The IECM:
A Plant-Level Simulation Model for Evaluating CO_2 Capture Options

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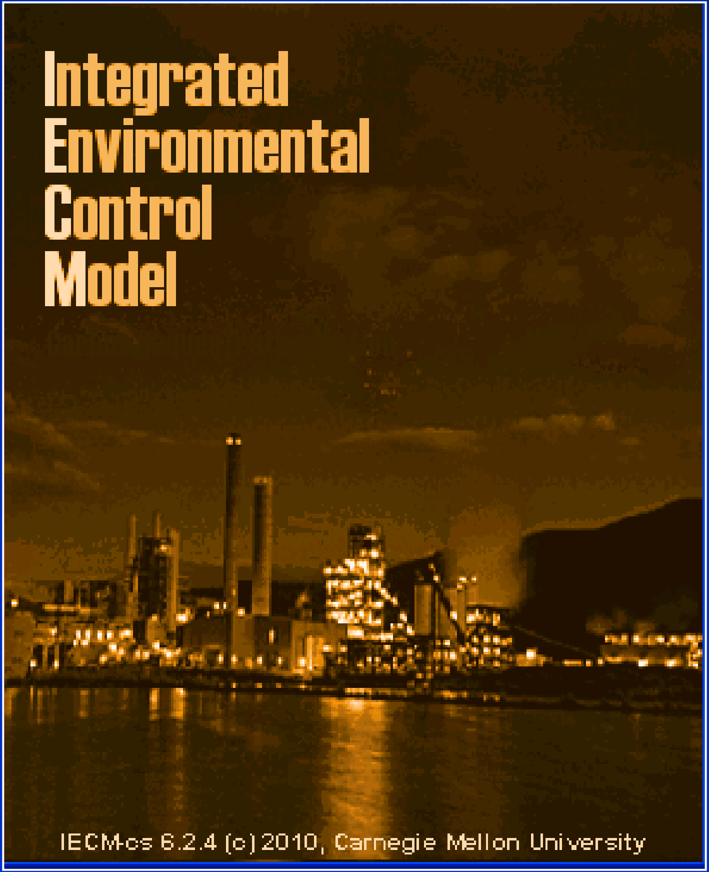
Outline

- Brief overview of the IECM
- Highlights of new model capabilities
- Illustrative applications
- Planned future enhancements

IECM Overview

The IECM:
Integrated Environmental Control Model

- A desktop/laptop computer model developed for DOE/NETL; free and available at: **www.iecm-online.com**
- Provides systematic estimates of performance, emissions, costs and uncertainties using user-specified designs and parameter values for:
  - PC, IGCC and NGCC plants
  - All flue/fuel gas treatment systems
  - CO_2 capture and storage options (pre- and post-combustion, oxy-combustion; transport, storage)



Modeling Approach

- Systems Analysis Approach
- Process Performance Models
- Engineering Economic Models
- Advanced Software Capabilities
  - Probabilistic analysis capability
  - User-friendly graphical interface
  - Built-in graphs/charts capability
  - Easy to add or update models

IECM Software Package

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

Power Plant Models

Graphical User Interface

Plant and Fuel Databases

Plant & Process Performance
- Efficiency
- Resource use

Environmental Emissions
- Air, water, land

Plant & Process Costs
- Capital
- O&M
- COE

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IECM Technologies for PC Plants

(excluding CO_2 capture, transport and sequestration)

Boiler Types
- Subcritical
- Supercritical
- Ultra-supercritical

Furnace Firing Types
- Tangential
- Wall
- Cyclone

Furnace NO_x Controls
- LNB
- SNCR
- SNCR + LNB
- Gas reburn

NO_x Removal
- Hot-side SCR
- Combined SO_2/NO_x systems

Mercury Removal
- Carbon/sorbent injection

Particulate Removal
- Cold-side ESP
- Fabric filter
  - Reverse Air
  - Pulse Jet

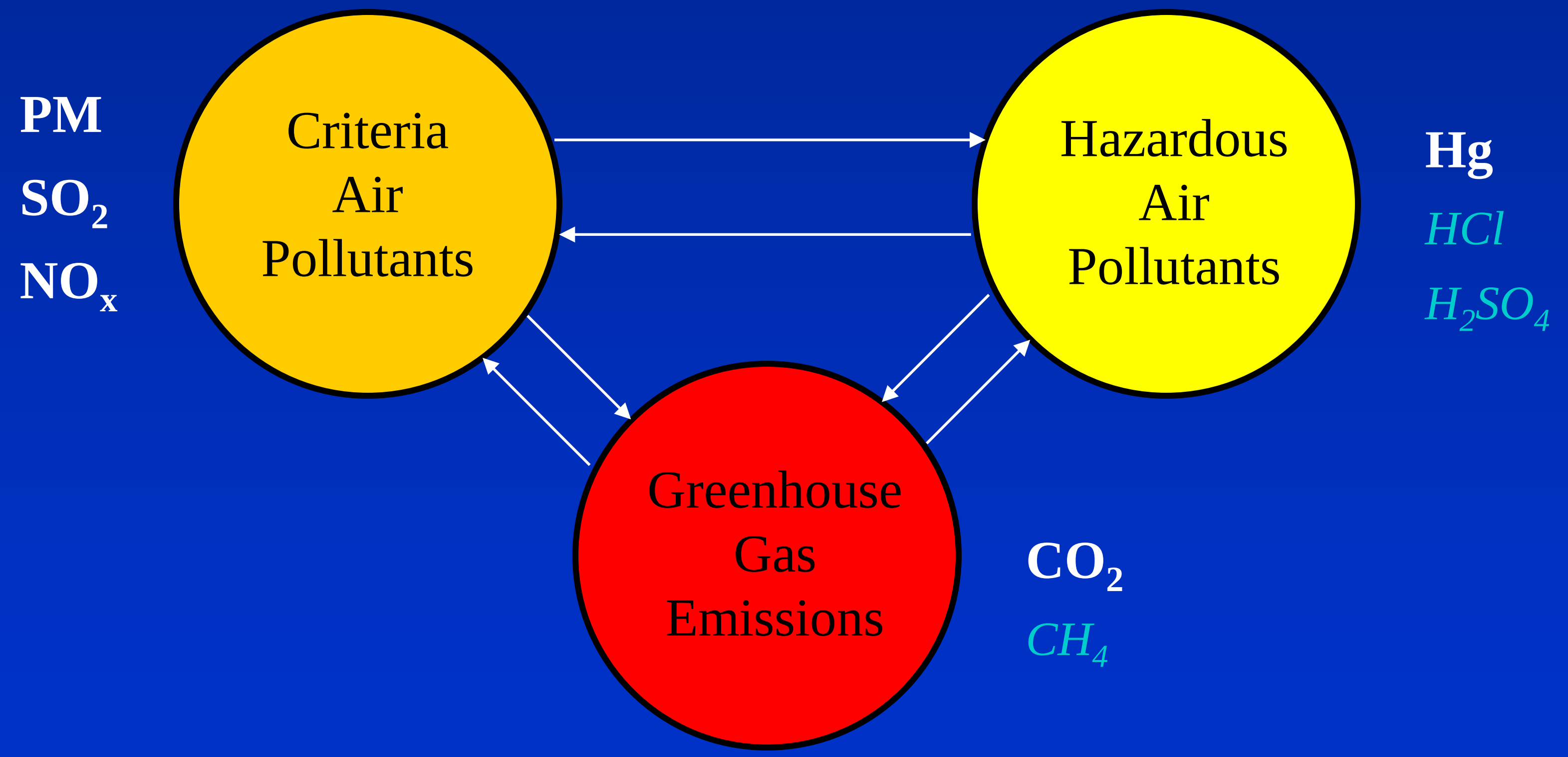
SO_2 Removal
- Wet limestone
  - Conventional
  - Forced oxidation
  - Additives
- Wet lime
- Lime spray dryer
- Combined SO_2/NO_x systems

Solids Management
- Ash pond
- Landfill
- Stacking
- Co-mixing
- Byproducts

IECM Technologies for CCS

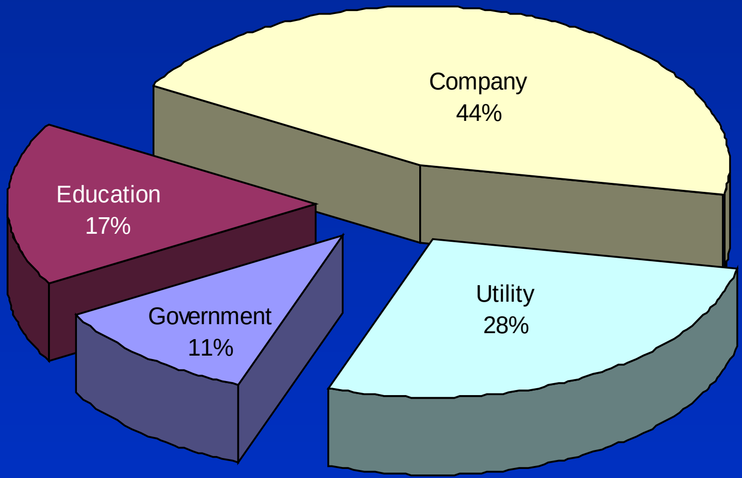
- CO_2 Capture Options
  - *PC Plants:* - Amine systems (post-combustion) (w/optional aux. NG boiler)
    - Oxyfuel combustion w/ flue gas recycle
  - *NGCC Plants:* - Amine systems (post-combustion)
  - *IGCC Plants:* - Water gas shift + CO_2 capture (pre-combustion)
- CO_2 Transport Options
  - Pipelines (six U.S. regions)
  - Other (user-specified)
- CO_2 Sequestration Options
  - Geological: Enhanced Oil Recovery (EOR)
  - Geological: Deep Saline Formation
  - Others (user-specified): ECBM; Ocean

Models Account for Multi-Pollutant Interactions



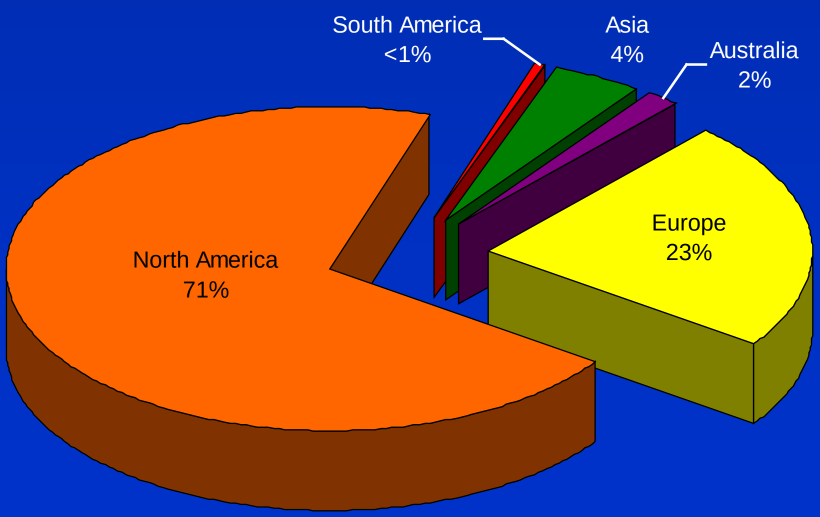
Profile of Recent IECM Users

Type of Organization



~ 500 organizations

Geographic Region



Model Applications

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

Recent Developments

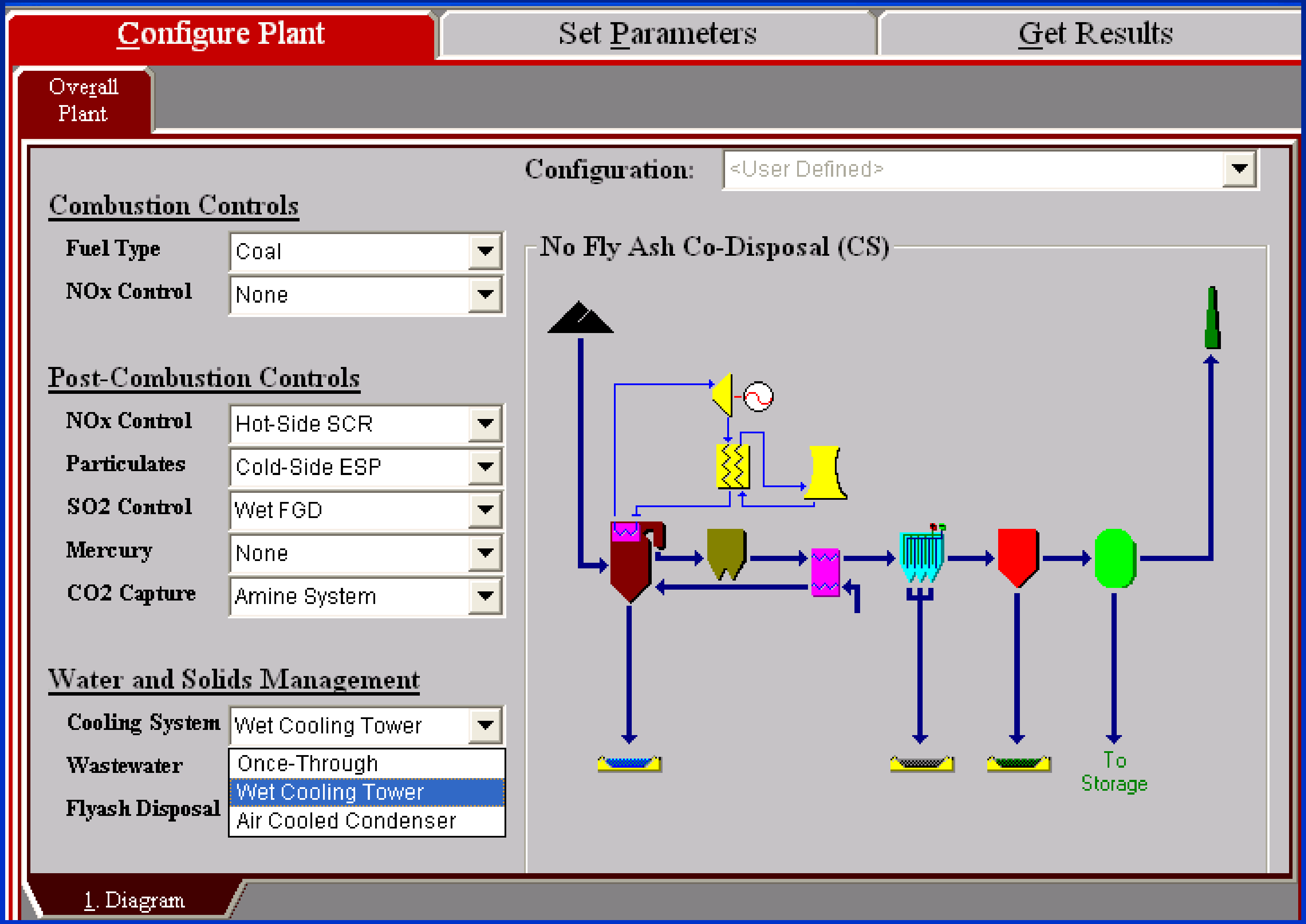
New IECM Release

(Version 6.2.4, May 2010)

- New Technology Options
  - Advanced amine system for CO_2 capture
  - Improved steam cycle models (subC-, SC-, USC-PC)
  - Dry feed gasifier and sulfur capture system (Shell)
  - Added gas turbine option for IGCC plants (GE 7FB)
  - Wet tower, dry tower and once-thru cooling water systems
  - Wastewater treatment systems for PC plants
- Updated Capital and O&M Cost Models
  - Aligned to NETL 2007 baseline studies
  - New default values for a number of model parameters
- New Software Capabilities
  - Additional user-friendly screens for data entry
  - Advanced graphing and uncertainty analysis capabilities

A quick tour of some model features

PC Plant with CCS



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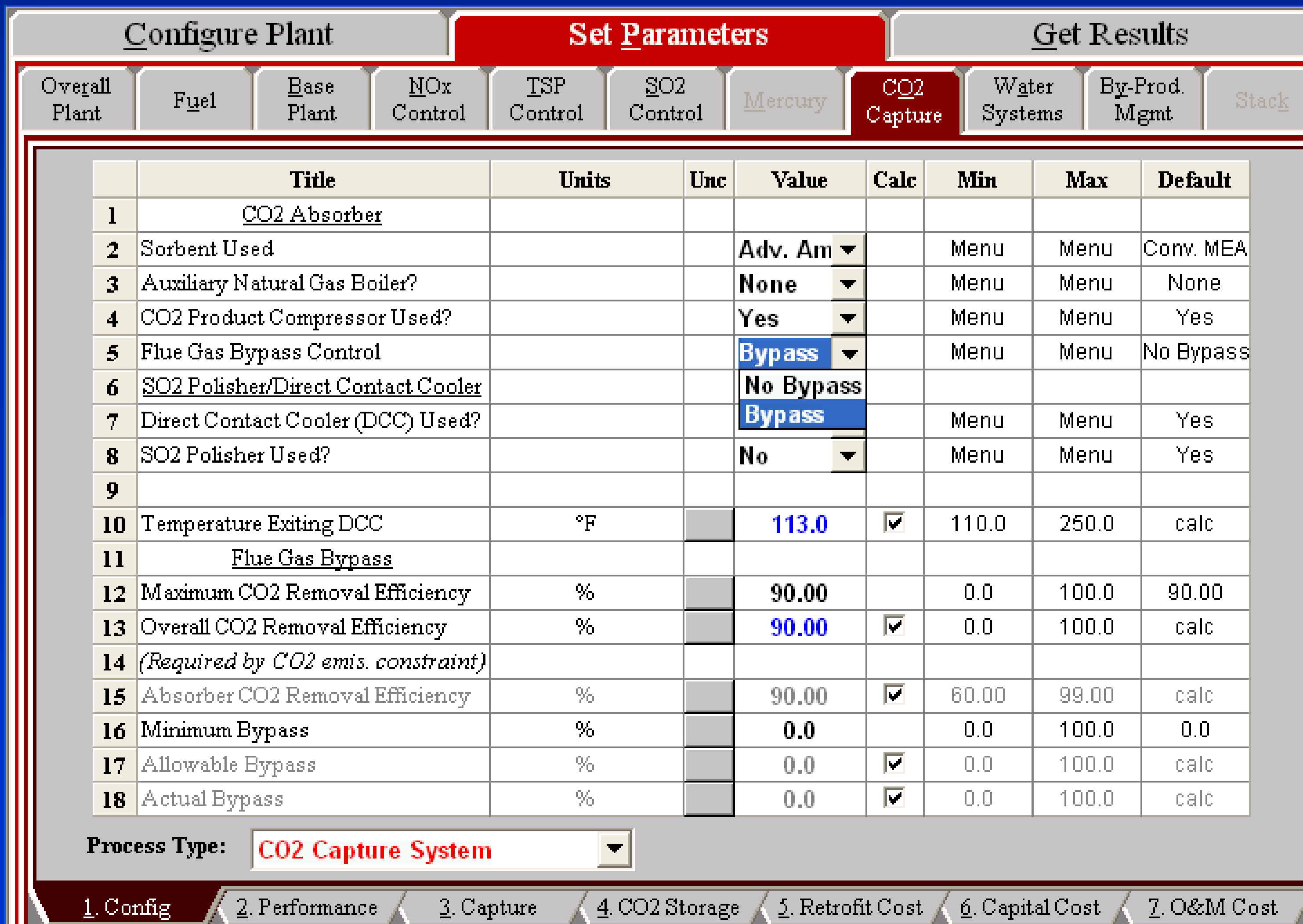
Set Parameters for CO_2 Capture System

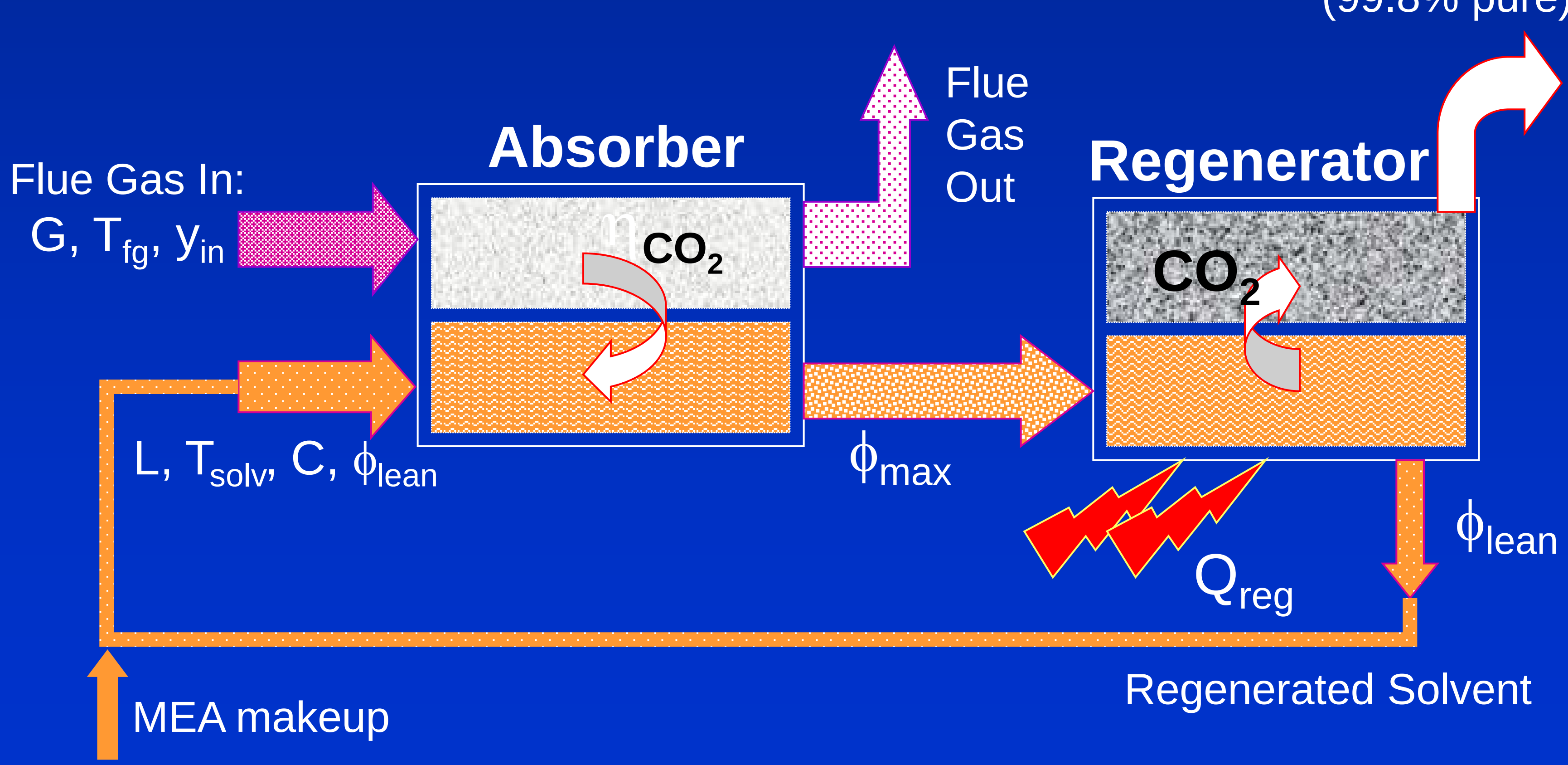


	Title	Units	Unc	Value	Calc	Min	Max	Default
1	CO2 Absorber							
2	Sorbent Used			Adv. Am		Menu	Menu	Conv. MEA
3	Auxiliary Natural Gas Boiler?			None		Menu	Menu	None
4	CO2 Product Compressor Used?			Yes		Menu	Menu	Yes
5	Flue Gas Bypass Control			Bypass		Menu	Menu	No Bypass
6	SO2 Polisher/Direct Contact Cooler			No Bypass				
7	Direct Contact Cooler (DCC) Used?			Bypass		Menu	Menu	Yes
8	SO2 Polisher Used?			No		Menu	Menu	Yes
9								
10	Temperature Exiting DCC	°F		113.0	☑	110.0	250.0	calc
11	Flue Gas Bypass							
12	Maximum CO2 Removal Efficiency	%		90.00		0.0	100.0	90.00
13	Overall CO2 Removal Efficiency	%		90.00	☑	0.0	100.0	calc
14	*(Required by CO2 emis. constraint)*							
15	Absorber CO2 Removal Efficiency	%		90.00	☑	60.00	99.00	calc
16	Minimum Bypass	%		0.0		0.0	100.0	0.0
17	Allowable Bypass	%		0.0	☑	0.0	100.0	calc
18	Actual Bypass	%		0.0	☑	0.0	100.0	calc

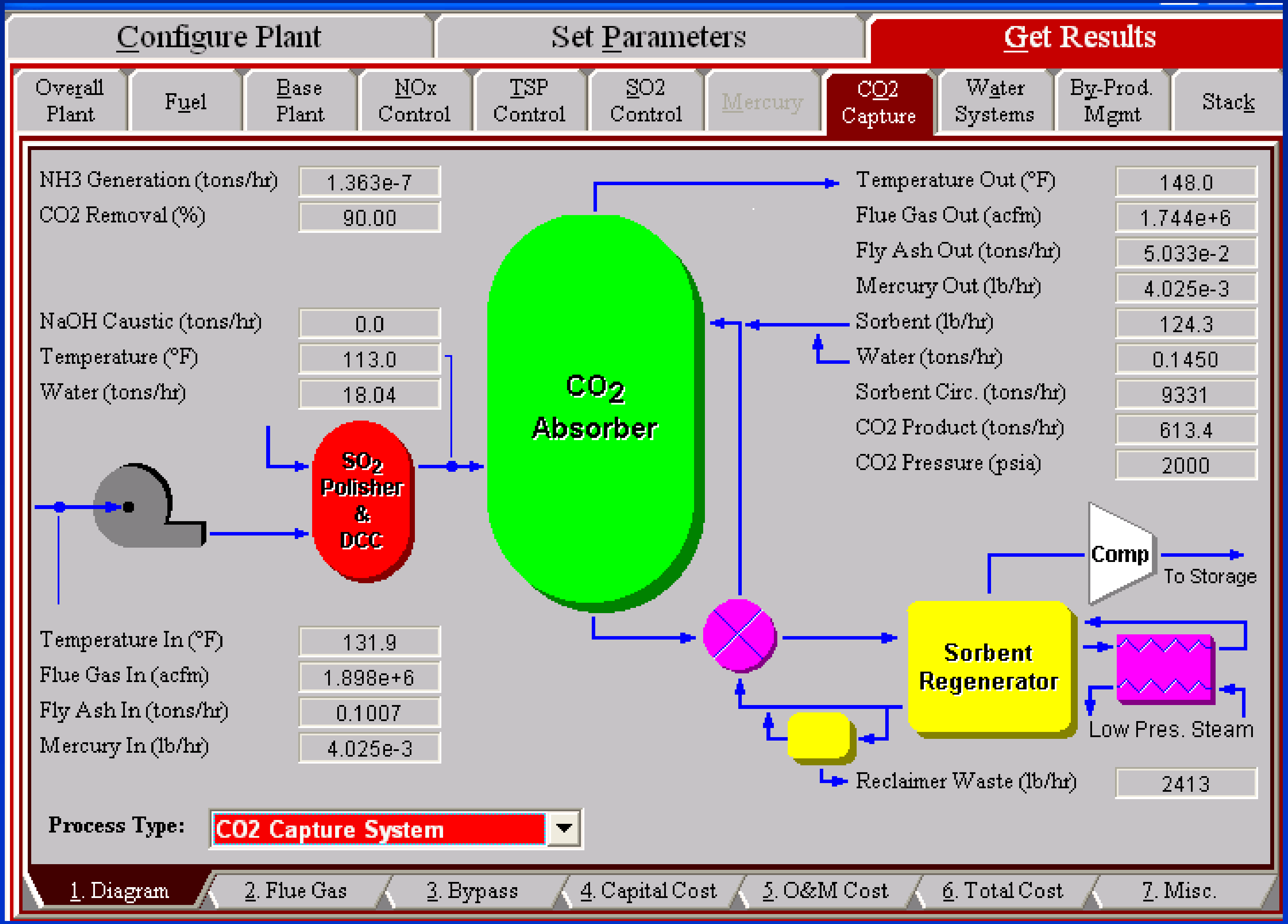
Process Type: CO2 Capture System

Performance Model for Amine Capture Systems

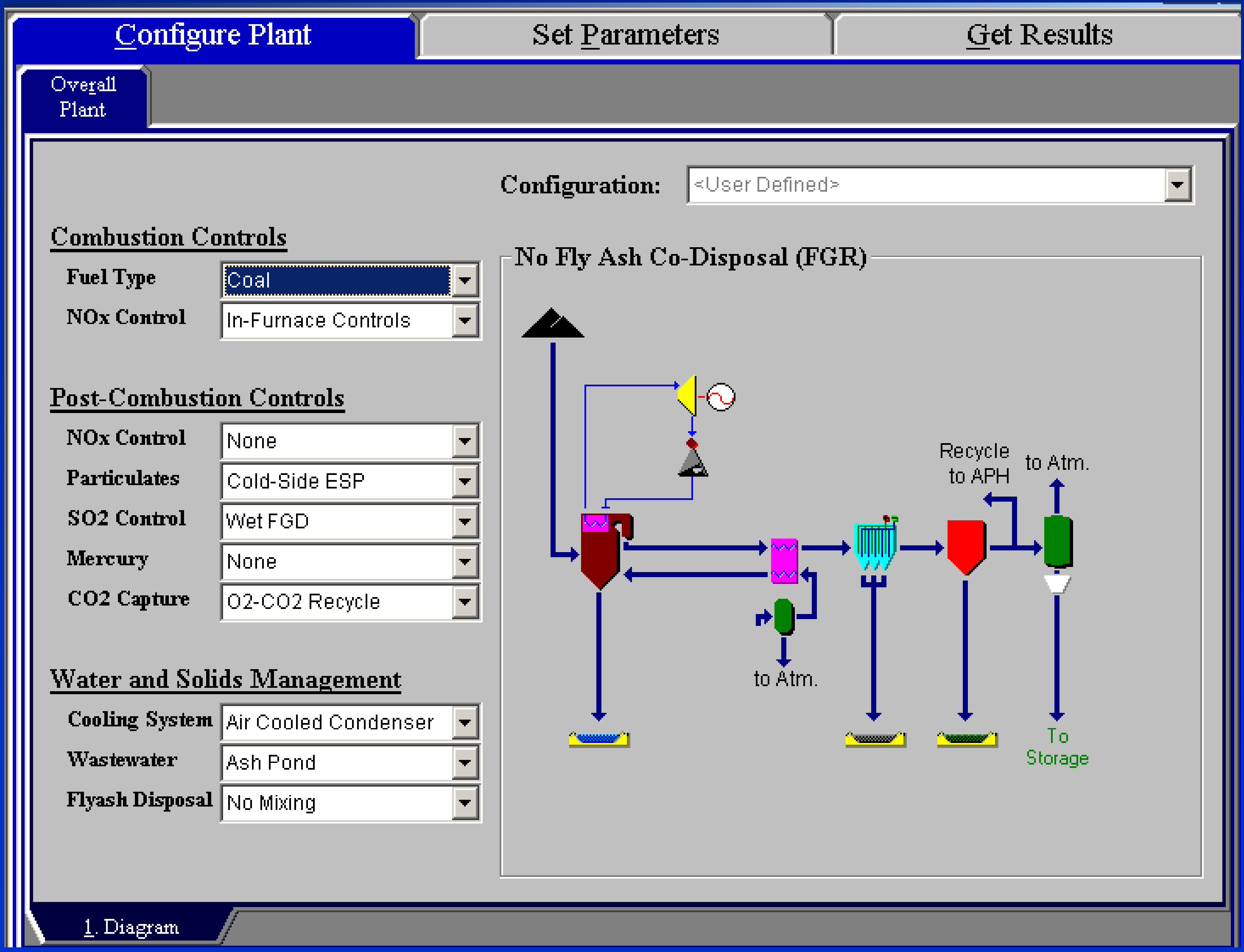
$$\eta_{CO2} = f(L/G,\ C,\ y_{in},\ \phi_{lean},\ T_{fg},\ T_{solv},\ H,\ D)$$



Results for CO_2 Capture System



PC Plant w/ Oxy-Combustion



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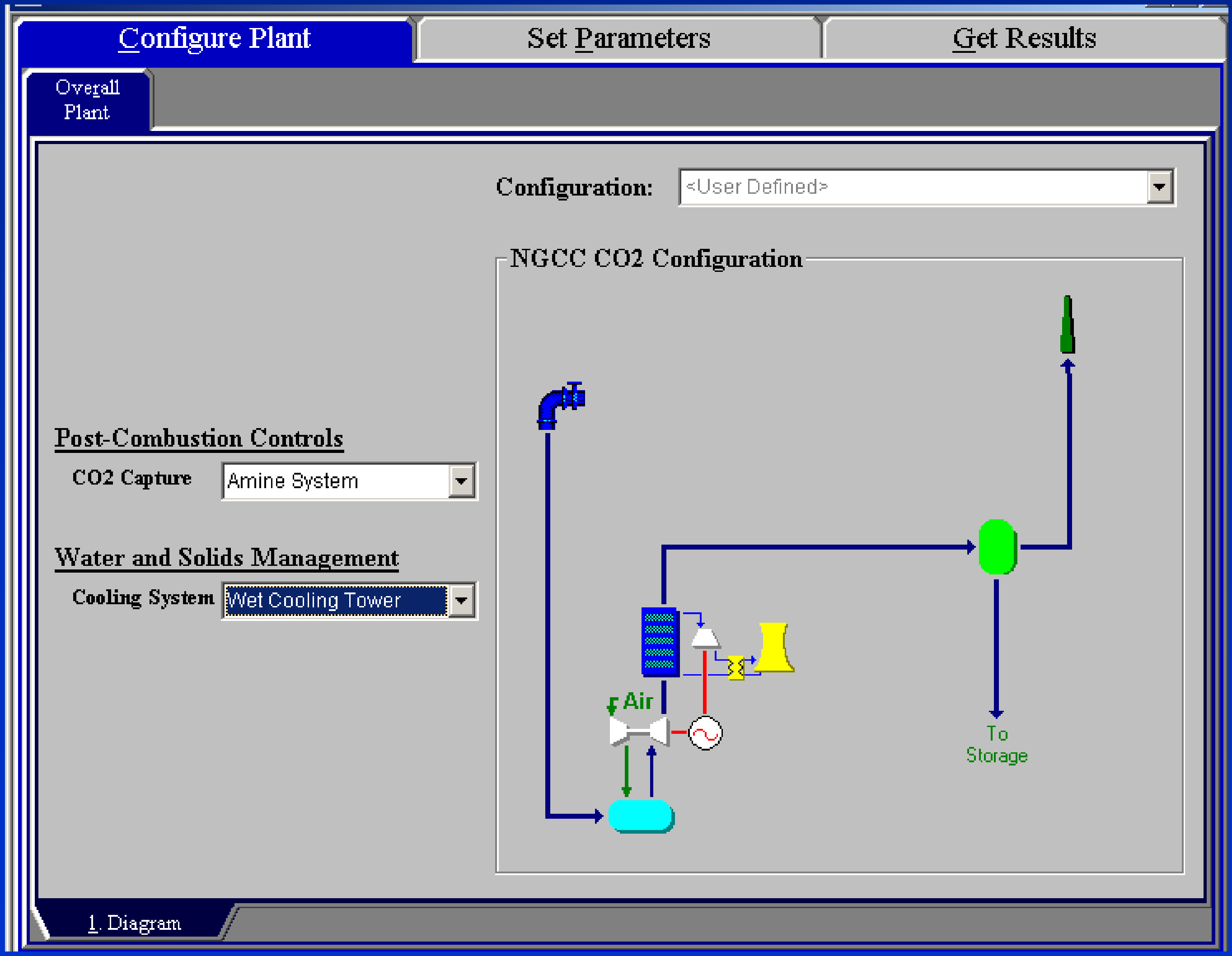
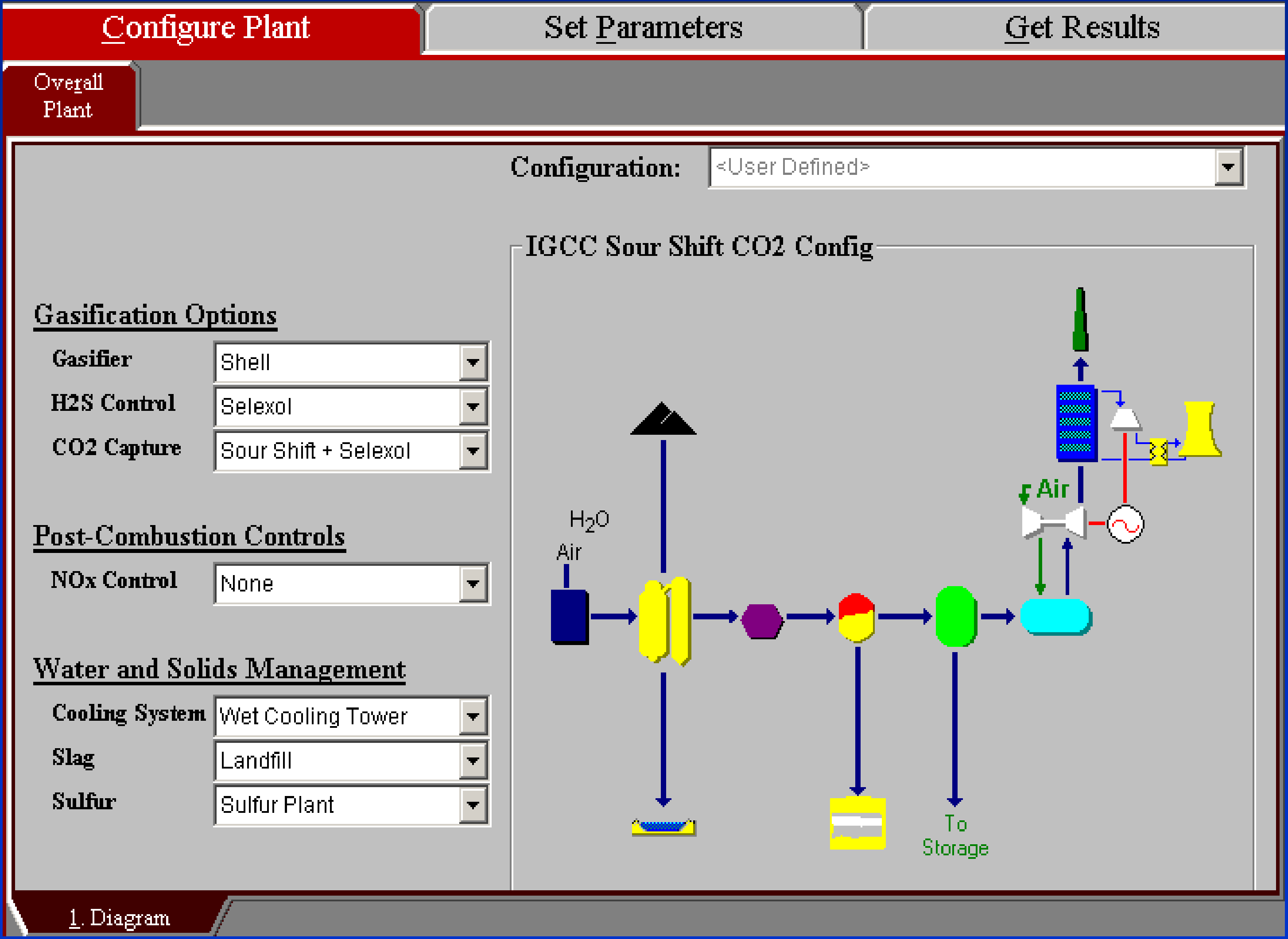
NGCC Plant with CCS



IGCC Plant with CCS



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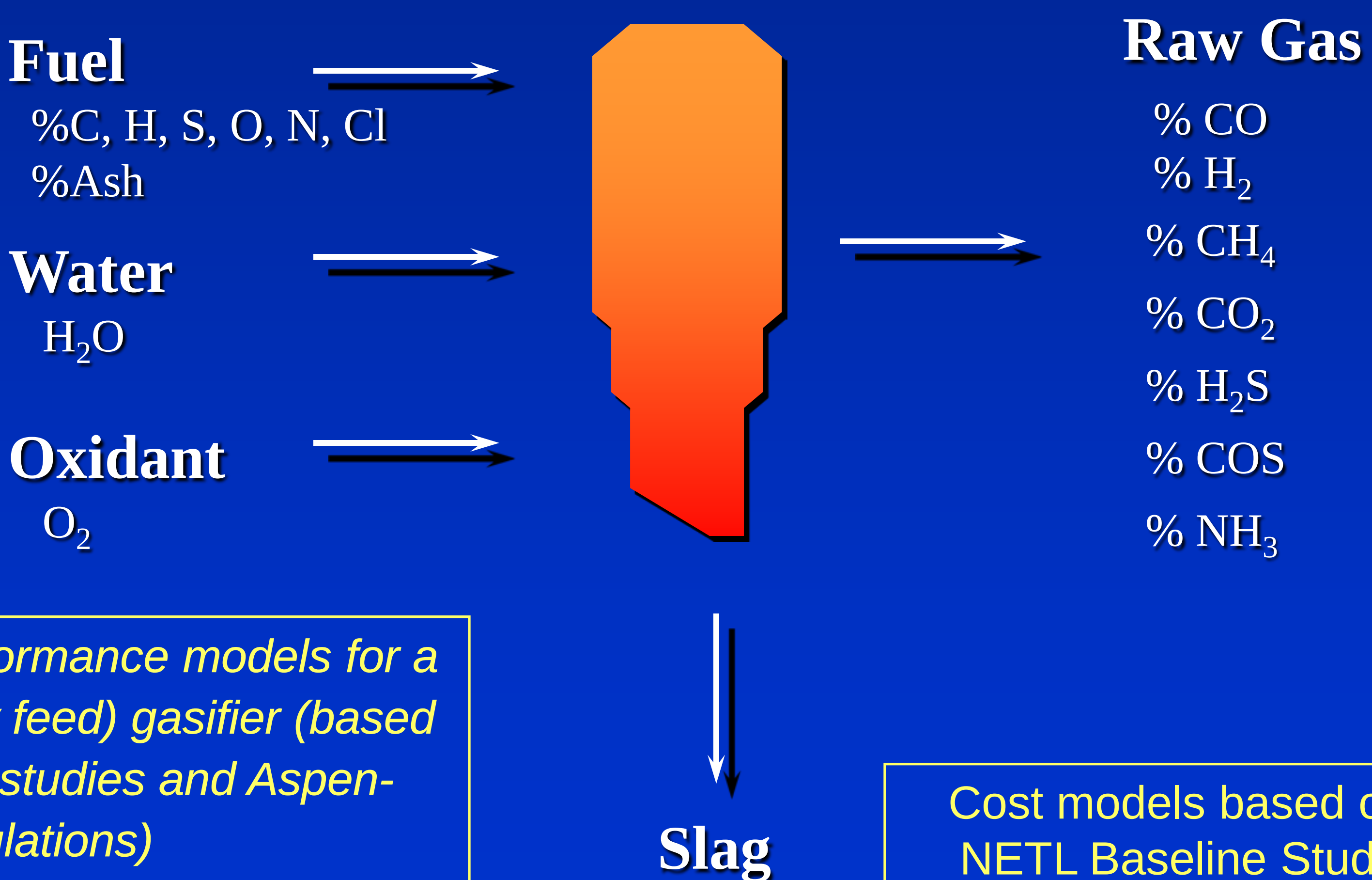
IECM Gasifier Model



New performance models for a Shell (dry feed) gasifier (based on NETL studies and Aspen-Plus simulations)

Cost models based on NETL Baseline Study

Wet Tower Performance Model

Cooling water quantity:

$$m_c = \frac{(Hr_s - 3413) \cdot MWg \cdot 1000 \cdot (1 + \mu_{aux})}{\Delta T_w \cdot 2000}$$

Makeup water quantity:

$$m_{makeup} = m_{evap} + m_{drift} + m_{blowdown}$$

$$m_{drift} = 0.001\% \cdot m_c$$

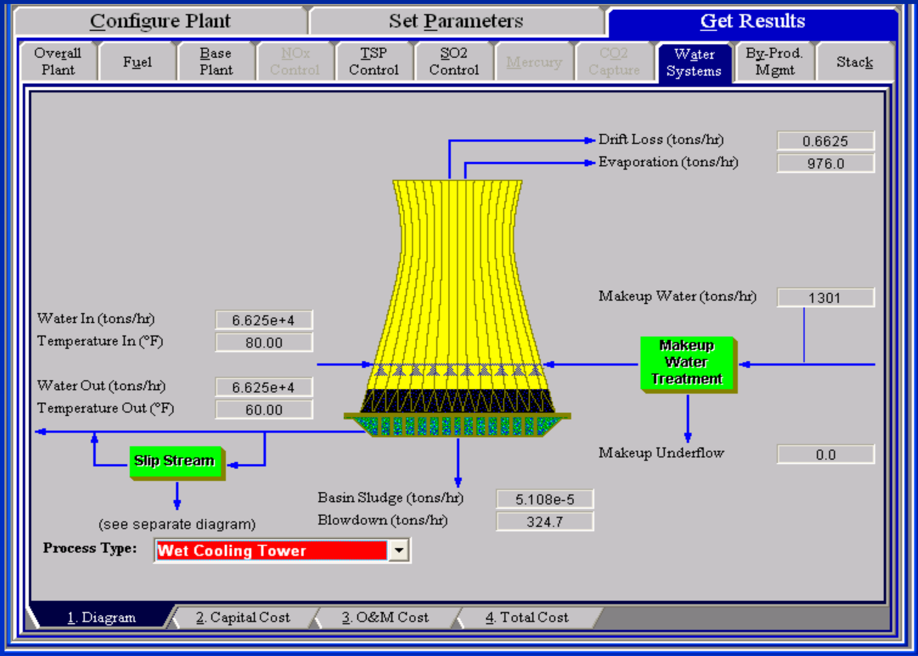
$$m_{blowdown} = \frac{m_{evap}}{CC - 1} - m_{drift}$$

$$m_{evap} = m_a (W_2 - W_1)$$

where:

- μ_{aux} = auxiliary cooling load
- Hr_s = steam cycle heat rate
- MW_g = plant gross output
- ΔT_w = water temp. change
- m_a = air flow rate
- W_1 = inlet air humidity
- W_2 = outlet air humidity
- CC = cycle of concentration

IECM User Interface

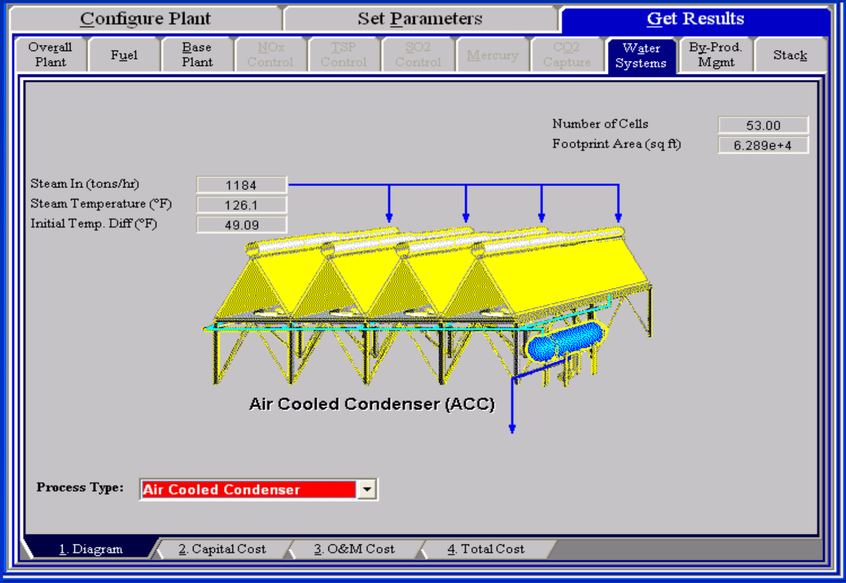


ACC Performance Model

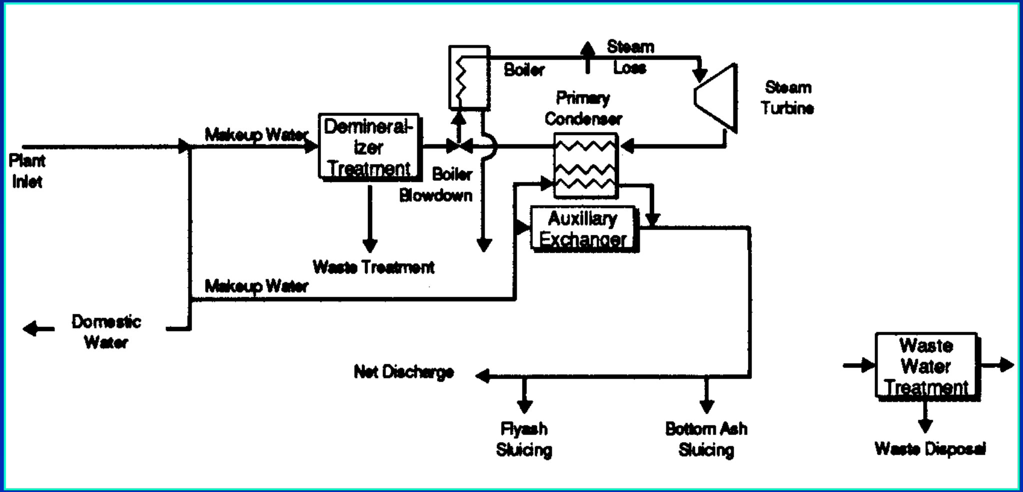
- ***Configuration:*** A-frame force-drafted ACC with double-row tubes. Each ACC cell consists of multiple bundles serviced by a fan

- **Key input parameters:**
  - Air dry bulb temperature
  - Turbine backpressure
  - Inlet steam temperature
  - Fan efficiency
  - Auxiliary cooling load
- **Key output parameters:**
  - Footprint area
  - Number of ACC cells
  - Fan power required

IECM User Interface

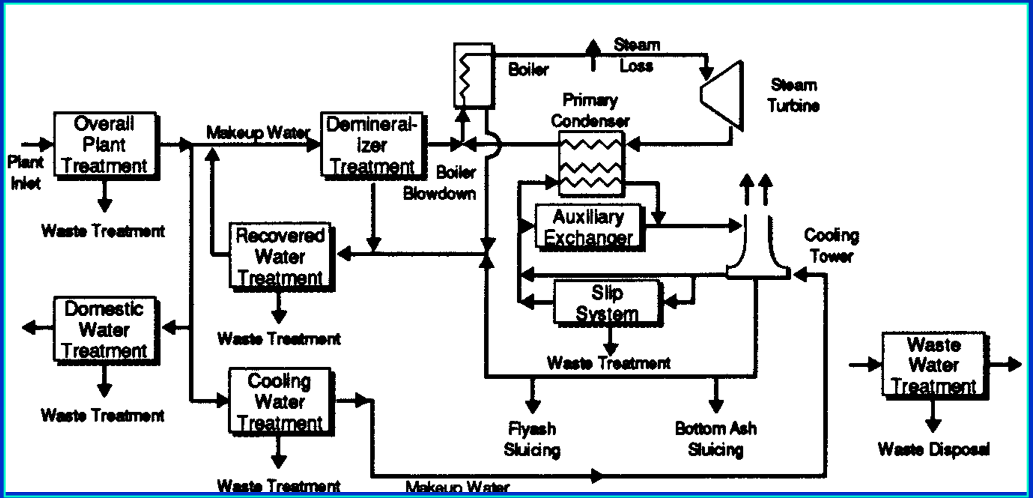


Model Allows a Range of Water Treatment System Options



Once-Through Cooling with Basic Waste Water Treatment

Evaporative Cooling with Zero Discharge Water & Waste Water Systems



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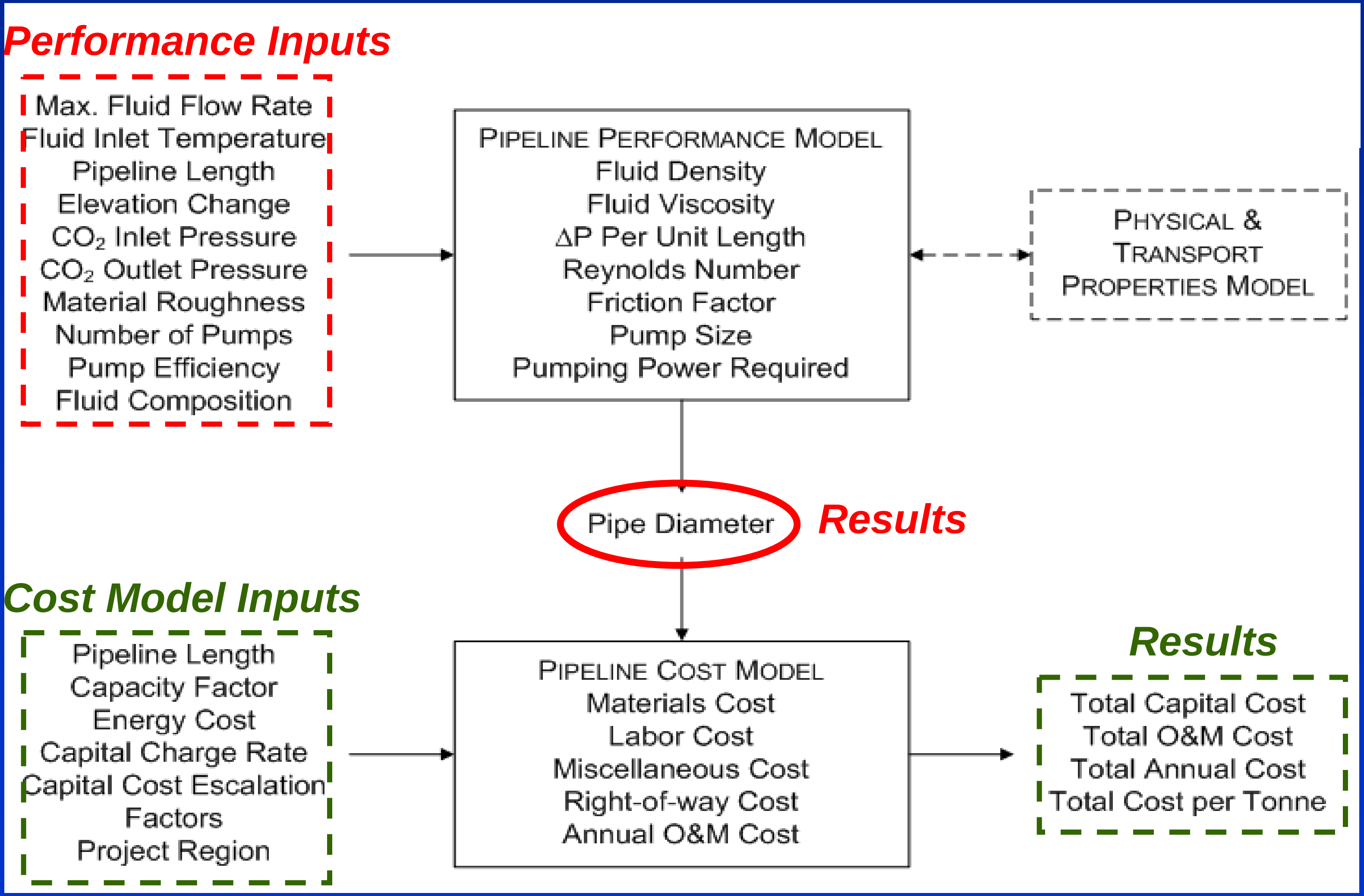
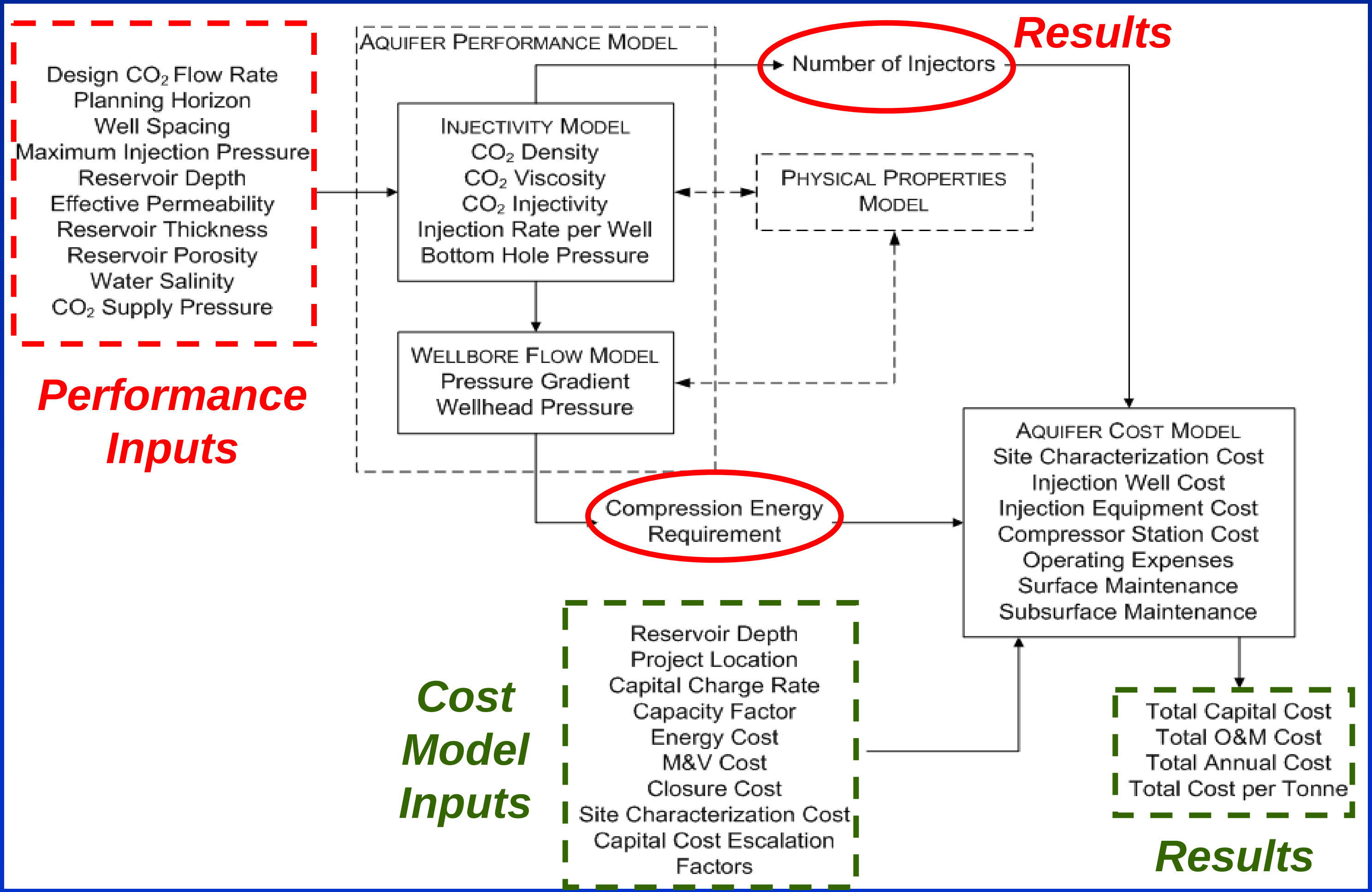
IECM Pipeline Transport Model

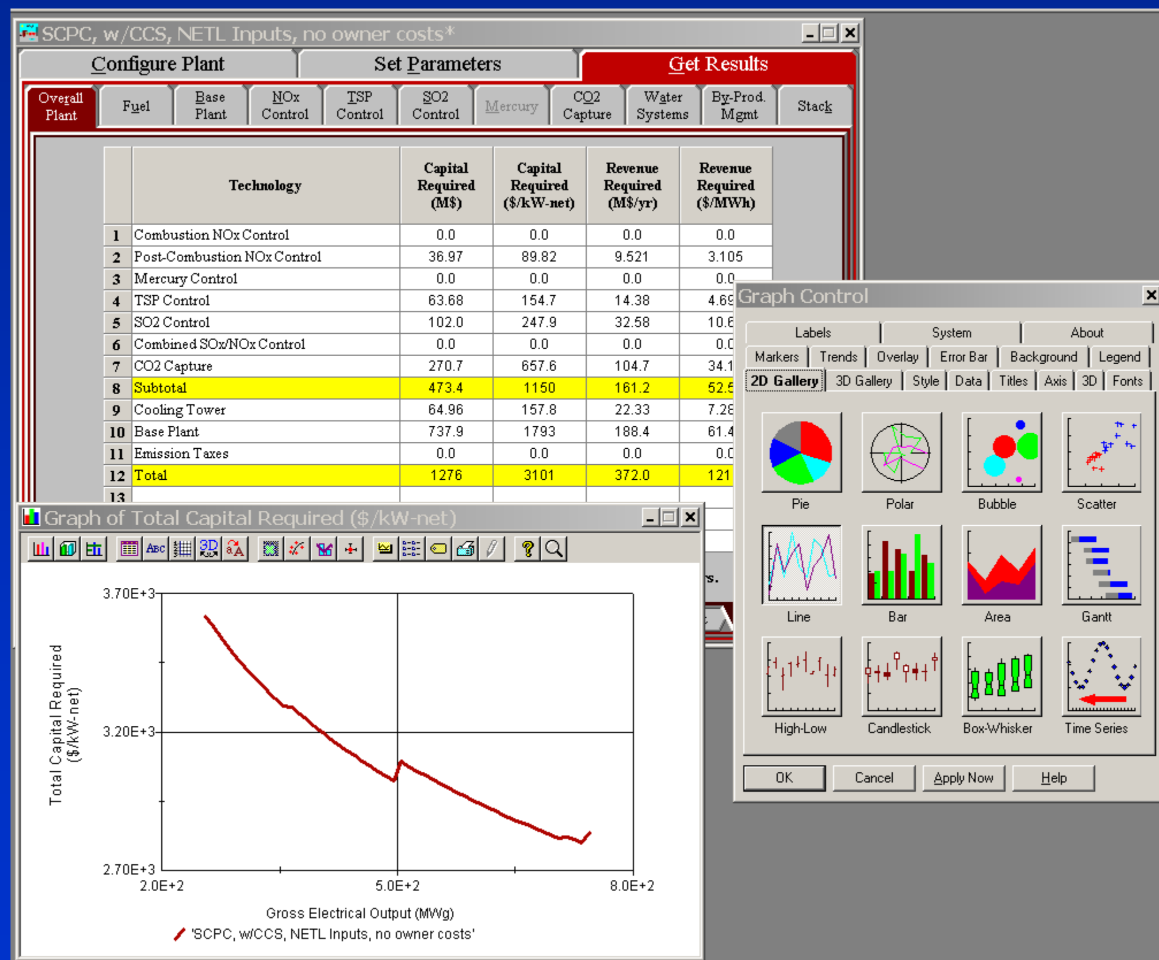


Saline Formation Storage Model



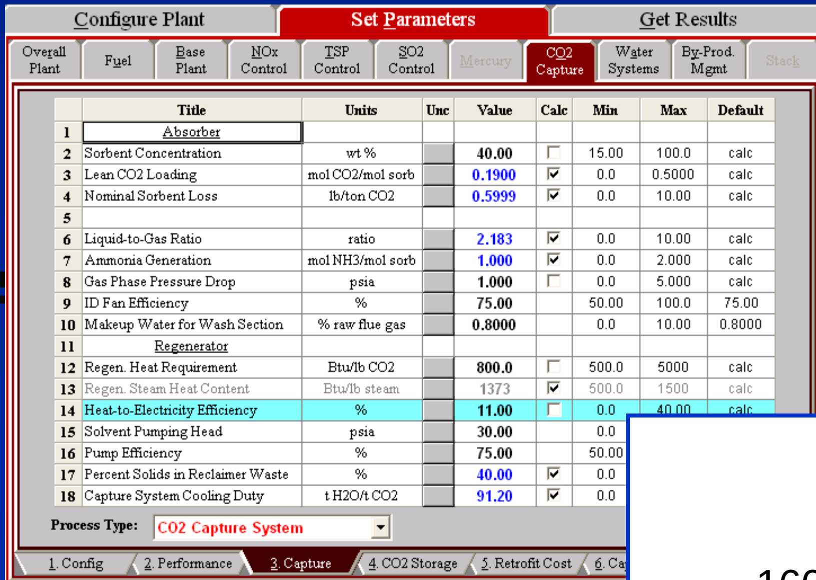
New Graphing Options

- Can easily and quickly plot any model variable as a function of any other variable
- Can display results from up to six different runs on same graph
- All graphs and data easily exported for display or further processing



Illustrative Application

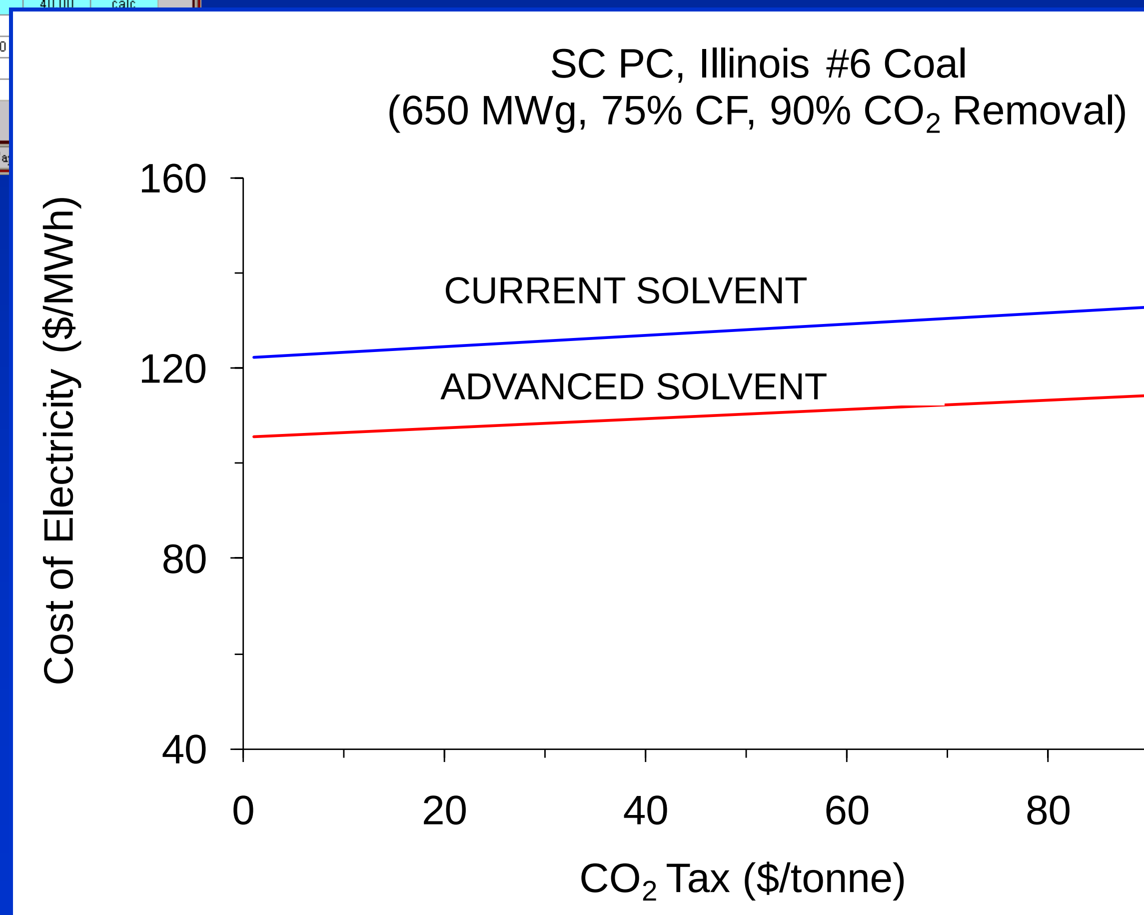
Effect of Advanced Solvent on COE



	Title	Units	Unc	Value	Calc	Min	Max	Default
1	Absorber							
2	Sorbent Concentration	wt %		40.00	☐	15.00	100.0	calc
3	Lean CO2 Loading	mol CO2/mol sorb		0.1900	☑	0.0	0.5000	calc
4	Nominal Sorbent Loss	lb/ton CO2		0.5999	☑	0.0	10.00	calc
5								
6	Liquid-to-Gas Ratio	ratio		2.183	☑	0.0	10.00	calc
7	Ammonia Generation	mol NH3/mol sorb		1.000	☑	0.0	2.000	calc
8	Gas Phase Pressure Drop	psia		1.000	☐	0.0	5.000	calc
9	ID Fan Efficiency	%		75.00		50.00	100.0	75.00
10	Makeup Water for Wash Section	% raw flue gas		0.8000		0.0	10.00	0.8000
11	Regenerator							
12	Regen. Heat Requirement	Btu/lb CO2		800.0	☐	500.0	5000	calc
13	Regen. Steam Heat Content	Btu/lb steam		1373	☑	500.0	1500	calc
14	Heat-to-Electricity Efficiency	%		11.00	☐	0.0	40.00	calc
15	Solvent Pumping Head	psia		30.00		0.0		
16	Pump Efficiency	%		75.00		50.00		
17	Percent Solids in Reclaimer Waste	%		40.00	☑	0.0		
18	Capture System Cooling Duty	t H2O/t CO2		91.20	☑	0.0		

Hypothetical Advanced Solvent Properties:

- Higher concentration
- Lower regen heat
- Lower losses
- Lower quality steam



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Future Developments

Future Work

Work in Progress

- Ammonia-based capture system
- Chemical looping combustion

Planned Future Work

- Capabilities for advanced solvents
- Capabilities for solid sorbents
- Capabilities for membrane systems
- More detailed models of selected technologies

Thank You

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