

The IECM: A Plant-Level Simulation Model for Evaluating CO₂ Capture Options

Edward S. Rubin

Department of Engineering and Public Policy

Department of Mechanical Engineering

Carnegie Mellon University

Pittsburgh, Pennsylvania

Presentation to the

UK-US CCS R&D Workshop

Pittsburgh, PA

May 10, 2010

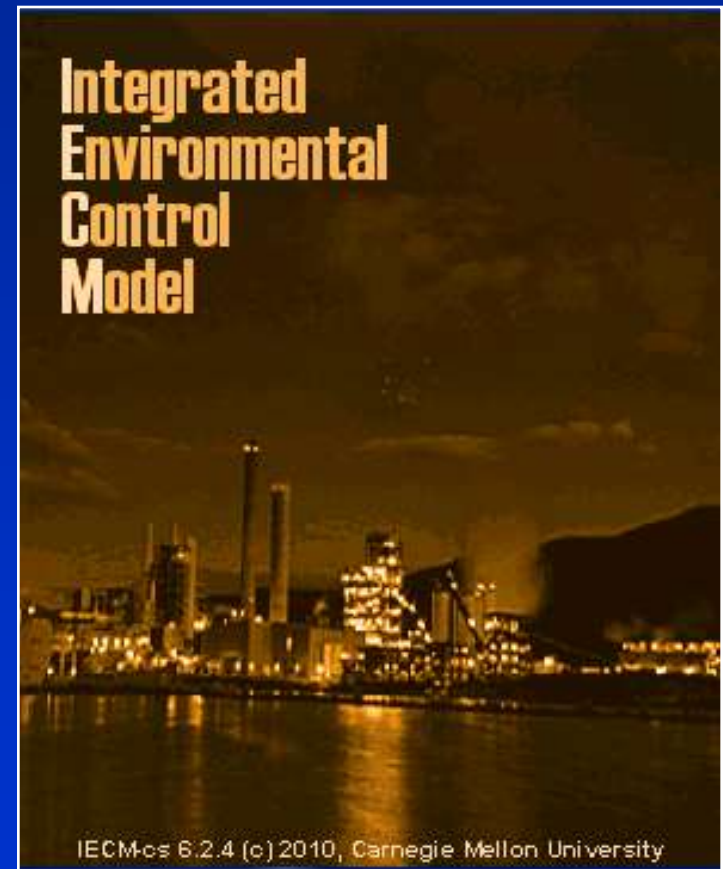
Outline

- 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
 - CO₂ 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

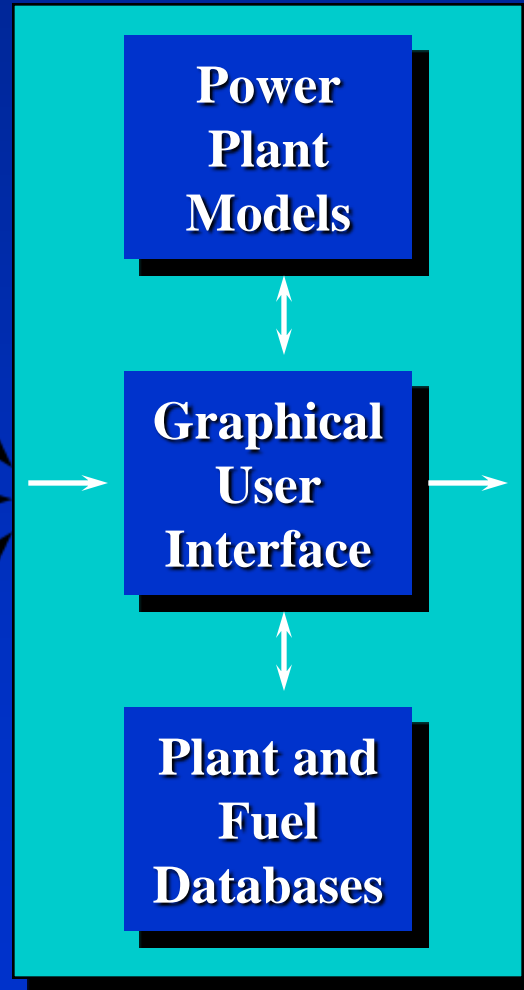
- Heating Value
- Composition
- Delivered Cost

Plant Design

- Conversion Process
- Emission Controls
- Solid Waste Mgmt
- Chemical Inputs

Cost Factors

- O&M Costs
- Capital Costs
- Financial Factors



Plant & Process Performance

- Efficiency
- Resource use

Environmental Emissions

- Air, water, land

Plant & Process Costs

- Capital
- O&M
- COE

IECM Technologies for PC Plants

(excluding CO₂ 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 SO₂/NO_x systems

Mercury Removal

- Carbon/sorbent injection

Particulate Removal

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

SO₂ Removal

- Wet limestone
 - Conventional
 - Forced oxidation
 - Additives
- Wet lime
- Lime spray dryer
- Combined SO₂/NO_x systems

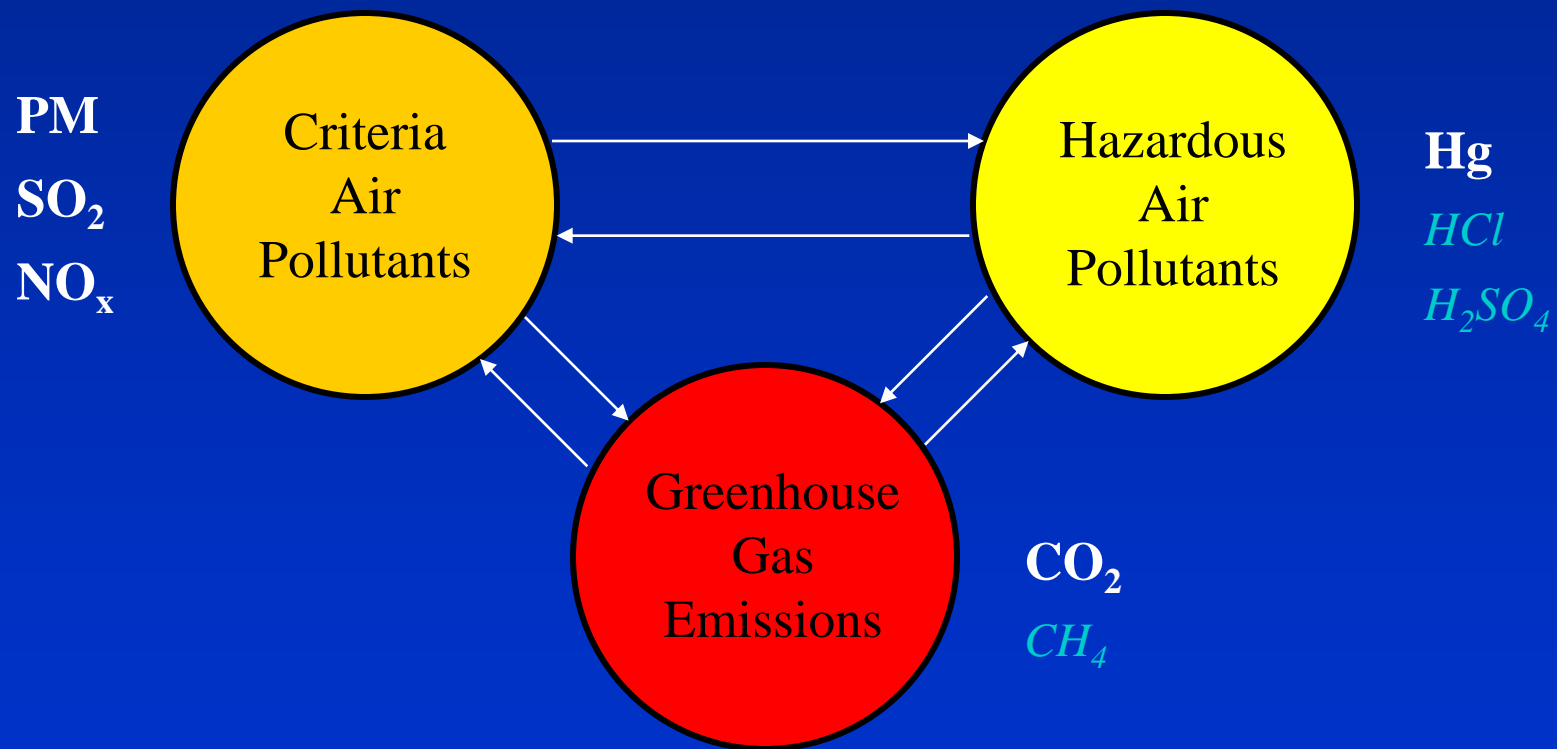
Solids Management

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

IECM Technologies for CCS

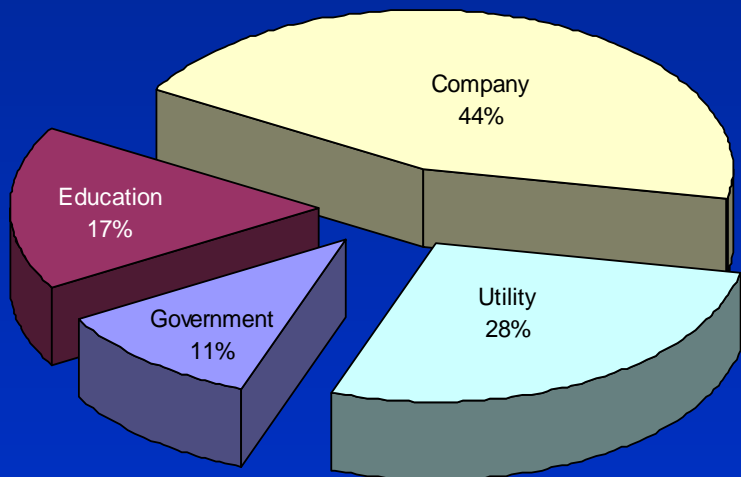
- CO₂ Capture Options
 - PC Plants: - Amine systems (post-combustion)
(w/optional aux. NG boiler)
 - Oxyfuel combustion w/ flue gas recycle
 - NGCC Plants: - Amine systems (post-combustion)
 - IGCC Plants: - Water gas shift + CO₂ capture (pre-combustion)
- CO₂ Transport Options
 - Pipelines (six U.S. regions)
 - Other (user-specified)
- CO₂ Sequestration Options
 - Geological: Enhanced Oil Recovery (EOR)
 - Geological: Deep Saline Formation
 - Others (user-specified): ECBM; Ocean

Models Account for Multi-Pollutant Interactions

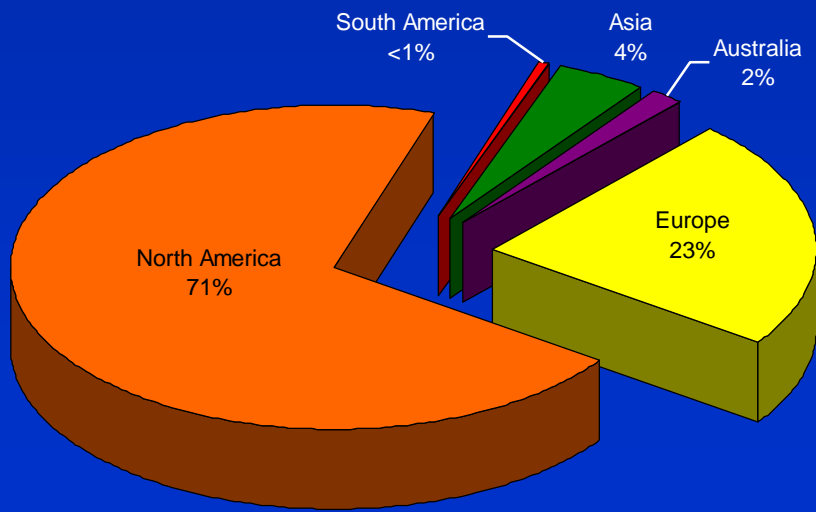


Profile of Recent IECM Users

Type of Organization



Geographic Region



~ 500 organizations

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 CO₂ 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*

Set Parameters for CO₂ Capture System

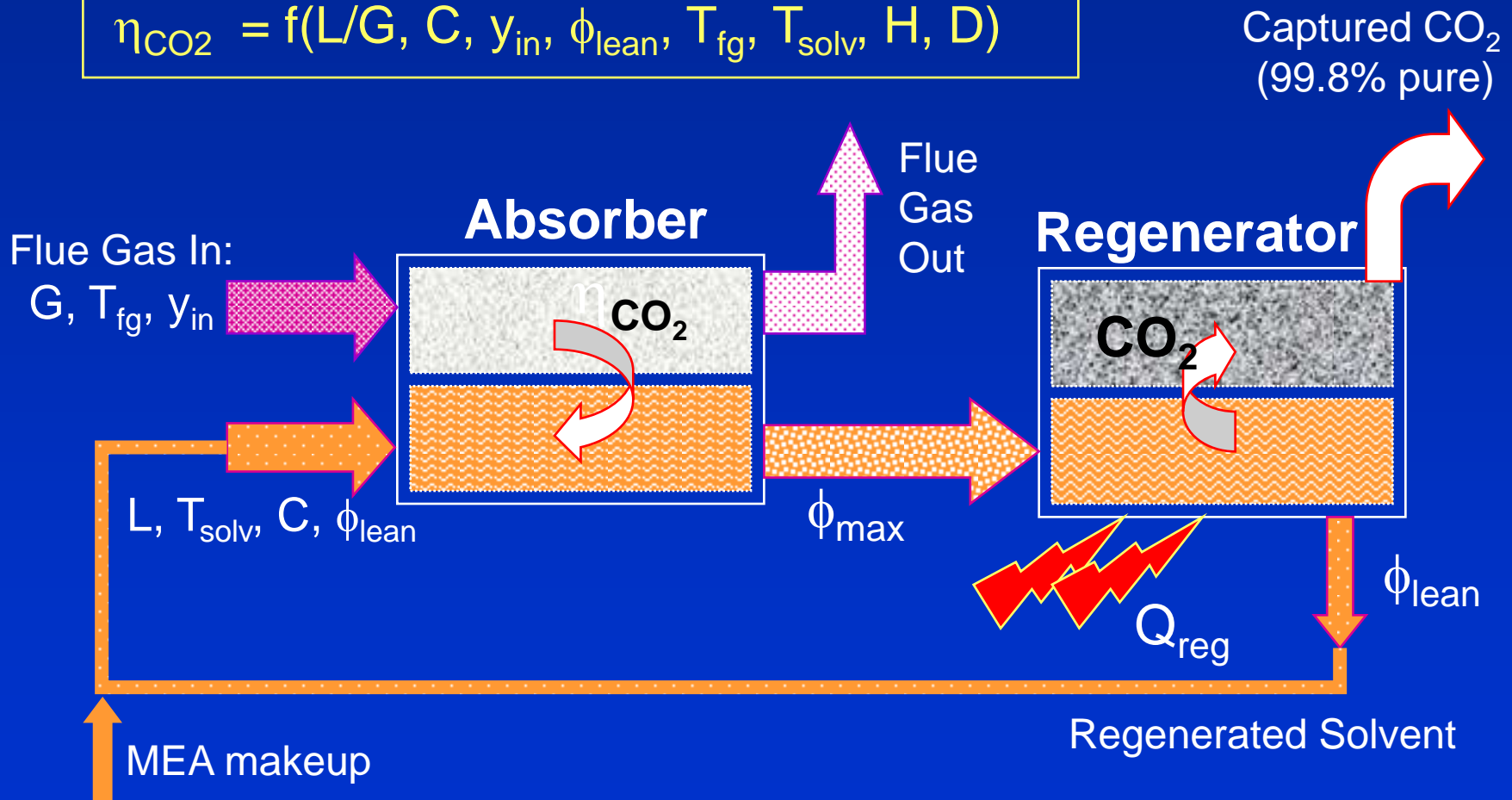
Configure Plant			Set Parameters				Get Results			
Overall Plant	Fuel	Base Plant	NOx Control	TSP Control	SO ₂ Control	Mercury	CO ₂ Capture	Water Systems	By-Prod. Mgmt	Stack
	Title	Units	Unc	Value	Calc	Min	Max	Default		
1	<u>CO₂ Absorber</u>									
2	Sorbent Used			Adv. Am ▾		Menu	Menu	Conv. MEA		
3	Auxiliary Natural Gas Boiler?			None ▾		Menu	Menu	None		
4	CO ₂ Product Compressor Used?			Yes ▾		Menu	Menu	Yes		
5	Flue Gas Bypass Control			Bypass ▾		Menu	Menu	No Bypass		
6	<u>SO₂ Polisher/Direct Contact Cooler</u>			No Bypass						
7	Direct Contact Cooler (DCC) Used?			Bypass		Menu	Menu	Yes		
8	SO ₂ Polisher Used?			No ▾		Menu	Menu	Yes		
9										
10	Temperature Exiting DCC	°F		113.0	<input checked="" type="checkbox"/>	110.0	250.0	calc		
11	<u>Flue Gas Bypass</u>									
12	Maximum CO ₂ Removal Efficiency	%		90.00		0.0	100.0	90.00		
13	Overall CO ₂ Removal Efficiency	%		90.00	<input checked="" type="checkbox"/>	0.0	100.0	calc		
14	<i>(Required by CO₂ emis. constraint)</i>									
15	Absorber CO ₂ Removal Efficiency	%		90.00	<input checked="" type="checkbox"/>	60.00	99.00	calc		
16	Minimum Bypass	%		0.0		0.0	100.0	0.0		
17	Allowable Bypass	%		0.0	<input checked="" type="checkbox"/>	0.0	100.0	calc		
18	Actual Bypass	%		0.0	<input checked="" type="checkbox"/>	0.0	100.0	calc		

Process Type: **CO₂ Capture System** ▾

1. Config 2. Performance 3. Capture 4. CO₂ Storage 5. Retrofit Cost 6. Capital Cost 7. O&M Cost

Performance Model for Amine Capture Systems

$$\eta_{\text{CO}_2} = f(L/G, C, y_{\text{in}}, \phi_{\text{lean}}, T_{\text{fg}}, T_{\text{solv}}, H, D)$$



PC Plant w/ Oxy-Combustion

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

Overall Plant

Configuration: <User Defined>

Combustion Controls

Fuel Type: Coal
NOx Control: In-Furnace Controls

Post-Combustion Controls

NOx Control: None
Particulates: Cold-Side ESP
SO2 Control: Wet FGD
Mercury: None
CO2 Capture: O2-CO2 Recycle

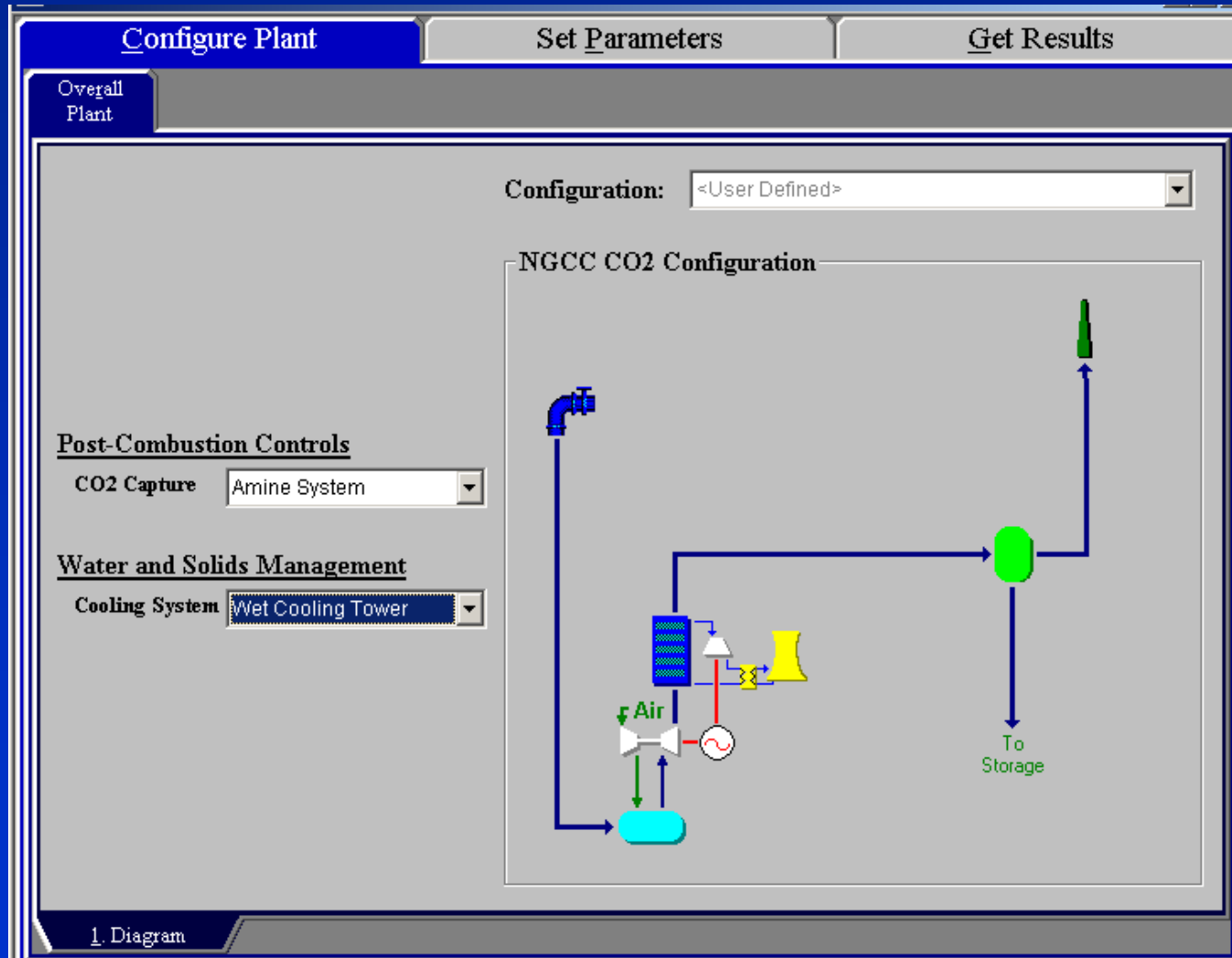
Water and Solids Management

Cooling System: Air Cooled Condenser
Wastewater: Ash Pond
Flyash Disposal: No Mixing

No Fly Ash Co-Disposal (FGR)

1. Diagram

NGCC Plant with CCS



IGCC Plant with CCS

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

Overall Plant

Configuration: <User Defined>

IGCC Sour Shift CO2 Config

Gasification Options

Gasifier	Shell
H2S Control	Selexol
CO2 Capture	Sour Shift + Selexol

Post-Combustion Controls

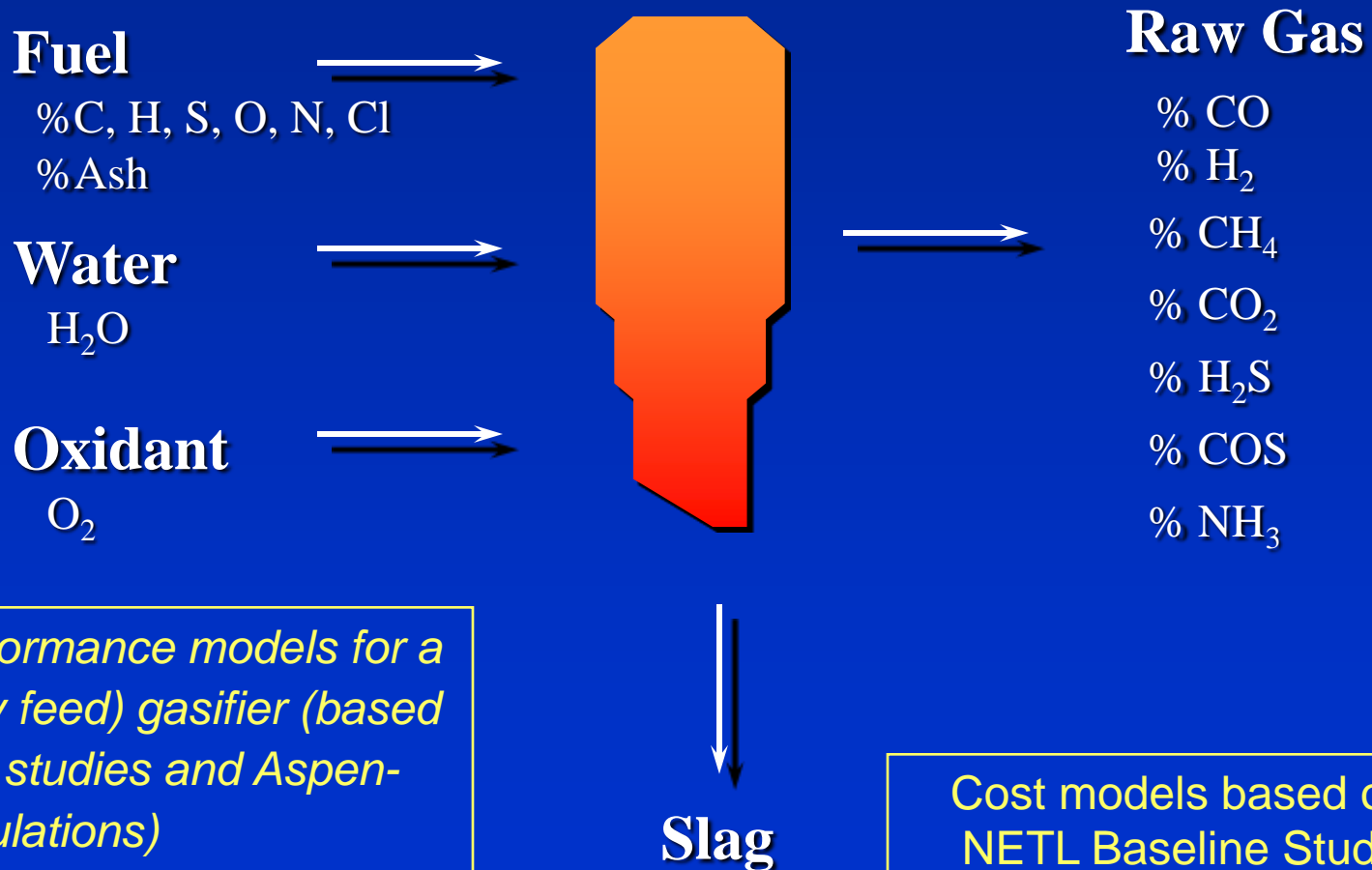
NOx Control	None
-------------	------

Water and Solids Management

Cooling System	Wet Cooling Tower
Slag	Landfill
Sulfur	Sulfur Plant

1. Diagram

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:

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

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

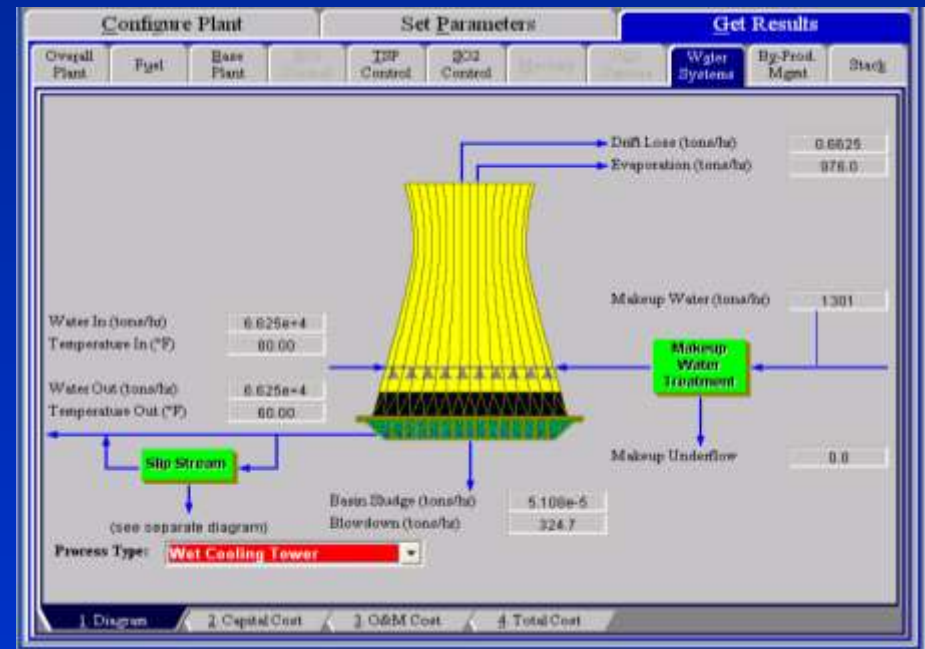
m_a = air flow rate

W_1 = inlet air humidity

W_2 = outlet air humidity

CC = cycle of concentration

IECM User Interface

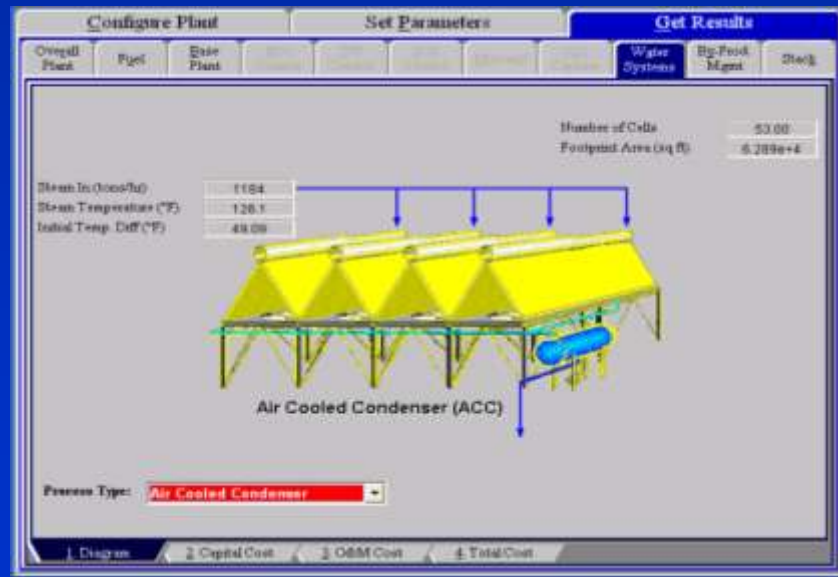


ACC Performance Model

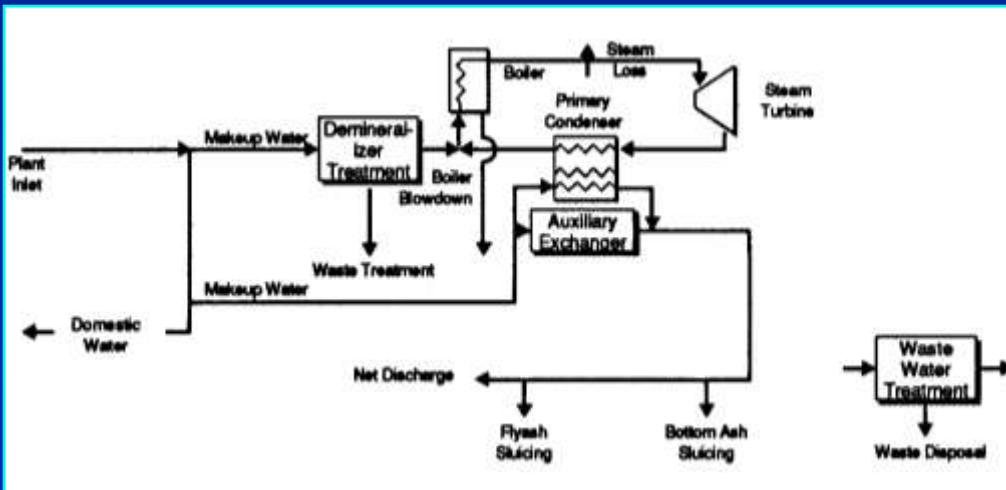
- **Configuration:** A-frame force-drafted ACC with double-row tubes. Each ACC cell consists of multiple bundles serviced by a fan

IECM User Interface

- **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

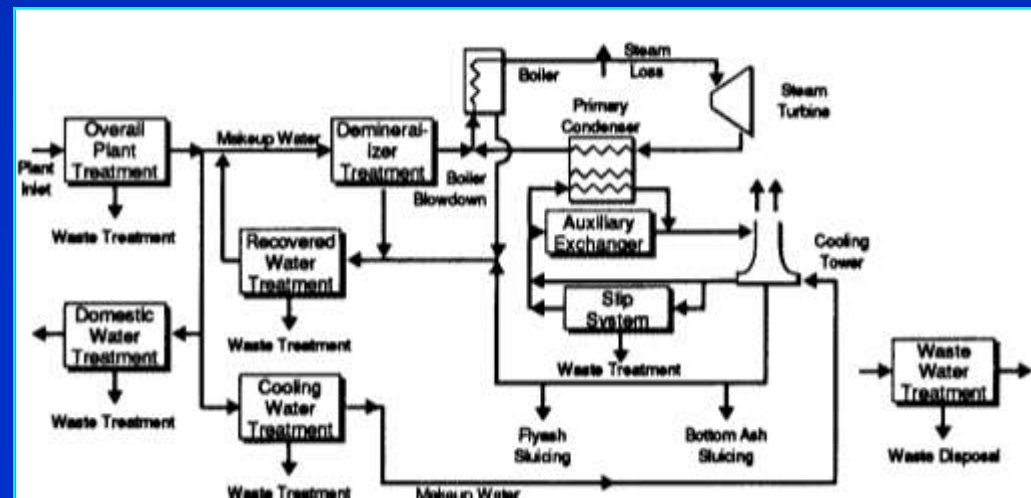


Model Allows a Range of Water Treatment System Options



Once-Through Cooling with Basic Waste Water Treatment

Evaporative Cooling with Zero Discharge Water & Waste Water Systems



IECM Pipeline Transport Model

Performance Inputs

Max. Fluid Flow Rate
Fluid Inlet Temperature
Pipeline Length
Elevation Change
CO₂ Inlet Pressure
CO₂ Outlet Pressure
Material Roughness
Number of Pumps
Pump Efficiency
Fluid Composition

PIPELINE PERFORMANCE MODEL
Fluid Density
Fluid Viscosity
 ΔP Per Unit Length
Reynolds Number
Friction Factor
Pump Size
Pumping Power Required

PHYSICAL &
TRANSPORT
PROPERTIES MODEL

Pipe Diameter

Results

Cost Model Inputs

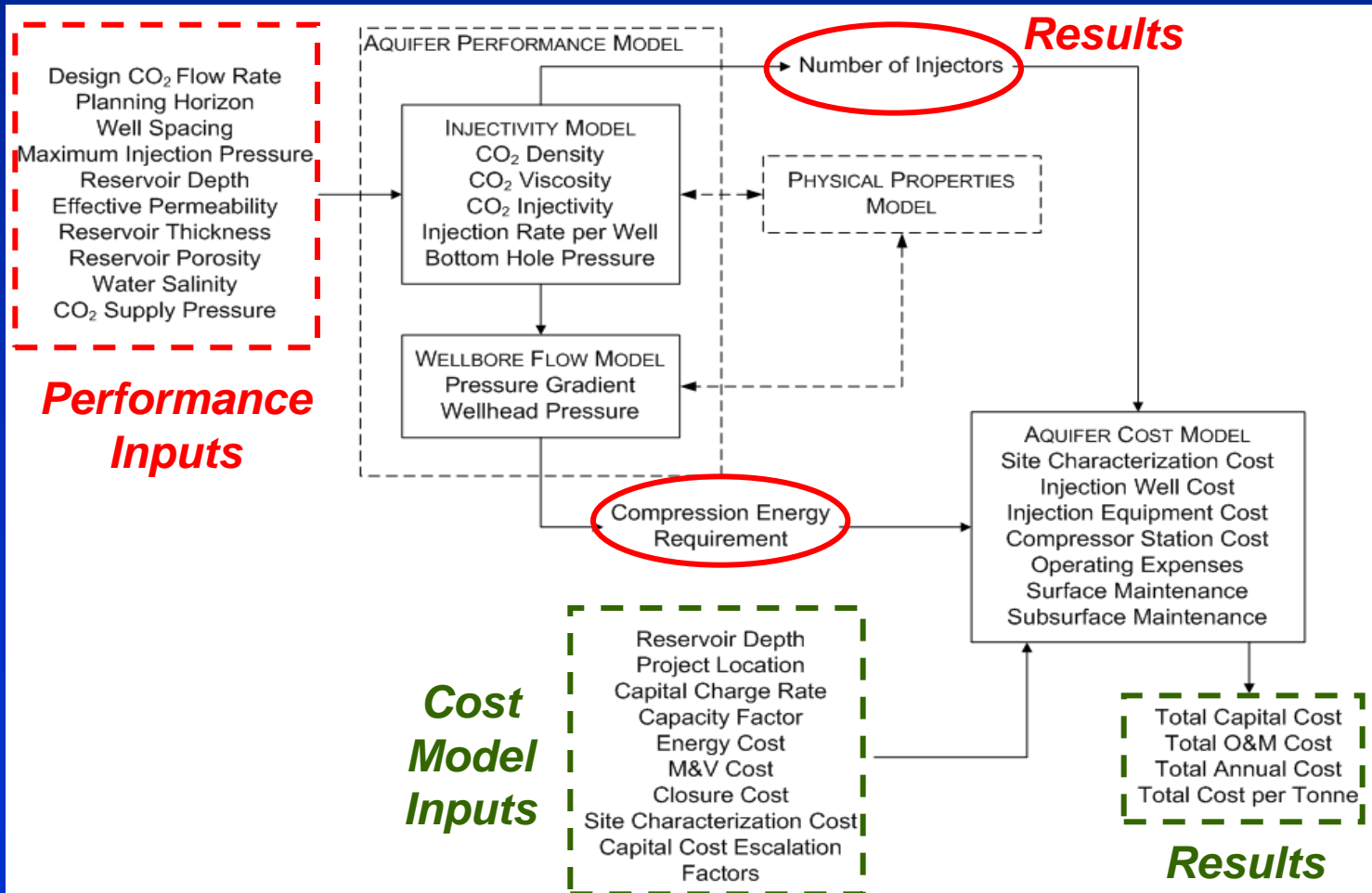
Pipeline Length
Capacity Factor
Energy Cost
Capital Charge Rate
Capital Cost Escalation
Factors
Project Region

PIPELINE COST MODEL
Materials Cost
Labor Cost
Miscellaneous Cost
Right-of-way Cost
Annual O&M Cost

Results

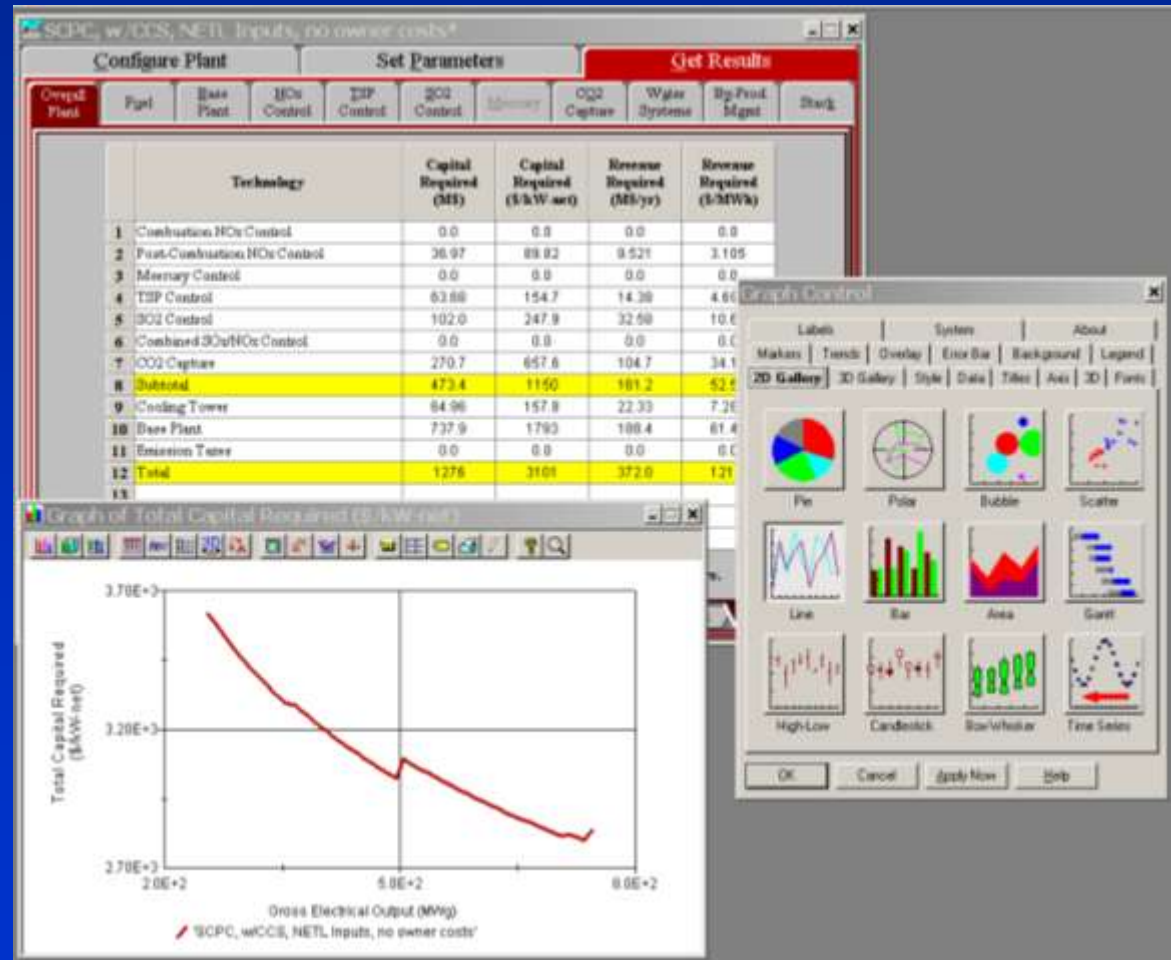
Total Capital Cost
Total O&M Cost
Total Annual Cost
Total Cost per Tonne

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

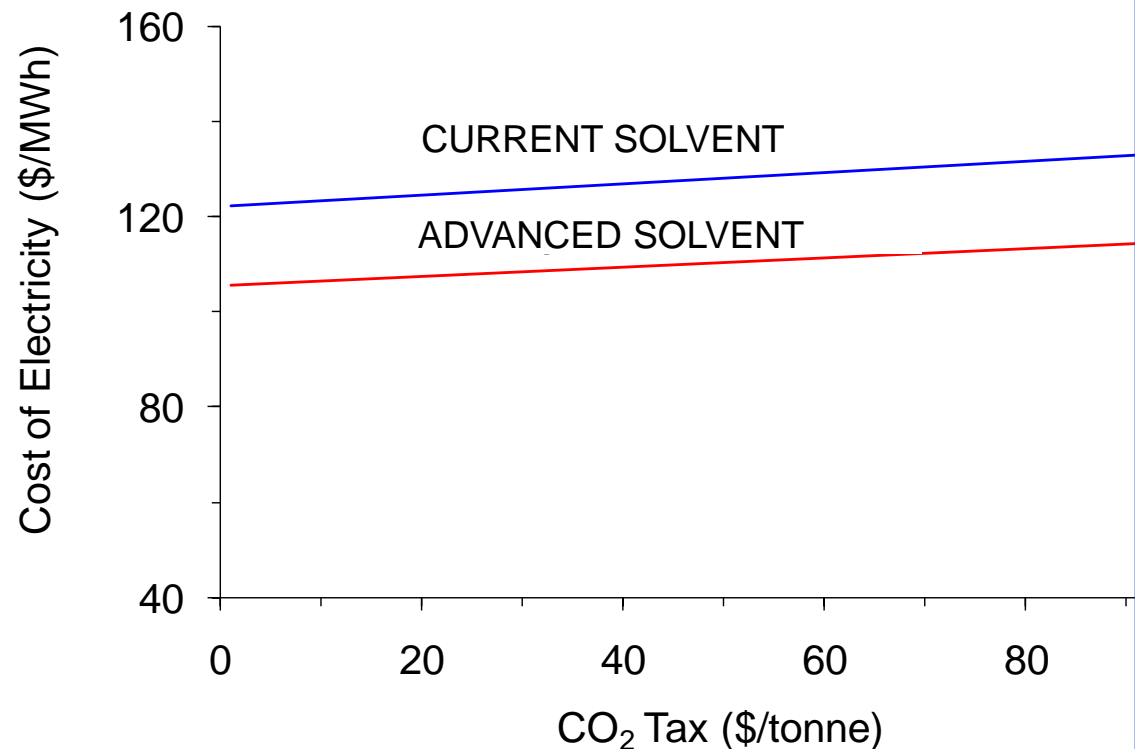
Configure Plant		Set Parameters				Get Results		
Overall Plant	Plant	Base Plant	ICV Control	ZIP Control	CO2 Control	CO2 Capture	Waste Systems	By-Prod Mgmt
Title	Units	Use	Value	Calc	Min	Max	Default	
Absorber								
1 Solvent Concentration	wt %		40.00	<input type="checkbox"/>	15.00	100.0	calc	
3 Lean CO2 Loading	mol CO2/mol sorb		0.1900	<input checked="" type="checkbox"/>	0.0	0.5000	calc	
4 Nominal Solvent Loss	lb/ton CO2		0.5999	<input checked="" type="checkbox"/>	0.0	10.00	calc	
Regenerator								
6 Liquid-to-Gas Ratio	ratio		2.183	<input checked="" type="checkbox"/>	0.0	10.00	calc	
7 Ammonia Generation	mol NH3/mol sorb		1.000	<input checked="" type="checkbox"/>	0.0	2.000	calc	
8 Gas Phase Pressure Drop	psia		1.000	<input checked="" type="checkbox"/>	0.0	5.000	calc	
9 ID Fan Efficiency	%		75.00	<input type="checkbox"/>	50.00	100.0	75.00	
10 Makeup Water for Wash Section	% use flue gas		0.0000	<input type="checkbox"/>	0.0	10.00	0.0000	
Reclaimer								
12 Regen. Heat Requirement	Btu/lb CO2		800.0	<input type="checkbox"/>	500.0	5000	calc	
13 Regen. Steam Heat Content	Btu/lb steam		1173	<input checked="" type="checkbox"/>	500.0	1500	calc	
14 Heat-to-Electricity Efficiency	%		11.00	<input type="checkbox"/>	0.0	40.00	calc	
15 Solvent Pumping Head	psia		30.00	<input type="checkbox"/>	0.0	0.0		
16 Pump Efficiency	%		75.00	<input type="checkbox"/>	50.00			
17 Percent Solids in Reclaimer Waste	%		40.00	<input checked="" type="checkbox"/>	0.0			
18 Capture System Cooling Duty	+H2O/A CO2		91.20	<input checked="" type="checkbox"/>	0.0			

Process Type: CO2 Capture System

Hypothetical Advanced Solvent Properties:

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

SC PC, Illinois #6 Coal
(650 MWg, 75% CF, 90% CO₂ Removal)



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

rubin@cmu.edu