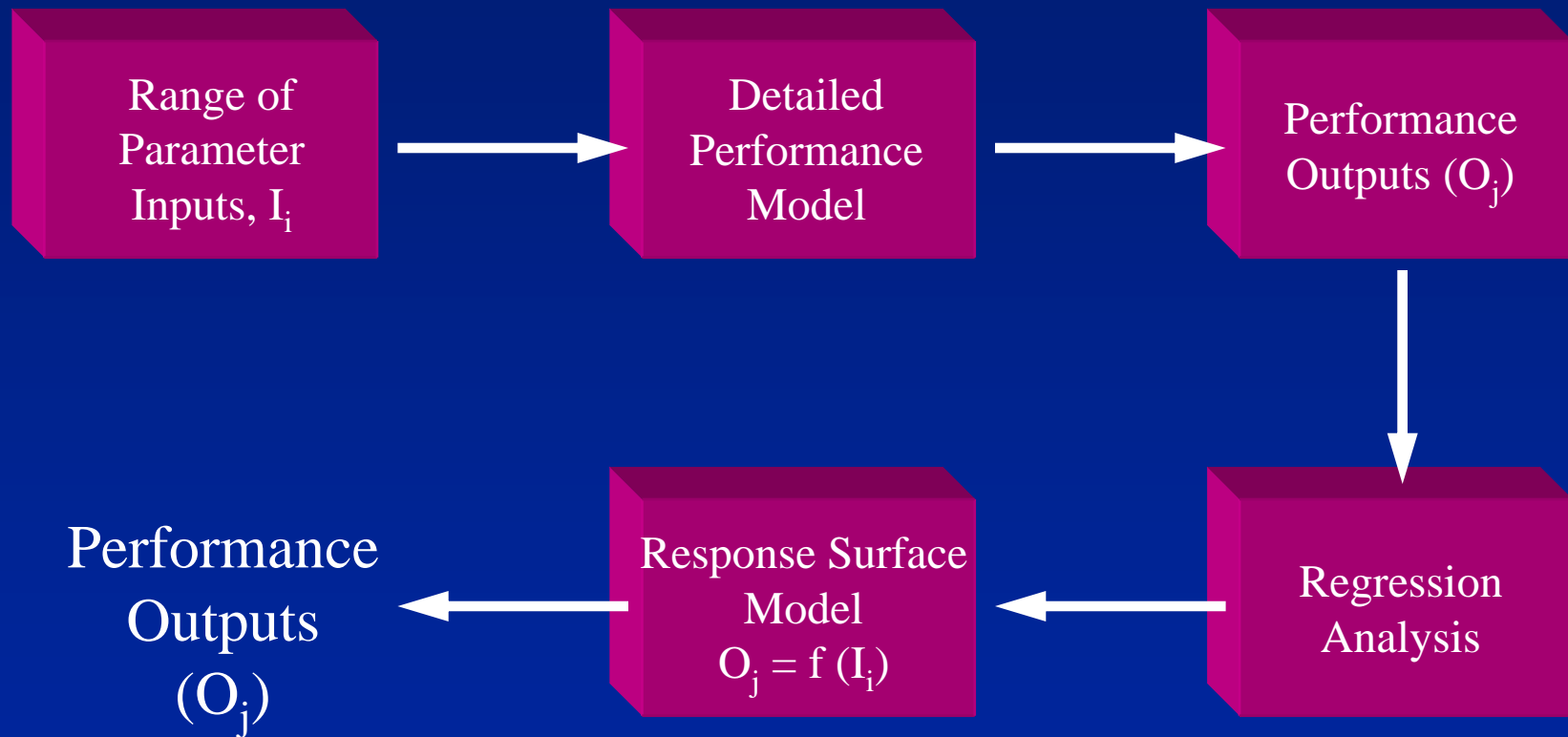
Configure a New System



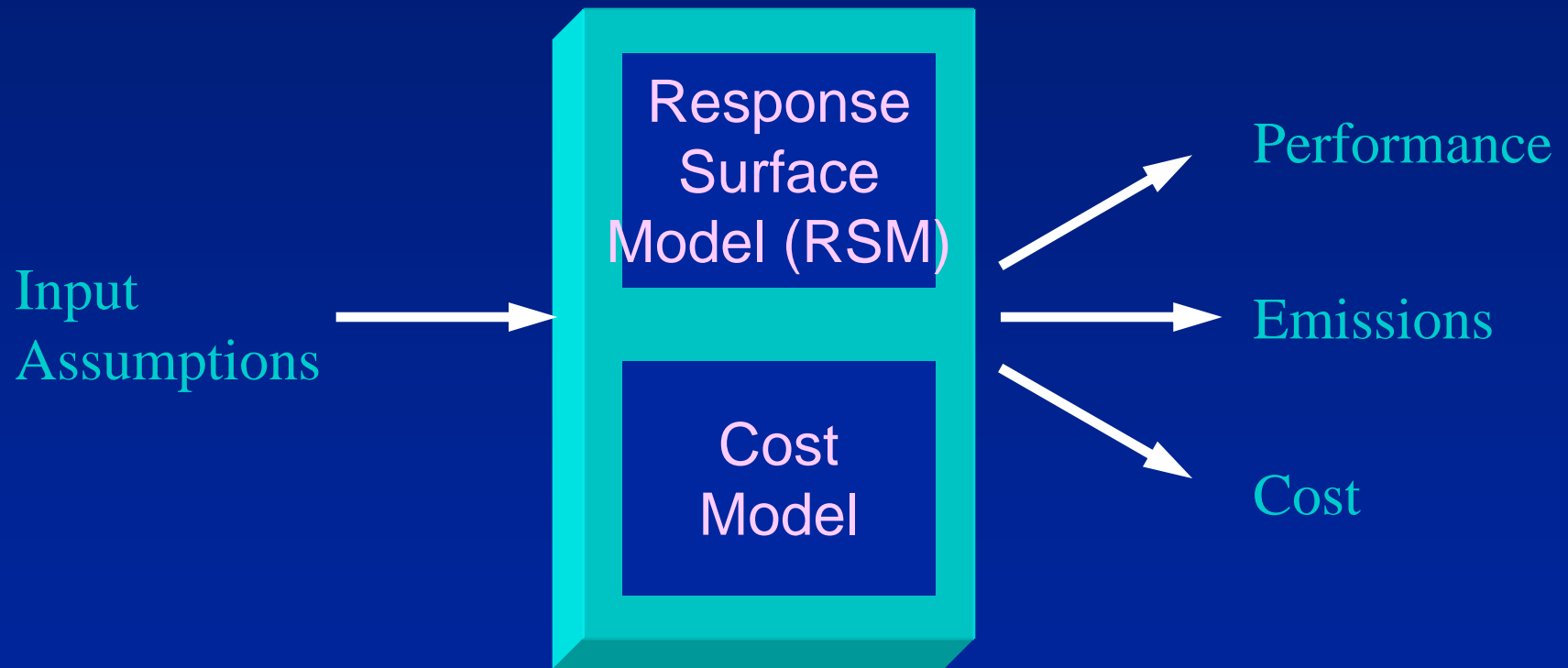
Linkage to More Detailed Process Models

- Where appropriate, use a Response Surface Model (RSM) to faithfully reproduce the results of a more detailed process model
- Captures effect of key process design variables
- Serves as a validation tool for desktop models
- Substantially reduces computational requirements and turnaround time

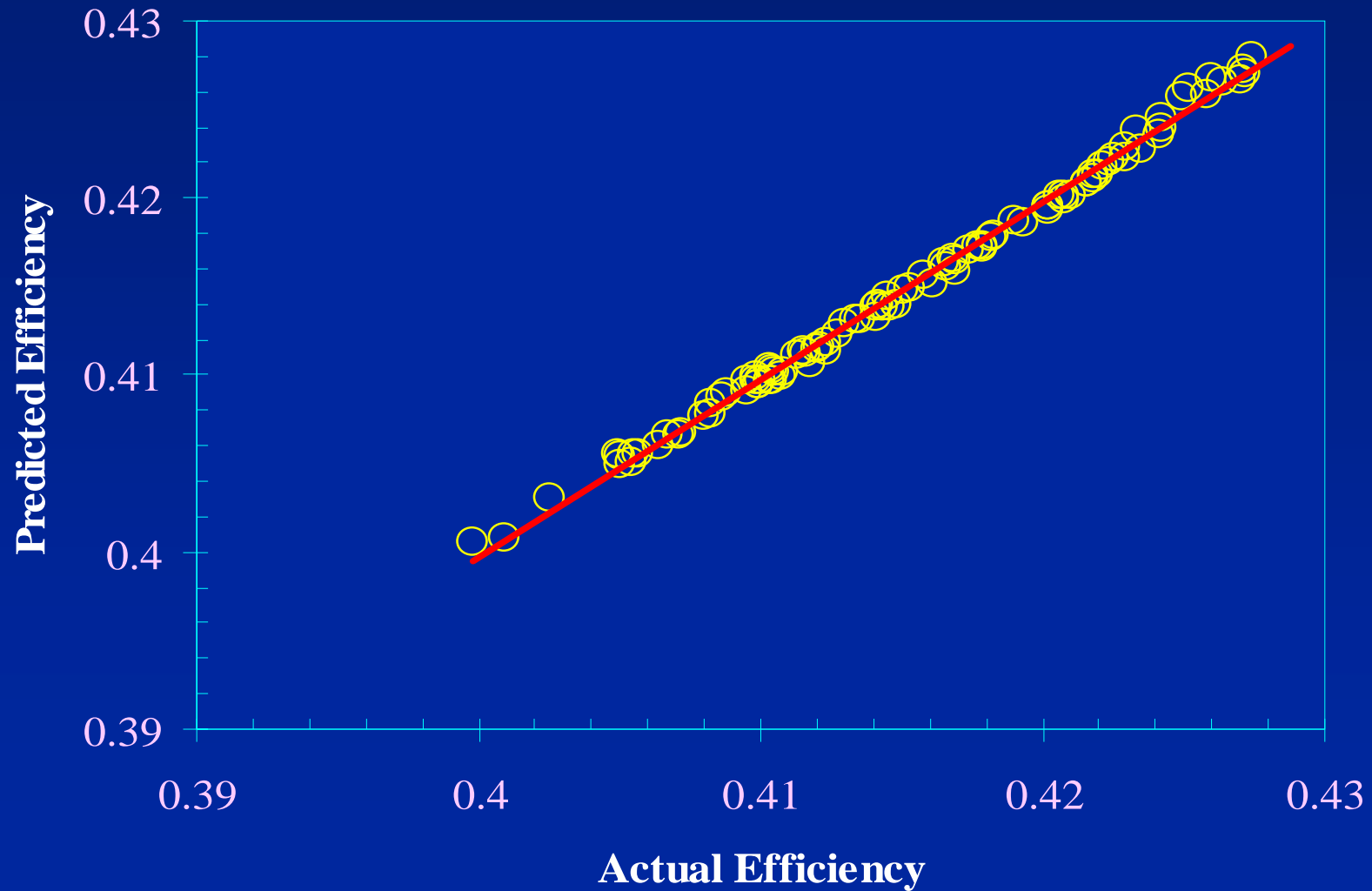
Response Surface Model Development



Desktop Model of a Process



Evaluation Of Desktop Model: IGCC Plant Efficiency



Benefits of Desktop Models

- Precise and accurate representation of detailed models
- Execution takes seconds, not hours
- Can run on any desktop PC
- Amenable to “what if” analyses
- Incorporates process performance, emissions, and cost models in one package
- Useful by analysts and decision makers who have no time, ability or resources (staff, software, hardware, funds) to run complex models

Model Applications

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

Where Do We Go from Here?

- Current project will implement and demonstrate:
 - Response surface models of several IGCC system configurations
 - Process optimization capability
- Further development would:
 - Use the Vision 21 Planner as a testbed for systems integration development
 - Add preliminary versions of enabling technology models
 - Add process synthesis capability
 - Explore system dynamics modeling

So, What Do You Think?