Technical and Economic Studies of Regional Transition Strategies toward Widespread Use of Hydrogen Energy

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Alexandria, VA
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This presentation does not contain any proprietary or confidential information
Overview

Timeline
Phase I: 4/04-1/05
Phase II: 5/05-5/06
Phase I complete, Phase II pending

Budget
• Total project funding: $130K (DOE share =100%)
• FY04: $130 K
• FY05: ($100 K pending)

Barriers Addressed:
• Lack of Understanding of transition of Hydrocarbon Based Economy to H2 Based Economy.
• Lack of consistent data, assumptions and guidelines

Technical Targets:
• By 2007, identify and evaluate transition scenarios consistent with developing infrastructure and H2 resources.

Partners/Collaboration
• H2A Delivery Team (NREL, ANL, DOE)
• UC Davis H2 Pathways Program
• NETL (C-sequestration)
• Princeton University
Objectives

- Assist the DOE in identifying promising paths for developing hydrogen infrastructure.
  - Use GIS-based simulation tools to evaluate alternative pathways toward widespread use of hydrogen, under various demand scenarios and regional conditions.
    - Understand which factors are most important in finding viable transition strategies.
    - Develop “rules of thumb” for future regional hydrogen infrastructure development.
  - Conduct regional case studies of H2 infrastructure transitions

- Work with H2A core group to develop models of hydrogen delivery systems.
Technical Approach

• TASK 1: Extend UCD’s simulation tools for assessing H2 transition strategies under various demand scenarios and regional conditions, to improve:
  – GIS-based method for estimating regional hydrogen demand
  – Engineering/Economic models of H2 Components (refueling stations, pipelines).
  – Methods for Designing an Hydrogen Infrastructure (idealized models of distribution systems in cities; methods for siting stations)
  – Preliminary Transition studies: Designing infrastructure for growing hydrogen demand

• TASK 2: Carry out regionally specific case studies of H₂ infrastructure development.

• TASK 3: Participate in H2A delivery team
Technical Accomplishments (1)

Task 1: Improve simulation tools

GIS-based method for estimating regional hydrogen demand

Population Density – US Census (people/km²)

Estimate H₂ Demand and Aggregate

Select Demand Centers

Legend

<table>
<thead>
<tr>
<th>Legend</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counties</td>
<td>Aggregate H₂ Demand</td>
</tr>
<tr>
<td>0.00 - 500.00</td>
<td>85.2500 - 1000.0000</td>
</tr>
<tr>
<td>500.01 - 2500.00</td>
<td>1000.0001 - 3000.0000</td>
</tr>
<tr>
<td>2500.01 - 5000.00</td>
<td>3000.0001 - 5000.0000</td>
</tr>
<tr>
<td>5000.01 - 10000.00</td>
<td>5000.0001 - 30000.0000</td>
</tr>
<tr>
<td>10000.01 - 17473.20</td>
<td>30000.0001 - 63235.4300</td>
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</tbody>
</table>

Legend

- Counties
- Demand Clusters
H$_2$ demand model can be applied to ANY region with GIS census data.
Task 1: Improve simulation tools
Improve Engineering/Economic models of H2 Components

Incorporate Costs from UCD H2 Pathways H2 Refueling Station Model

Improve Models for H2 Pipeline Costs via analysis of NG pipeline data

<table>
<thead>
<tr>
<th>Refueling station - external production</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># of stations</td>
<td></td>
</tr>
<tr>
<td>Station capacity</td>
<td>823,258 kg/yr</td>
</tr>
<tr>
<td>Station Capacity</td>
<td>1,705 kg/day</td>
</tr>
<tr>
<td>% utilization</td>
<td>100.0%</td>
</tr>
<tr>
<td>Actual Demand</td>
<td>1,705 kg/day</td>
</tr>
<tr>
<td>Delivery</td>
<td>823,258 kg/yr</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Summary</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Discount rate</td>
<td>10%</td>
</tr>
<tr>
<td>CRF (25 years)</td>
<td>11.7%</td>
</tr>
<tr>
<td>CRF (25 years)</td>
<td>11.8%</td>
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</table>

<table>
<thead>
<tr>
<th>Land</th>
<th></th>
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<tbody>
<tr>
<td>Existing land</td>
<td></td>
</tr>
<tr>
<td>Total Capital Costs</td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td>$191,759</td>
</tr>
<tr>
<td>Electrical (comp)</td>
<td>$71,997</td>
</tr>
<tr>
<td>Total O&amp;M</td>
<td>$119,324</td>
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<table>
<thead>
<tr>
<th>Installation Costs</th>
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<tbody>
<tr>
<td>TotalInstallation Cost</td>
<td>$357,973</td>
</tr>
<tr>
<td>Land Costs</td>
<td>$400,000</td>
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<tr>
<td>Total Installation Cost</td>
<td>$757,973</td>
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<table>
<thead>
<tr>
<th>Annual Costs</th>
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<tbody>
<tr>
<td>Capital</td>
<td>$131,457</td>
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<tr>
<td>Installation</td>
<td>$83,504</td>
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<table>
<thead>
<tr>
<th>Miscellaneous</th>
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<tr>
<td>Fuel Electricity</td>
<td>1 kW</td>
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<tr>
<td>Variable Electricity</td>
<td>0 kW</td>
</tr>
<tr>
<td>Total Electricity</td>
<td>8760 kWh</td>
</tr>
<tr>
<td>Efficiency</td>
<td>0.08%</td>
</tr>
<tr>
<td>CO2</td>
<td>710756 g/yr</td>
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</table>

<table>
<thead>
<tr>
<th>Storage Tanks</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Storage</td>
<td>20%</td>
</tr>
<tr>
<td>Storage Size</td>
<td>400 kg</td>
</tr>
<tr>
<td>Tank size</td>
<td>200 kg</td>
</tr>
<tr>
<td>Fuel Dispensers</td>
<td></td>
</tr>
<tr>
<td>Number of Pumps</td>
<td>4</td>
</tr>
<tr>
<td>Cost/pump</td>
<td>$30,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compressor</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Size (kW)</td>
<td>164.4</td>
</tr>
<tr>
<td>Electricity usage</td>
<td>1.94 kWh</td>
</tr>
<tr>
<td>Peak Flowrates</td>
<td>20%</td>
</tr>
<tr>
<td>Average storage</td>
<td>20%</td>
</tr>
<tr>
<td>Efficiency (PE)</td>
<td>13.33%</td>
</tr>
<tr>
<td>CO2 (elec)</td>
<td>1.1E+09 g/yr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Construction Cost (dia, length)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Where (dia) is in inches, (length) is in miles, and Cost is in dollars.</td>
<td></td>
</tr>
</tbody>
</table>
Technical Accomplishments (3)

Task 1: Improve simulation tools

Designing Hydrogen Infrastructure for an Idealized City

*Idealized city model with 25 and 125 hydrogen stations distributed in rings throughout the city.*
Distribution System Layout for Idealized City => lengths, costs

Truck delivery

Pipeline
Technical Accomplishments (5)

Task 2: Carry out regionally specific case studies of H₂ infrastructure development

Coal-Based H₂ Infrastructure w/ CO₂ Capture and Sequestration in Ohio

- Combine spatial tools and geographic data with engineering and economic models. Develop methods that can be used anywhere in US
- Build GIS data base, incl. H₂ demand, potential H₂ supply, existing infrastructure, CO₂ sequestration sites
- Design H₂ infrastructure, estimate costs, performance, emissions
- Cases analyzed:
  - Central coal w/CO2 Seq. & pipeline delivery
  - Onsite NG reforming
GIS Database

Data Used:
1. Existing Rights-of-Way (DOE GasTrans)
2. Coal Plants over 100MW (EPA E-Grid)
3. Brine Wells (NETL)
4. Demand Centers
5. Interstates (Ohio DOT)
Shortest path intercity network

10% market penetration

- One coal plant - 253 tons H₂/day
- 12 demand centers
- 936 km of intercity pipeline
- CO₂ sequestration system: 4,500 tons CO₂/day

Brine Well (CO₂ Sequestration Site)
Intracity Distribution and Station Siting

“Idealized City” Model

Equivalent Circles

Pipeline Design
Intercity Stations

Selection criteria

- Maximize average daily traffic flow at station sites
- Locate close to large demand clusters
- Place greater than 30 km from corridor endpoints (large cities)

Results

- 10 Stations (onsite H$_2$ production)
- Max stretch without a H$_2$ station: ~60 miles
- Total H2 demand ~ 20 tons H$_2$/day
Results – 10% market penetration

**Capital Cost**

- 1 coal plant producing 253 tons H₂/day ($381 MM)
- 936 km of intercity pipeline ($358 MM)
- 12 demand centers serving 48% of the population (~420,000 vehicles)
  - 1,105 km of local distribution pipelines ($352 MM)
  - 91 refueling stations, each dispensing ~2,800 kg/day ($135 MM)
- 10 intercity stations, each dispensing ~ 2,000 kg/day ($37 MM)
- 1 CO₂ sequestration site: 4,500 tons CO₂/day ($55 MM w/compressor)

**Total capital cost:** $1.3B or $3,100/vehicle

**Delivered H₂ cost:** ~$3.35/kg
Technical Accomplishments (6)  

Participation in H2A Delivery Group

- H2A is a group of analysts convened by DOE to produce a credible, well-documented set of information on H2 production, delivery and forecourt refueling technologies and options.

- FY’05 Accomplishments
  - Member of H2A team analyzing H2 delivery infrastructure. (Close collaboration with researchers at DOE, NREL, Argonne)
  - Developed base case scenarios for hydrogen delivery.
  - Developed EXCEL model for hydrogen delivery system design and cost.
  - Presentation to USDOE FreedomCar Delivery Tech Team on H2A’s work
H2A Delivery Results

- H2A Delivery Cases Analyzed; large and small cities; rural and interstate regions; delivery by gas truck, LH2 truck, gas pipeline; different market penetration levels.

<table>
<thead>
<tr>
<th>Market Type</th>
<th>Early Fleet Market (1%)</th>
<th>General Light Duty Vehicles: Market Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small (10%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium (30%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large (70%)</td>
</tr>
<tr>
<td>Metro</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Rural</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Interstate</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
We developed an EXCEL program to calculate infrastructure layout, equipment sizes, costs.

H2 Production 50 t/d

Storage 250 t

Refueling Bays

Liquefier

LH2 Trucks

City

Terminal

100 km

Other Uses

Refueling Stations

LH2 Trucks

We developed an EXCEL program to calculate infrastructure layout, equipment sizes, costs.
Capital Cost for LH2 Truck Delivery $/light duty vehicle

Levelized Cost of LH2 Truck Delivery ($/kg H2) from Large H2 Plant to Forecourt
Response to Previous Year Reviewers’ Comments

• “Need a more robust demand model”
  - H2 Pathways Demand Conference September 2004. Surveyed current work on this. It’s tough to model demand!
  - Developed new GIS-based methods for demand
  - Future plans: estimate market penetration from consumer choice model and couple to infrastructure layout

• “Optimization leads to ideal case.” Maybe misplaced emphasis at this point.
  - Concentrated on constraining problem to make optimization easier (e.g. assume minimum # of stations needed; only use existing ROWs or refueling sta sites; pipeline cost $\alpha$ length)

• “Model depends greatly on assumptions”
  - Sensitivity studies w/ H2A show importance of scale, city size, population density, market fraction, feedstock cost, station size
Future Work

Remainder of FY’05

• Continue to refine simulation tools for modeling hydrogen energy infrastructure development based on geographic information system (GIS) input data and optimization methods.
• Complete a case study of implementing a near-zero emission hydrogen energy system in one or more regions of the US
• Continued participation in the H2A delivery group.

Proposed for FY’06

• Work with NREL and DOE to integrate UC Davis infrastructure models with other H2 models, to answer specific questions related to the development of H2 infrastructure development.
• The goal is to make the best use of existing modeling tools to understand which factors are most important in finding viable transition strategies under different regional conditions.
• Develop “rules of thumb”, as a means to more efficiently study infrastructure development in succeeding years.
Publications and Presentations (1)


J. Ogden, “Hydrogen Research at UC Davis,” Presentation at Lawrence Livermore National Lab, October 21, 2005

J. Ogden, “The Outlook for Hydrogen as an Energy Carrier,” presented at the Annual Meeting og the American Society of Mechanical Engineers, November 15, Anaheim, CA


Publications and Presentations (2)


J. Ogden, “Pathways to a H2 Economy: Early Results from the Hydrogen Pathways Program,” Department of Environmental Science and Policy, Faculty Seminar, University of California, Davis, March 16, 2005.


Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

Inadequate attention to safety as an inherent part of H2 system design, when creating computer model descriptions of real systems.

We address this by including only model components and designs that fully incorporate safety, and by “reality checks” from industry reviewers.