The Vision 21 Planner: A New Modeling Tool for Preliminary Cost and Performance Assessments of Vision 21 Plants

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Vision 21 Modeling Needs

- A hierarchy of models tailored to the needs of different users and applications, ranging from:
  - Preliminary design and screening analysis, to
  - Detailed design of a “virtual” plant
- A range of capabilities for predicting the performance, reliability and cost of:
  - Individual plant components
  - Integrated Vision 21 plant designs
The Vision 21 Planner Would …

- Bring together performance and cost models for a variety of enabling technologies and Vision 21 system designs
- Run quickly and easily on a desktop or laptop computer for preliminary design and analysis
- Allow new process concepts and components to be easily incorporated into new Vision 21 designs
- Allow uncertainties to be characterized explicitly
- Facilitate rapid analysis of “what if” questions and the selection of promising designs for further study
Attributes of Different Models

- Turnaround Time
  - Weeks
  - Days
  - Hrs
  - Min
  - Sec

- Scope
  - Micro-Scale
  - Plant Component
  - Mult-Component
  - Integrated Plant

- Complexity
  - Algebraic
  - Mechanistic

- Models
  - CFD
  - ASPEN
  - IECM/V21P
Modeling Approach

- Systems Analysis Framework
- Process Technology Models
- Engineering Economic Models
- Advanced Software Capabilities
  - Probabilistic analysis capability
  - User-friendly graphical interface
  - Easy to add or update models
Framework for the V21 Planner:
The Integrated Environmental Control Model (IECM)
# Current IECM Technologies

## Furnace Types
- Tangential
- Wall
- Cyclone

## Furnace NO\(_x\) Controls
- LNB
- SNCR
- SNCR + LNB
- Gas reburn

## NO\(_x\) Removal
- Hot-side SCR

## Mercury Removal
- Carbon injection
- Carbon + water

## 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\(_2/NO_x\) Removal
- Copper oxide
- NOXSO

## Solids Management
- Ash pond
- Landfill
- Stacking
- Co-mixing
- Byproducts
  - Ash
  - Gypsum
  - Sulfuric Acid
IECM User Group

ABB
AEP-SCR Engineering
Airborne Technologies
Akzo Nobel Functional Chem
Alberta Economic Development
Alberta Environment
ALCOA Power Generating, Inc.
Allegheny Energy Supply
Aliant Energy
Alstom Power Inc.
American Electric Power
Apogee Scientific, Inc.
Applied Technology Services
Argonne National Laboratory
ATCO Power
Babcock Borsig Power, Inc.
Babcock & Wilcox Co.
Bechtel Power Corp.
Black & Veatch Corp.
BOC Gases
Boiler Systems Engineering
Canada Environment
Canada Natural Resources
Carnegie Mellon University
Cinergy Power Generation
Clean Energy Int.
Cogentrix Energy, Inc.
CONSOL Energy, Inc.
Consumers Energy
CP&L
CPG, Inc.
CQ, Inc.
Croll-Reynolds
Department of Environmental Prot
Detroit Edison Co.
Diamond Power Specialty Co
Doyen & Associates, Inc.
Duke Engineering & Services.
Duke Fluor Daniel
Dynegy Midwest Generation
Electric Energy, Inc. (EEI)
Electricite de France
Emera Inc.
Emery Recycling Corporation
Enerco
Enepro
Energy & Environ Research Corp.
Energy & Environ Strategies
Energy Systems Associates
Energy Technology Enterprises
ENSR, Inc.
Environmental Defense
Enviro & Renewable Energy Syst
EPRI, Palo Alto
Exportech Company, Inc.
FirstEnergy Corp.
Florida Power & Light Co.
FLS Miljo A/S
Fortum Power and Heat Oy
Fossil Energy Research Corp.
Foster Wheeler Development
Foster Wheeler USA Corp.
Fuel Tech, Inc.
General Electric Company
Goodwin Environmental
Great River Energy
Gyeongsang National University
H&W Management Science
Hamon Research Cottrell, Inc.
Harza Engineering
Holland Board of Public Works
IEA Coal Research
Illinois Clean Coal Institute
Illinois Dept. of Natural Resources
Illinois EPA
Illinois Institute of Technology
Indiana Dept. of Env. Mgt.
Intermountain Power Service Corp.
Jack R. McDonald, Inc.
Kansas City Power & Light Co.
KEMA Nederland B.V.
Kinectrics
Korea Electric Power Corporation
Korea Institute of Energy Research
Korea Western Power Co.
Krupp Polysius Corp.
LAB SA
Lehigh University
Lower Colorado River Authority
Mail Station PA8358
McDermott Technology, Inc.
MidAmerican Energy Co.
Minakota Power Cooperative, Inc.
Mitsubishi Heavy Industries, Ltd.
Mitsui Babcock Energy Ltd.
National Park Service
National Power Plc.
NESCAUM
New Hampshire Dept. of Env. Svc
New Jersey DEP
Nicholson Environmental, Inc.
Niksa Energy Associates
NIPSCO
Niro A/S
North Carolina DENR
North Carolina State Univ
Ontario Power Generation
Pacific Corp.
Parsons Technology
Pavillon Technologies, Inc.
Pennsylvania Electric Assoc
PEPCO
PG&E National Energy Group
Pinnacle West Energy
Potomac Electric Power Co.
PowerGen
PPL Generation, LLC
PPL Montana, LLC
Predict Maintenance Tech
Princeton University
Progress Materials, Inc.
PSEG Power LLC
Public Power Institute
Reaction Engineering Intl
Research Triangle Institute
Rheinbraun Brennstoff GmbH
Sargent & Lundy, LLC
SaskPower
Savvy Engineering, LLC
Scientech
Sierra Pacific Power Co.
Southern Company Services, Inc.
State of New Jersey
Stone & Webster Engineering Corp.
Superior Adsorben, Inc.
Syncrude
Tampa Electric Co.
Tennessee Valley Authority
Texas Natural Resource Conv Comm
TNO Envit, Energy & Process Innov
TransAlta
TXU Electric
U.S. DOE
U.S. EPA
University of California
University of New Orleans
University of Pittsburgh
URS Corporation
Utah Dept. of Env. Quality
W.L. Gore & Associates, Inc.
Washington Power
Western Kentucky Energy Corp.
Wheelabrator Air PollControl
Wisconsin Dept. of Nat Resources
Wisconsin Electric Power Co.
Wisconsin Energy Corp.
Wisconsin Public Service Corp.
Wisvest-Connecticut, LLC
Expanding the Framework to Vision 21 Plants
Major Components of V21 Plants

- Gasifiers
- Combustors
- Fuel Cells
- Gas Turbines
- Steam Turbines
- Air Separation Units
- Byproduct Recovery Systems

- Gas Purification Systems for:
  - Solids (ash)
  - Sulfur compounds
  - Nitrogen oxides
  - Mercury
  - Other trace elements
  - Carbon dioxide
Current Modeling Activities

• Enhanced Software Capabilities
• **Plant Component Models** (perf & cost)
  ▪ Air separation units
  ▪ Oxygen-blown gasifiers
  ▪ Advanced gas turbines
  ▪ Solid oxide fuel cells
  ▪ CO$_2$ capture systems
• **Integrated Plant Models**
  ▪ Current IGCC with cold gas cleanup
  ▪ Advanced IGCC with CO$_2$ capture and storage
  ▪ Combustion-based systems w/ CO$_2$ capture
  ▪ Hybrid plants with SOFC/gas turbines
Water-Gas Shift Reactor Model

Syngas → Steam → High Temp Reactor → H₂O Heater → Low Temp Reactor → Fuel Gas Heater → H₂O Heater → Shifted Syngas
CO$_2$ Capture System Model
(Selexol Process)

Absorber

Turb

Sump

Comp

Turb

Flash 1

Flash 2

Flash 3

Comp

Refrigeration

Lean Selexol

Pump

CO$_2$ to Storage

Shifted Syngas

H$_2$ Fuel Gas

COCO$_2$ Capture System Model
(Selexol Process)

H$_2$ Fuel Gas

CO$_2$ to Storage
Gasifier Models

Coal
% C, H, S, O, N, Cl
% Ash

Hydrogen
H₂O

Oxygen
Air or O₂

Syngas
% CO
% H₂
% CH₄
% CO₂
% H₂S
% COS
% NH₃

Slag
Gasifier Model Parameters

• Independent variables for V21 Planner include:
  ▪ Gasifier type (Texaco, E-Gas, Shell, KRW)
  ▪ Coal type (6 coal choices)
  ▪ Water-to-coal input ratio
  ▪ Oxygen-to-coal input ratio
  ▪ Gasifier temperature
  ▪ Carbon loss in gasifier

• Performance models derived from ASPEN-based IGCC flowsheets developed by DOE/NETL
Gasifier Response Surface Model
(Carbon partitioning to CO, E-Gas gasifier, PRB coal)
Linking Performance and Cost

- Fuel and Plant Input Data
- Performance Model
- Cost Model

- Performance
- Emissions
- Cost
### Example IGCC Capital Cost Process Areas and their Dependent Variables

<table>
<thead>
<tr>
<th>Area</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR SEPARATION UNIT</td>
<td>oxygen feed rate to gasifier</td>
</tr>
<tr>
<td>COAL HANDLING AND SLURRY PREPARATION</td>
<td>coal feed rate to gasifier</td>
</tr>
<tr>
<td>GASIFICATION</td>
<td>as-received coal flow rate</td>
</tr>
<tr>
<td></td>
<td>percent moisture in coal</td>
</tr>
<tr>
<td></td>
<td>percent ash in coal feed</td>
</tr>
<tr>
<td></td>
<td>solids mass flow leaving gasifier</td>
</tr>
<tr>
<td>LOW TEMPERATURE GAS COOLING</td>
<td>syngas mass flow rate</td>
</tr>
<tr>
<td>SELEXOL UNIT</td>
<td>syngas mass flow rate</td>
</tr>
<tr>
<td>CLAUS PLANT</td>
<td>recovered sulfur mass flow rate</td>
</tr>
<tr>
<td>BEAVON-STRETTFORD UNIT</td>
<td>mass flow rate sulfur produced</td>
</tr>
<tr>
<td>BOILER FEEDWATER SYSTEM</td>
<td>raw water flow to demineralizer</td>
</tr>
<tr>
<td></td>
<td>polished water flow to polisher</td>
</tr>
<tr>
<td>PROCESS CONDENSATE TREATMENT</td>
<td>scrubber blowdown flow rate</td>
</tr>
<tr>
<td>GAS TURBINE</td>
<td>net gas turbine shaft work</td>
</tr>
<tr>
<td>HEAT RECOVERY STEAM GENERATOR</td>
<td>high pressure flow to steam turbine</td>
</tr>
<tr>
<td>STEAM TURBINE</td>
<td>net steam turbine shaft work</td>
</tr>
<tr>
<td>AUXILIARY EQUIPMENT</td>
<td>miscellaneous power consumption</td>
</tr>
<tr>
<td></td>
<td>steam cycle auxiliary power consumption</td>
</tr>
</tbody>
</table>
Prototype
Graphical
Interface
Open a New Session

![New Session dialog box with options: IGCC, Combustion, FuelCell, Vision 21]
<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>
</tr>
</thead>
<tbody>
<tr>
<td>Syngas Composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>vol %</td>
<td></td>
<td>33.06</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Hydrogen (H2)</td>
<td>vol %</td>
<td></td>
<td>20.27</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Methane (CH4)</td>
<td>vol %</td>
<td></td>
<td>0.5096</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Hydrogen Sulfide (H2S)</td>
<td>vol %</td>
<td></td>
<td>0.9648</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
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<tr>
<td>Carbonyl Sulfide (COS)</td>
<td>vol %</td>
<td></td>
<td>5.120e-02</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Ammonia (NH3)</td>
<td>vol %</td>
<td></td>
<td>8.301e-03</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Hydrochloric Acid (HCl)</td>
<td>vol %</td>
<td></td>
<td>4.913e-02</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Carbon Dioxide (CO2)</td>
<td>vol %</td>
<td></td>
<td>15.87</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Moisture (H2O)</td>
<td>vol %</td>
<td></td>
<td>19.39</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Nitrogen (N2)</td>
<td>vol %</td>
<td></td>
<td>0.6081</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Argon (Ar)</td>
<td>vol %</td>
<td></td>
<td>1.152</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
<tr>
<td>Total</td>
<td>vol %</td>
<td></td>
<td>100.0</td>
<td></td>
<td>0.0</td>
<td>100.0</td>
<td>calc</td>
</tr>
</tbody>
</table>

Process Type: Texaco
Gasification Options
- Gasifier: Texaco (Oxygen-blown)
- Gas Cleanup: Cold-gas
- CO2 Control: Sour Shift + Selexol

Post-Combustion Controls
- NOx Control: None

Solids Management
- Slag: Landfill
- Sulfur: Sulfur Plant

IGCC Base Configuration

<table>
<thead>
<tr>
<th>Process Type: Gas Turbine</th>
<th>Direct Capital Costs (M$)</th>
<th>Gas Turbine System</th>
<th>Indirect Capital Costs (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gas Turbine</td>
<td>32.00</td>
<td>1 Process Facilities Capital</td>
<td>63.63</td>
</tr>
<tr>
<td>2 Heat Recovery Steam Generator</td>
<td>7.485</td>
<td>2 General Facilities Capital</td>
<td>6.363</td>
</tr>
<tr>
<td>3 Steam Turbine</td>
<td>21.94</td>
<td>3 Eng. &amp; Home Office Fees</td>
<td>6.363</td>
</tr>
<tr>
<td>4 HRSG Feedwater System</td>
<td>2.201</td>
<td>4 Project Contingency Cost</td>
<td>9.544</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>5 Process Contingency Cost</td>
<td>4.736</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>6 Interest Charges (AFUDC)</td>
<td>9.656</td>
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<tr>
<td>7</td>
<td></td>
<td>7 Royalty Fees</td>
<td>0.3181</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>8 Reproduction (Startup) Cost</td>
<td>2.310</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>9 Inventory (Working) Capital</td>
<td>0.4532</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>10 Total Capital Requirement (TCR)</td>
<td>103.4</td>
</tr>
<tr>
<td>11 Process Facilities Capital</td>
<td>63.63</td>
<td>11 Effective TCR</td>
<td>103.4</td>
</tr>
</tbody>
</table>

Costs are in Constant 2000 dollars.
Case Study Results for Cost of CO₂ Avoided

![Graph showing cumulative probability vs. cost of CO₂ avoided.](image)

- **Deterministic**
- **Performance + cost models**
- **CO₂ compres, transp & storage**
- **All uncertainties combined**

Cost of CO₂ Avoided ($/tonne CO₂)
Solid Oxide Fuel Cell Model

- Fuel Composition
- Oxidant
- Pressure
- Temperature

- Ideal Nerst Voltage
  - Activation Polarization
  - Exchange Current
  - Concentration Polarization
  - Limiting Current

- Actual Cell Voltage
  - Ohmic Polarization
  - Fuel Utilization
  - Resistivity
  - Thickness
  - Area

- Power Output
  - No. of Cells
  - Current Density
  - Cell Area
Fuel Cell – Gas Turbine Hybrid

Fuel Desulfurizer → Internal Reformer → SOFC → After Burner → Gas Turbine

Fuel Input (Gas) → Compressor

Heat Exchanger → Exhaust

Compressor

Air
Coming Later . . .
Configure a New System

Vision 21 Plant:
User Specified

Plant Diagram

- Air
- Water
- Chemical
- Gas
- Liquid
- Solid

Air → H$_2$O → H$_2$ → CO$_2$
Looking Ahead

• Finish implementing and testing prototype V21P model (including SOFC); distribute for beta testing and user feedback

• Continue to develop and improve modeling of:
  ▪ Individual plant components (Performance/Cost)
  ▪ Interactions and integration across components

• Develop “seamless” linkages with higher-level models
  ▪ CFD models of key components (e.g., gasifiers)
  ▪ Virtual Engineering simulation of an entire plant