Overview

Timeline
- Project start: December 2006
- Project end: October 2007
- Percent complete: 40%

Budget
- Total funding: $265K
  - FY 2007: $265K

Barriers Addressed
- Stove-piped/siloed analytical capabilities (B)
- Inconsistent data, assumptions, and guidelines (C)
- Need for improvement in models for better consistency and usability (D)
- Need flexible capabilities for unplanned studies & analysis (E)

Collaborators
- NETL, DTI, Technology Insights, ANL
Objectives

• The H2A model aims to make analyses:
  – Consistent
  – Transparent
  – Comparable

• Phase II goals:
  – Reflect current DOE program direction
  – Reflect best understanding of available technologies
    • Cost assumptions
    • Performance assumptions
  – Simplify model structure and user interface
  – Improve transparency
  – Provide new features
Model Approach

• Excel spreadsheet
• Discounted cash flow rate-of-return analysis
• Provides the levelized selling price of hydrogen required to attain a specified internal rate-of-return
  – i.e., minimum hydrogen price or profited cost (not market price)
• Model is meant to be a means of reporting assumptions as well as calculating minimum hydrogen selling price
• Transparency is absolute
Revision Approach

• Build on existing H2A model
• Develop specific revisions to the model structure and user interface
• Insure accuracy and detail of specific production cases
• Improve model outputs and user-specified inputs
• Develop model documentation
• Only addressing H2A production, not HD-SAM (H2A delivery)
Model Changes

- Simplify underlying spreadsheet structure
- Develop user interface and improve user inputs
- Develop flat-file output capability
- Use Hydrogen Analysis Resource Center data
  - Hydrogen and physical properties data
- Monte Carlo sensitivity analysis
- Develop specific new features
- Develop import/export capabilities
New Features

- Plant size scaling
- Automated sensitivity analyses and graphing
- Carbon sequestration costs and amounts
- WTW/WTP emissions calculations
- Maintain 2005 for baseline feedstock and utility prices (AEO2005 High A), but develop toggle to use AEO2007 prices
**H2A Cash Flow Modeling Tool**

**Standard Price and Property Data**

- **Feedstock and Utility Prices**
- **Physical Property Data**

**Cost Analysis**

- **Financial Inputs**
- **Cost Inputs**
- **Replacement Costs**

- **Performance Assumptions**
- **Process Flowsheet**
- **Stream Summary**

**Results**

- **Cost of H₂**
- **Cost Contribution**
- **Sensitivity Analyses**

**Spreadsheet Examples**

**Table A. Feedstock and Utility Costs Used in H2A Spreadsheet Calculations if escalated prices used (Year 2000 $)**

<table>
<thead>
<tr>
<th>Feedstock and Utility</th>
<th>Commercial Natural Gas</th>
<th>Industrial Natural Gas</th>
<th>Electric Utility Natural Gas</th>
<th>Commercial Electricity</th>
<th>Industrial Electricity</th>
<th>Electric Utility Steam Coal</th>
<th>Diesel Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price $(2000)/Nm³</td>
<td>Commercial Natural Gas</td>
<td>Industrial Natural Gas</td>
<td>Electric Utility Natural Gas</td>
<td>Commercial Electricity</td>
<td>Industrial Electricity</td>
<td>Electric Utility Steam Coal</td>
<td>Diesel Fuel</td>
</tr>
<tr>
<td><strong>Cost Analysis</strong></td>
<td><strong>Cost Analysis</strong></td>
<td><strong>Cost Analysis</strong></td>
<td><strong>Cost Analysis</strong></td>
<td><strong>Cost Analysis</strong></td>
<td><strong>Cost Analysis</strong></td>
<td><strong>Cost Analysis</strong></td>
<td><strong>Cost Analysis</strong></td>
</tr>
<tr>
<td><strong>Category</strong></td>
<td><strong>Contribution to Required Hydrogen Selling Price ($/kg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital Costs</td>
<td>$1.424</td>
<td>$0.002</td>
<td>$0.372</td>
<td>$2.408</td>
<td>$0.022</td>
<td>$0.000</td>
<td>$0.000</td>
</tr>
<tr>
<td>Decommissioning Costs</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
</tr>
<tr>
<td>Fixed O&amp;M</td>
<td>$0.500</td>
<td>$1.000</td>
<td>$1.500</td>
<td>$2.000</td>
<td>$2.500</td>
<td>$3.000</td>
<td>$3.500</td>
</tr>
<tr>
<td>Feedstock Costs</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
</tr>
<tr>
<td>Other Raw Material Costs</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
</tr>
<tr>
<td>Byproduct Credits</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
<td>$0.029</td>
</tr>
<tr>
<td>Other Variable Costs</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
<td>$0.000</td>
</tr>
</tbody>
</table>

**Technical Analysis**

- **Press this button to determine the minimum hydrogen selling price**

- **Solve Cash Flow for Desired IRR**
H2A Spreadsheet Features

- Color-coded to facilitate user input

<table>
<thead>
<tr>
<th></th>
<th>Calculated Cells</th>
<th>User Input Required</th>
<th>Optional Input</th>
<th>Information</th>
</tr>
</thead>
</table>

- Inputs may be either H2A standard inputs or user-defined
- Error messages included to alert user when input errors are made
- Documentation available for model support
Key Financial Parameters

- Reference year (2005 $)
- Debt versus equity financing (100% equity)
- After-tax internal rate-of-return (10% real)
- Inflation rate (1.9%)
- Effective total tax rate (38.9%)
- Design capacity (varies)
- Capacity factor (90% for central [exc. wind]; 70% for forecourt)
- Length of construction period (0.5 - 3 years for central; 0 for forecourt)
- Production ramp-up schedule (varies according to case)
- Depreciation schedule (MACRS – 20 yrs for central; 7 yrs for forecourt)
- Plant life and economic analysis period (40 yrs for central; 20 yrs for forecourt)
- Cost of land ($5,000/acre for central; land is rented in forecourt)
- Burdened labor cost ($50/hour central; $15/hour forecourt)
- G&A rate as % of labor (20%)
H2A Current Technology Results

Profited Cost Contributions, Current Technology Status, 10% IRR

- Central Biomass
- Central Coal without CO2 sequestration
- Central Natural Gas without CO2 Seq
- Central Wind Current
- Forecourt Electrolyser 1500 kg/day
- Forecourt SMR 1500 kg/day

$/kg Hydrogen

- Feedstock O&M
- Fixed O&M Cost Contribution
- Capital Cost Contribution
Sample Sensitivity Analysis

“Tornado” Chart: Single-parameter sensitivity
Production Case Updates

• Up-to-date technology assumptions
  – Performance assumptions, cost assumptions (capital, fixed O&M)

• Consistency and robustness
  – Consistent assumptions, level of detail, process flow diagrams, conversions

• Improve transparency
  – More detailed break down of costs, technologies modeled, components and subsystems used
## Case Studies: Central Technologies

<table>
<thead>
<tr>
<th></th>
<th>Coal Gasification</th>
<th>Coal Gasification w/ CO₂ Sequestration</th>
<th>Coal Gasif w/ CO₂ Seq &amp; Power Co-Production</th>
<th>Biomass Gasif Gasification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod Rate</td>
<td>250 tpd</td>
<td>250 tpd</td>
<td>250 tpd</td>
<td>155 tpd</td>
</tr>
<tr>
<td>Current</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Distinct</td>
</tr>
<tr>
<td>Future</td>
<td>+Membrane</td>
<td>+Membrane Separation</td>
<td>+Membrane Separation</td>
<td>Integrated</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Natural Gas Reforming</th>
<th>Nat Gas Reforming w/ CO₂ Sequestration</th>
<th>Nuclear-Steam Electrolysis</th>
<th>Nuclear Sulfur-Iodine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod Rate</td>
<td>250 tpd</td>
<td>250 tpd</td>
<td>700 tpd</td>
<td>700 tpd</td>
</tr>
<tr>
<td>Current</td>
<td>Conventional</td>
<td>Conventional</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Future</td>
<td>Improved Efficiency</td>
<td>Improved Efficiency</td>
<td>High-Temp Steam Electrolysis</td>
<td>SI Thermo-Chemical</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Electrolysis (Grid Electricity)</th>
<th>Electrolysis (Wind + Grid)</th>
<th>Electrolysis (Low-Temp Nuclear)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod Rate</td>
<td>100 tpd</td>
<td>100 tpd</td>
<td>700 tpd</td>
</tr>
<tr>
<td>Current</td>
<td>Low Pressure</td>
<td>Low Pressure</td>
<td>Low Pressure</td>
</tr>
<tr>
<td>Future</td>
<td>High Pressure</td>
<td>High Pressure</td>
<td>High Pressure</td>
</tr>
</tbody>
</table>

Note: tpd = tons of hydrogen per day
## Case Studies: Forecourt Technologies

<table>
<thead>
<tr>
<th>Type of Station</th>
<th>Small (100 kg/day)</th>
<th>Large (1,500 kg/day)</th>
<th>Current Technology / Design Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Reformer</td>
<td>X</td>
<td>X</td>
<td>SMR with PSA cleanup, 6250 psi piston compressors, cascade dispensing</td>
</tr>
<tr>
<td>Methanol Reformer</td>
<td>X</td>
<td>X</td>
<td>Comparable to SMR design, low temperature</td>
</tr>
<tr>
<td>Ethanol Reformer</td>
<td>X</td>
<td>X</td>
<td>Comparable to SMR design</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>X</td>
<td>X</td>
<td>Electrolyzer, 6250 psi piston compressors, cascade storage and dispensing</td>
</tr>
</tbody>
</table>

Note: All cases include assessment of current and future technologies.
Future Work

• Expand model to address hydrogen quality
• Address other environmental concerns
  – e.g., water use and water quality
• Develop city-gate/semi-central production cases
• Expand available production cases
  – Coal to Fischer-Tropsch liquids
  – Forecourt aqueous phase reactor
  – Advanced bio-derived liquids
Project Summary

- Specific revisions to existing H2A model structure and interface
- Add new model features
  - Plant scaling, carbon sequestration, WTP emissions, automated sensitivity analyses
- Improve model outputs and user-specified inputs
- Insure accuracy/detail of specific production cases and improve transparency
- Develop model documentation
- Only addressing H2A production, not HD-SAM (H2A delivery)