The Integrated Environmental Control Model (IECM)

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March 15, 2000
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
Probabilistic Software Capability

- Allows you to explicitly model and quantify the effects of uncertainty in performance, emissions and cost
- Allows you to specify input parameter values as distribution functions, as well as conventional deterministic values
- Probabilistic results are displayed as cumulative distribution functions, yielding confidence intervals for uncertain results
Conventional Process Modeling (Deterministic Simulation)

Parameter Values → Process Model → Results
Parameter Uncertainty Distributions

- Normal
- Uniform
- Lognormal
- Triangular
- Beta
- Fractile
Stochastic Simulation

Parameter Uncertainty Distributions → Stochastic Modeler → Process Model → Results

SAMPLING LOOP
Example of a Probabilistic Result

Cumulative Probability

Total Capital Requirement ($/kW)

- 1000
- 1100
- 1200
- 1300
- 1400
- 1500

Probabilistic Result

Cumulative Probability
Calculated Plant Efficiency

Cumulative Probability

Net Plant Efficiency (%, HHV basis)

- Probabilistic
- Deterministic
Welcome to the DOE Integrated Environmental Control Model

IECM 3.1 ©1999, Carnegie Mellon University
IECM Interface 3.1 ©1999, Carnegie Mellon University
**Configuring the 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
### Combustion Controls
- **Furnace Type:** Tangential
- **NOx Control:** Low NOx Burners

### Post-Combustion Controls
- **NOx Control:** Hot-Side SCR
- **Particulates:** None
- **SO2 Control:** None
- **SO2/NOx:** None

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

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

Plant Diagram
**Configure Plant**

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

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

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Heating Value</td>
<td>1.326e+04</td>
</tr>
<tr>
<td>2 Carbon</td>
<td>73.81</td>
</tr>
<tr>
<td>3 Hydrogen</td>
<td>4.880</td>
</tr>
<tr>
<td>4 Oxygen</td>
<td>5.410</td>
</tr>
<tr>
<td>5 Chlorine</td>
<td>7.000e-02</td>
</tr>
<tr>
<td>6 Sulfur</td>
<td>2.130</td>
</tr>
<tr>
<td>7 Nitrogen</td>
<td>1.420</td>
</tr>
<tr>
<td>8 Ash</td>
<td>7.230</td>
</tr>
<tr>
<td>9 Moisture</td>
<td>5.050</td>
</tr>
<tr>
<td>10 Cost ($/ton)</td>
<td>32.07</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Heating Value</td>
<td>8340</td>
</tr>
<tr>
<td>2 Carbon</td>
<td>48.18</td>
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<tr>
<td>3 Hydrogen</td>
<td>3.310</td>
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<tr>
<td>4 Oxygen</td>
<td>11.87</td>
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<tr>
<td>5 Chlorine</td>
<td>1.000e-02</td>
</tr>
<tr>
<td>6 Sulfur</td>
<td>0.3700</td>
</tr>
<tr>
<td>7 Nitrogen</td>
<td>0.7000</td>
</tr>
<tr>
<td>8 Ash</td>
<td>5.320</td>
</tr>
<tr>
<td>9 Moisture</td>
<td>30.24</td>
</tr>
<tr>
<td>10 Cost ($/ton)</td>
<td>12.46</td>
</tr>
<tr>
<td>Title</td>
<td>Units</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Gross Electrical Output</td>
<td>MWg</td>
</tr>
<tr>
<td>Steam Cycle Heat Rate</td>
<td>Btu/kWh</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>%</td>
</tr>
<tr>
<td>Capacity Factor</td>
<td>%</td>
</tr>
<tr>
<td>Excess Air For Furnace</td>
<td>% stoich.</td>
</tr>
<tr>
<td>Leakage Air at Preheater</td>
<td>% stoich.</td>
</tr>
<tr>
<td>Gas Temp. Exiting Economizer</td>
<td>deg. F</td>
</tr>
<tr>
<td>Gas Temp. Exiting Air Preheater</td>
<td>deg. F</td>
</tr>
<tr>
<td>Ambient Air Temperature</td>
<td>deg. F</td>
</tr>
<tr>
<td>Ambient Air Pressure</td>
<td>psia</td>
</tr>
<tr>
<td>Ambient Air Humidity</td>
<td>lb H2O/lb dry air</td>
</tr>
<tr>
<td>Collected Bottom Ash Solids</td>
<td>%</td>
</tr>
<tr>
<td>Base Plant Energy Requirements</td>
<td></td>
</tr>
<tr>
<td>Coal Pulvenzer</td>
<td>% MWg</td>
</tr>
<tr>
<td>Steam Cycle Pumps</td>
<td>% MWg</td>
</tr>
<tr>
<td>Forced Draft Fans</td>
<td>% MWg</td>
</tr>
<tr>
<td>Cooling System</td>
<td>% MWg</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>% MWg</td>
</tr>
</tbody>
</table>
Maximum SO2 Removal Efficiency

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

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

**Normalized:**
- Min: 0.9000
- Mode: 1.000
- Max: 1.023

**Nominal:**
- Min: 85.50
- Mode: 95.00
- Max: 97.18

**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.

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

**Uncertainty Tools: Untitled**
- Select All
- Select None

**Sample Size:** 50

**Sampling Method:** Median LHS
### Stack Gas Component

<table>
<thead>
<tr>
<th>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><strong>Total</strong></td>
<td><strong>2629</strong></td>
</tr>
</tbody>
</table>

### Overall Flow Component

<table>
<thead>
<tr>
<th>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>
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<tr>
<td><strong>Total</strong></td>
<td><strong>176.6</strong></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><strong>Total</strong></td>
<td><strong>31.45</strong></td>
</tr>
<tr>
<td>Technology</td>
<td>Capital Cost (M$)</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------------</td>
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<tr>
<td>NOx Control</td>
<td>24.04</td>
</tr>
<tr>
<td>TSP Control</td>
<td>19.67</td>
</tr>
<tr>
<td>SO2 Control</td>
<td>64.13</td>
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<tr>
<td>Comb. SOx/NOx</td>
<td>0.0</td>
</tr>
<tr>
<td>Subtotal</td>
<td>107.8</td>
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<tr>
<td>Base Plant</td>
<td>437.7</td>
</tr>
<tr>
<td>Total</td>
<td>545.5</td>
</tr>
</tbody>
</table>

Costs are in Constant 1996 dollars.
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

Total Variable Costs (M$/yr)
Model Applications

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

- Risk analysis
- Environmental compliance
- Marketing studies
- Strategic planning
The IECM is Available for Downloading

- **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
Additional Technology Options

- **In Progress**
  - Combustion NO\textsubscript{x} Controls
    - Selective Non-Catalytic Reduction (SNCR)
    - Low NO\textsubscript{x} Burners (LNB)
    - LNB + Overfire air
    - LNB + SNCR
    - Natural Gas Reburn
    - Tangential, Wall & Cyclone Firing

- **Proposed**
  - Post-Combustion Controls
    - Air Toxics (mercury)
  - Other Fuels
    - Natural Gas
    - Petroleum
    - Fuel Blending
  - Alternative Power Generation Systems
Opening Screen:
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
Select Gasification Combined Cycle (IGCC) Options
Select KRW Gasifier
Select Oxygen Plant

Configure Plant

Goal: Optimization

Gasification Options
Gasifier: KRW
Oxidant: Oxygen
Gas Cleanup: Oxygen

Post-Combustion Controls
NOx Control: None

Solids Management
Slag: Landfill
Sulfur: Landfill

Plant Diagram
Select Cold Gas Cleanup

Configure Plant

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
Select NO$_x$ Control

Configure Plant

**Goal:**
- Optimization

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

**Post-Combustion**
- **NOx Control:**
  - SCR
  - None
  - SCR

**Solids Management**
- **Slag:** Landfill
- **Sulfur:** Landfill

Plant Diagram
Select Byproduct Recovery

Configure Plant

Goal: Optimizatization

Gasification Options
- Gasifier: KRW
- Oxidant: Oxygen
- Gas Cleanup: Hot

Post-Combustion Controls
- NOx Control: SCR

Solids Management
- Slag: Landfill
- Sulfur: Sulfur, Landfill, Sulfuric Acid
## Set Process Parameters

### Configure Plant
- Overall Plant
- Coal Properties
- IGCC

### Set Parameters
- Furnace Factors
- Emission Constraints
- NOx Control
- Particulate Control
- SO2 Control
- Solid Waste Mgmt

### Table: Process Parameters

<table>
<thead>
<tr>
<th>Title</th>
<th>Units</th>
<th>Unc</th>
<th>Value</th>
<th>Calc</th>
<th>Min</th>
<th>Max</th>
<th>Default</th>
<th>DV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasifier Design</td>
<td>%</td>
<td></td>
<td>95.0</td>
<td>90.0</td>
<td>98.0</td>
<td>95.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasifier Carbon Conversion</td>
<td>mol O2 / mol C</td>
<td>0.46</td>
<td>0.45</td>
<td>0.47</td>
<td>0.455</td>
<td>0.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasifier Steam to Carbon Ratio</td>
<td>mol H2O / mol C</td>
<td>0.46</td>
<td>0.445</td>
<td>0.455</td>
<td>0.46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal-bound N Converted to NH3</td>
<td>%</td>
<td>10.0</td>
<td>5.0</td>
<td>15.0</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur Retained in Gasifier Bot Ash</td>
<td>%</td>
<td>90.0</td>
<td>80.0</td>
<td>95.0</td>
<td>90.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions Control</td>
<td>mol Ca / mol C</td>
<td>2.60</td>
<td>2.10</td>
<td>3.00</td>
<td>2.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium to Sulfur Ratio</td>
<td>%</td>
<td>95.0</td>
<td>90.0</td>
<td>98.0</td>
<td>95.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfation Unit Conversion</td>
<td>%</td>
<td>90.0</td>
<td>50.0</td>
<td>90.0</td>
<td>90.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH3 Converted to NOx in Turbine</td>
<td>%</td>
<td>80.0</td>
<td>50.0</td>
<td>90.0</td>
<td>80.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCR NOx Removal Efficiency</td>
<td>%</td>
<td>10.0</td>
<td>5.0</td>
<td>20.0</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCR NH3 Slip</td>
<td>ppmw</td>
<td>10.0</td>
<td>5.0</td>
<td>20.0</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Open Vision 21 Plant Options

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
Configure a New System

Vision 21 Plant:
User Specified

Plant Diagram:
- Air
- CO₂
- H₂

Configure Plant  Set Objectives  Set Parameters  Get Results
Advanced Design Capabilities: Operation Overview
THE END

(applause)