An Integrated Modeling Framework for Carbon Management Technologies

Project Kickoff Meeting
National Energy Technology Laboratory
April 17, 2001

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Carnegie Mellon University
Project Overview

- Starting Date: October 1, 2000
- Duration: 36 months
- DOE Funding: $717,200
- Cost Sharing: $179,200
- Total Amount: $896,400
- Project P.I.: Ed Rubin
- DOE COTR: Sean Plasynski
Current Project Participants

- Mike Berkenpas
- Karen Kietzke
- Anand Rao
- Ed Rubin
- Zach Slaton
- Guodong Sun
- Connie Zaremsky
- Chris Frey (NCSU)
Outline of Today’s Presentation

- Project Description
- Current Status
- Future Plans
- Open Discussion
Scope and Objectives

- Develop an easy-to-use, state-of-the-art computer model that will allow different technology options for carbon capture and storage to be systematically evaluated at the level of an individual plant or facility.
- Incorporate models of current (baseline) technologies, plus potential future options applicable to different types of fossil-fueled power systems.
- Integrate models of carbon management technologies with other environmental control systems for criteria air pollutants and air toxics.
- Conduct case studies to illustrate model applications for R&D management and environmental policy analysis.
Some Questions to be Addressed

- How do alternative carbon capture and sequestration options compare in terms of performance, emissions and cost?
- What are the key parameters that most affect the performance and cost of a given option?
- What are the uncertainties and technological risks of different options?
- What are the priorities and payoffs of R&D to reduce key uncertainties?
- What are the most promising markets for advanced separation and capture technologies?
Major Project Tasks

- Develop computer-based models of:
  - Fossil fuel power system options
  - CO$_2$ capture technologies
  - CO$_2$ transport/storage options
- Characterize key uncertainties
- Illustrate model applications
- Provide model documentation
- Conduct user training sessions
## Project Timetable & Milestones

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<tr>
<th>Task</th>
<th>Months from Project Initiation</th>
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Model Overview

- Coal or Natural Gas
- Air or Oxygen
- Energy Conversion
- CO$_2$ Capture
- CO$_2$ Transport
- CO$_2$ Storage or Disposal
Power Generation Options

Power Generation Technologies

Fuel
- Coal
  - Combustion-based
  - Gasification-based
- Natural Gas
  - Direct Combustion
  - Gas Reforming

Oxidant
- Air
- Oxygen

Technology
- Simple Cycle
  - Pulverized Coal Gas Turbines
- Combined Cycle
  - Gas Turbines
  - Coal Gasification
  - Fuel Cells
  - Other
CO₂ Capture Technologies

CO₂ Separation and Capture

**Absorption**
- Chemical
  - MEA
  - Caustic
  - Other
- Physical
  - Selexol
  - Rectisol
  - Other

**Adsorption**
- Adsorber Beds
  - Alumina
  - Zeolite
  - Activated C
- Regeneration Method
  - Pressure Swing
  - Temperature Swing
  - Washing

**Cryogenics**

**Membranes**
- Gas Separation
  - Polyphenyleneoxide
  - Polydimethylsiloxane
- Gas Absorption
  - Polypropelene
- Ceramic Based Systems

**Microbial/Algal Systems**

CO₂ Separation and Capture
CO₂ Sequestration Options

CO₂ Disposal / Storage Options

Geological Sequestration
- Deep Saline Reservoirs
- Depleted Oil and Gas Wells
- Abandoned Coal Seams

Ocean Sequestration
- Very Deep Ocean Injection
- Unconfined Release (@ ~ 1000 m)
- Dense Plume Formation (shallow)
- Dry Ice Injection

Biological Sequestration
- Forests and Terrestrial Systems
- Marine Alga

Other Methods
- Storage as a solid in an Insulated Repository
- Utilization Schemes (e.g. Polymerization)

Utilization Schemes (e.g. Polymerization)
Modeling Framework

- Build on the Integrated Environmental Control Model (IECM) developed for DOE/NETL under a previous award
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
Approach

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

- A comprehensive modeling framework to estimate the performance, emissions, and cost of coal-based power plants

- A tool for comparing alternative options on a systematic basis, including the effects of uncertainty in performance and cost
IECM Software Package

Fuel Properties
- Heating Value
- Composition
- Delivered Cost

Plant Design
- Furnace Type
- Emission Controls
- Solid Waste Mgmt
- Chemical Inputs

Cost Data
- O&M Costs
- Capital Costs
- Financial Factors

Power Plant Model

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
The IECM is Available Now

- **Web Access:**

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
Welcome to the DOE
Integrated Environmental Control Model

IECM 3.3 B © 2000, Carnegie Mellon University
IECM Interface 3.3 B © 2000, Carnegie Mellon University
Configure Base Plant

**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
Select NO\textsubscript{x} Controls

**Combustion Controls**
- **Furnace Type:** Tangential
- **NO\textsubscript{x} Control:** Low NO\textsubscript{x} Burners

**Post-Combustion Controls**
- **NO\textsubscript{x} Control:** Hot-Side SCR
- **Particulates:** None
- **SO\textsubscript{2} Control:** None
- **SO\textsubscript{2}/NO\textsubscript{x}:** None

**Solids Management**
- **Recovery:** None
- **Fly Ash Disposal:** mixed w/ Landfill

**Plant Diagram**
Select Particulate Controls

**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
Select SO$_2$ Controls

**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
Set Coal Properties

Current Coal
Name: Appalachian Medium Sulfur
Rank: Bituminous
Source: Model Default Coals

Composition (wt% as fired) and Higher Heating Value (Btu/lb)

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Favorite Coals
Name: Wyoming Powder River Basin
Rank: Sub-Bituminous

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Set Base Plant Parameters

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<td>1.5</td>
<td>0</td>
<td>4</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Forced Draft Fans</td>
<td>% MWg</td>
<td></td>
<td>1.8</td>
<td>0</td>
<td>2</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Cooling System</td>
<td>% MWg</td>
<td></td>
<td>1.3</td>
<td>0</td>
<td>4</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>% MWg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Specify Input Uncertainties

### Uncertainty Editor

<table>
<thead>
<tr>
<th>Plant Parameter</th>
<th>Units</th>
<th>Value</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum SO2 Removal Efficiency</td>
<td>%</td>
<td>95</td>
<td>90</td>
<td>99</td>
</tr>
</tbody>
</table>

#### Description:

Triangular(a,b,c) describes a triangular-shaped distribution where the values a, b, and c represent the minimum, most likely and maximum values, respectively.

#### Distribution:
- Normal
- **Triangular**
- Uniform
- Fractiles

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Min</th>
<th>Mode</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0.9000</td>
<td>1.000</td>
<td>1.023</td>
</tr>
<tr>
<td>Nominal</td>
<td>85.50</td>
<td>95.00</td>
<td>97.18</td>
</tr>
</tbody>
</table>

#### Uncertainty Tools: Untitled

**Uncertainty Areas**
- Base Plant
- Air Preheater
- Solid Waste Mgmt.
- NOx Control
- Particulate Control
- SO2 Control
- SO2/NOx Control

**Sample Size:** 50

**Sampling Method:** Median LHS
### Results: Plant Mass Flows

#### Stack Gas Component

<table>
<thead>
<tr>
<th>Stack Gas Component</th>
<th>Flow Rate (ton/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2</td>
<td>1771</td>
</tr>
<tr>
<td>O2</td>
<td>149.0</td>
</tr>
<tr>
<td>H2O</td>
<td>252.7</td>
</tr>
<tr>
<td>CO2</td>
<td>454.3</td>
</tr>
<tr>
<td>CO</td>
<td>0.0</td>
</tr>
<tr>
<td>HCl</td>
<td>2.395e-02</td>
</tr>
<tr>
<td>SO2</td>
<td>1.300</td>
</tr>
<tr>
<td>SO3</td>
<td>3.137e-02</td>
</tr>
<tr>
<td>NO</td>
<td>0.2053</td>
</tr>
<tr>
<td>NO2</td>
<td>1.656e-02</td>
</tr>
<tr>
<td>Ash</td>
<td>3.313e-02</td>
</tr>
<tr>
<td>Total</td>
<td>2629</td>
</tr>
</tbody>
</table>

#### Overall Flow Component

<table>
<thead>
<tr>
<th>Overall Flow Component</th>
<th>Flow Rate (ton/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>166.5</td>
</tr>
<tr>
<td>Lime/Limestone</td>
<td>9.729</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0.3460</td>
</tr>
<tr>
<td>Total</td>
<td>176.6</td>
</tr>
<tr>
<td>Bottom Ash</td>
<td>3.997</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>9.638</td>
</tr>
<tr>
<td>FGD Waste</td>
<td>17.82</td>
</tr>
<tr>
<td>By-Product Ash</td>
<td>0.0</td>
</tr>
<tr>
<td>By-Product Gypsum</td>
<td>0.0</td>
</tr>
<tr>
<td>By-Product Sulfur</td>
<td>0.0</td>
</tr>
<tr>
<td>By-Product Acid</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>31.45</td>
</tr>
</tbody>
</table>
### Table: Plant Cost Summary

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capital Cost (M$)</th>
<th>Capital Cost ($/kW)</th>
<th>O&amp;M Cost (M$/yr)</th>
<th>Revenue Required (M$/yr)</th>
<th>Revenue Required (mills/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 NOx Control</td>
<td>24.04</td>
<td>52.97</td>
<td>3.16</td>
<td>5.645</td>
<td>1.892</td>
</tr>
<tr>
<td>2 TSP Control</td>
<td>19.67</td>
<td>43.34</td>
<td>1.739</td>
<td>3.565</td>
<td>1.194</td>
</tr>
<tr>
<td>3 SO2 Control</td>
<td>64.13</td>
<td>141.3</td>
<td>10.13</td>
<td>17.66</td>
<td>5.817</td>
</tr>
<tr>
<td>4 Comb. SOx/NOx</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>107.8</strong></td>
<td><strong>237.6</strong></td>
<td><strong>15.03</strong></td>
<td><strong>26.87</strong></td>
<td><strong>9.003</strong></td>
</tr>
<tr>
<td>5 Base Plant</td>
<td>437.7</td>
<td>964.2</td>
<td>58.29</td>
<td>99.73</td>
<td>34.69</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>545.5</strong></td>
<td><strong>1202</strong></td>
<td><strong>73.32</strong></td>
<td><strong>126.6</strong></td>
<td><strong>43.70</strong></td>
</tr>
</tbody>
</table>

Costs are in constant 1996 dollars.
Probabilistic Results

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

1.750  2.250  2.750  3.250  3.750

Total Variable Costs (M$/yr)
Model Applications

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

- Risk analysis
- Environmental compliance
- Marketing studies
- Strategic planning
Current Project Status

- Developed preliminary models of performance, emissions, and cost for CO$_2$ capture, transport and storage
- Initial focus on modeling current (baseline) commercial technologies for combustion-based power systems
- Expand the IECM framework to accommodate a wide variety of new process options
- Integrated the new CO$_2$ module for coal combustion systems
CO₂ Capture Using Amine-Based System

Absorber

Exhaust Gas

Blower

Flue Gas

Pump

MEA Storage

CO₂ product

Cooler

Flash

H-Ex*

Regenerator

Spent Sorbent

Reboiler

Lean-hot

rich-hot

rich-cool

lean-cool

MEA makeup

COCO₂ Capture Using Amine-Based System

Absorber

Exhaust Gas

Blower

Flue Gas

Pump

MEA Storage

CO₂ product

Cooler

Flash

H-Ex*

Regenerator

Spent Sorbent

Reboiler

Lean-hot

rich-hot

rich-cool

lean-cool

MEA makeup
MEA-Based CO₂ Capture Process

Flue gas (12% CO₂) → Absorber → Exhaust Gas (1.3% CO₂) → Regenerator → Captured CO₂ (99.8% CO₂) → Regenerated Solvent

MEA-based Solvent

MEA makeup

Acid Gases

CO₂

Carbamate

Heat

Spent Sorbent

Regenerated Solvent
**Amine (MEA-based) Process**

**Model Performance Parameters**

- CO₂ removal efficiency
- SO₂ removal efficiency
- NO₂ removal efficiency
- MEA concentration
- Maximum CO₂ loading
- Lean solvent loading
- Nominal MEA make-up
- MEA loss for SO₂
- MEA loss for NO₂
- MEA regeneration heat
- Equiv. elec. requirement
- CO₂ product pressure
- CO₂ product purity
- Compressor efficiency
- Solvent pumping head
- Pump efficiency
- Gas-phase pressure drop
- Fan efficiency
MEA Model Cost Parameters

- Process Area Costs
- Process Facilities Cost
- Eng’g & Home Office
- General Facilities
- Contingency Costs
- Interest d/ Construction
- Royalty Fees
- Pre-production Costs
- Inventory (startup) Cost
- Total Capital Reqm’t
- Operating Labor
- Maintenance Labor
- Admin./Support Labor
- Maintenance Materials
- Reagent (MEA) Cost
- Waste Disposal Cost
- Water Cost
- Power Cost*
- CO₂ Transport Cost
- CO₂ Storage Cost
CO₂ Module Outputs

- Flue gas composition
- Emission rate of CO₂
- Purity of CO₂ product
- Solvent make-up rate
- Waste generation rate
- Energy penalty
- Net power generation
- Cost of electricity
- Cost of CO₂ avoided
**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
Concentrated CO2 (mt/yr) | 2.711e+06
Multi-Pollutant Interactions

Criteria Air Pollutants
- PM
- SO$_2$
- NO$_x$

Hazardous Air Pollutants
- Hg
- HCl
- H$_2$SO$_4$

Greenhouse Gas Emissions
- CO$_2$
- CH$_4$
### Case Study Plant Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross plant size (MW)</td>
<td>500</td>
<td>Emission standards</td>
<td>2000 NSPS(^a)</td>
</tr>
<tr>
<td>Gross plant heat rate (kJ/kWh)</td>
<td>9767</td>
<td>NO(_x) controls</td>
<td>LNB(^b) + SCR(^c)</td>
</tr>
<tr>
<td>Annual avg. capacity factor (%)</td>
<td>75</td>
<td>Particulate control</td>
<td>ESP(^d)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SO(_2) control</td>
<td>FGD(^e)</td>
</tr>
<tr>
<td><strong>Coal characteristics</strong></td>
<td></td>
<td><strong>Financial Factors</strong></td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>Sub-bit.</td>
<td>CO(_2) capture efficiency (%)</td>
<td>90</td>
</tr>
<tr>
<td>HHV (MJ/kg)</td>
<td>19.4</td>
<td>CO(_2) product pressure (atm)</td>
<td>137</td>
</tr>
<tr>
<td>% S</td>
<td>0.48</td>
<td>Distance to storage site (km)</td>
<td>100</td>
</tr>
<tr>
<td>% C</td>
<td>47.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Ash</td>
<td>6.4</td>
<td>Cost year basis (constant dollars)</td>
<td>1999</td>
</tr>
<tr>
<td>Delivered cost ($/ton)</td>
<td>23.19</td>
<td>Capital charge rate</td>
<td>0.15</td>
</tr>
</tbody>
</table>
## Summary of Plant Emissions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Reference Plant</th>
<th>w/ CO₂ Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net plant capacity</td>
<td>MW (net)</td>
<td>456</td>
<td>358</td>
</tr>
<tr>
<td>CO₂ emitted</td>
<td>tons CO₂/year</td>
<td>2.91 million</td>
<td>0.29 million</td>
</tr>
<tr>
<td>SO₂ emitted</td>
<td>tons SO₂/year</td>
<td>7500</td>
<td>14</td>
</tr>
<tr>
<td>NOₓ emitted</td>
<td>tons NOₓ/year</td>
<td>1390</td>
<td>1290</td>
</tr>
<tr>
<td>CO₂ emission rate</td>
<td>g CO₂ / kWh (net)</td>
<td>971</td>
<td>124</td>
</tr>
<tr>
<td>SO₂ emission rate</td>
<td>g SO₂ / kWh (net)</td>
<td>2.50</td>
<td>0.006</td>
</tr>
<tr>
<td>NOₓ emission rate</td>
<td>g NOₓ / kWh (net)</td>
<td>0.46</td>
<td>0.55</td>
</tr>
</tbody>
</table>
Cost of CO₂ Avoided

Slope = $ / ton CO₂ avoided
Cost of CO$_2$ Avoided

Cumulative probability

Mitigation cost ($/ton CO$_2$ avoided)
Uncertainty in Regeneration
Heat Requirement

Cum. Frequency or Prob.

- Normalized CFD
- CPD used in the model

Regeneration heat (kJ/kg CO₂)

Frequency

Regeneration heat (kJ/kg CO₂)
Sensitivity to Disposal Cost

Cumulative probability vs. Mitigation cost ($/ton CO$_2$ avoided)

- Disposal Cost Case
- EOR Revenue Case
Case Studies of Retrofit Plants

A
Low-S Coal

Power plant → Particulate Control → CO₂ Capture Unit

B
Low-S Coal

Power plant → Particulate Control → New FGD System → CO₂ Capture Unit

C
Low-S Coal

Power plant → Particulate Control → FGD Upgrade → CO₂ Capture Unit

D
High-S Coal

Power plant → Particulate Control → FGD Upgrade → CO₂ Capture Unit
Future Model Development (1)

Power System + CO$_2$ Separation & Capture

- Coal gasification combined cycle systems (IGCC) with current physical adsorption technology (e.g., Rectisol, Selexol)
  - Advanced gasifier (KRW) w/ HGCU
  - Current gasifier (Texaco) w/ CGCU
- Advanced CO$_2$ separation/capture system (e.g., membranes)
Select Gasification Combined Cycle (IGCC) Options

Choose Power System

Please Choose a Power System:
- Conventional Combustion
- Gasification Comb. Cycle
- Advanced Combustion
- Fuel Cells
- Vision 21 Plant
Select Gasifier

Gasification Options
- Gasifier: KRW
- Oxidant: KRW
- Gas Cleanup: Lurgi, Texaco

Post-Combustion Controls
- NOx Control: None

Solids Management
- Slag: Landfill
- Sulfur: Landfill
Select Oxygen Plant

Gasification Options
- Gasifier: KRW
- Oxidant: Oxygen
- Gas Cleanup: Air, Oxygen

Post-Combustion Controls
- NO\textsubscript{x} Control: None

Solids Management
- Slag: Landfill
- Sulfur: Landfill
Select Gas Cleanup System

**Gasification Options**

- **Gasifier:** KRW
- **Oxidant:** Oxygen
- **Gas Cleanup:** Cold

**Post-Combustion**

- **NOx Control:** SCR, None, SCR

**Solids Management**

- **Slag:** Landfill
- **Sulfur:** Landfill
ASPEN Model of an IGCC System

- **Coal Handling**
- **Boiler Feedwater Treatment**
- **Gasification, Particulate & Ash Removal, Fines Recycle**
- **Gasifier Steam**
- **Shift & Regen. Steam**
- **Steam Cycle & SCR**
- **Sulfur Removal Process**
- **Gas Turbines**
- **Sulfuric Acid Plant**
- **Net Electricity Output**
- **Internal Electric Loads**
- **Exhaust Gas**
- **Boiler Feedwater**
- **Return Water**
- **Steam**
- **Turbine**
- **Cooling Water Makeup**
- **Cooling Water Blowdown**
- **Raw Syngas**
- **Captured Fines**
- **Off-Gas**
- **Clean Syngas**
- **Cooling Water**
- **Makeup**
- **Blowdown**
- **Exhaust Gas**
- **Raw Water**
- **Coal**
- **Ash**
- **Tailgas**
- **Sulfuric Acid**
- **Air**
Response Surface Model for an IGCC System
Future Model Development (2)

Power System + CO$_2$ Separation & Capture

- Natural gas combustion systems
  - Simple cycle
  - Combined cycle
  - Current chemical absorption technology (e.g., MEA-based)
Future Model Development (3)

*Power System + CO₂ Separation & Capture*

- Coal combustion with pure oxygen (recycle)
  - Current oxygen plant
  - Current chemical absorption system
  - Advanced oxygen plant
  - Advanced CO₂ capture system
Future Developments:
A Menu of Technology Options

Choose Power System

Please Choose a Power System:
- Conventional Combustion
- Gasification Comb. Cycle
- Advanced Combustion
- Fuel Cells
- Vision 21 Plant
Simple Cycle Gas Plant

Configure Plant

Gasification Options
Plant Type: Simple Cycle

Post-Combustion Controls
NOx Control: None
CO2 Control: None

Solids Management
Slag: Landfill
Sulfur: Landfill

Plant Diagram
Air
Combined Cycle Gas Plant

Gasification Options

- Plant Type: Simple Cycle, Combined Cycle

Post-Combustion Controls

- NOx Control: None
- CO2 Control: None

Solids Management

- Slag: Landfill
- Sulfur: Landfill

Plant Diagram
NGCC Plant with SCR System

Configure Plant

Set Parameters

Get Results

Gasification Options

Plant Type: Combined Cycle

Post-Combustion Controls

NOx Control: SCR
CO2 Control: None

Solids Management

Slag: Landfill
Sulfur: Landfill

Plant Diagram
NGCC Plant with CO₂ Capture

Gasification Options
- Plant Type: Combined Cycle

Post-Combustion Controls
- NOx Control: SCR
- CO₂ Control: None, Absorption - MEA

Solids Management
- Slag: Landfill
- Sulfur: Landfill
Future Model Development (4)

Power System + \( CO_2 \) Separation & Capture

- Natural gas reforming (\( H_2 \) production)
  - Current technology
  - Advanced technology
Case Study Applications

- R&D management
  - Payoffs and risks of new technology
  - Priorities for R&D

- Power plant control strategies
  - Multi-pollutant controls including CO₂
  - Assessment of site-specifics options
Comparisons of Competing Options

Comparisons of Competing Options

Cumulative Probability

Technology A

Technology B

Total Cost Savings Relative to Baseline Technology ($/MWh)
DOE Guidance Needed

- Priorities for advanced technology options
- Formation of a project Advisory Committee
- Case study applications of interest
- Audience for user training sessions
A Hierarchy of Models for Technical and Policy Analysis

- Detailed (mechanistic) models or codes for specific processes or components
- Design options for a single facility (tech. feasibility, cost, efficiency, emissions)
- Multi-facility (or multi-sector) optimization or simulation (dynamic)
- Integrated assessment models (including measures of impacts)