Hydrogen Production in a GHG-Constrained Situation: Major Results & Conclusions

Alison Bailie, Bill Dougherty, Charles Heaps, Sivan Kartha, and Chella Rajan
Tellus Institute

DOE Contractor’s Meeting
26 May 2005

This presentation does not contain any proprietary or confidential information. #ANP 1
Objectives

To examine in a detailed quantitative manner plausible scenarios through 2050 for a transition to a hydrogen economy.

To explicitly illustrate the staging and sequencing of major phases of the transition scenarios and their implications.

To quantify the greenhouse gas (GHG) reduction benefits of each of the transition scenarios.

To explore the spatial characteristics of the transition scenarios based on GIS analyses for four greater metropolitan areas of the USA: Boston, Denver, Houston, & Seattle

To account for relevant techno-economic and policy factors:

- demographic and spatial characteristics,
- cost & performance of technologies for H₂ production, distribution, storage, and end-use (both transportation and stationary)
- regulatory contexts
- timing and extent of transition pathways
Budget

• Total funding for project: $309,345
  • Initial tasks: $215,488
  • Proposal modification: $ 93,857
• Funding for FY04-5: $200,000
Technical Barriers and Targets

• This project is a cross-cutting analysis, linked most closely to the Technology Validation component of the Technical Plan. It seeks to contribute to “testing complete system solutions that will address all elements of infrastructure and vehicle technology and investigate novel new approaches…”

• As a long-term scenario analysis, it helps to “validate whether the technical targets for the individual components (developed within other subprograms) can still be met when integrated into a complex system”

• Specifically, this project relates to the following subtasks within Technical Tasks 6 –”Technical Analysis”:
  • Analyze hydrogen and electricity as energy carriers and evaluate potential synergies from “marrying” the electrical transmission and transportation systems.
  • Analyze integrated renewable hydrogen production systems that combine electrolysis powered by wind, solar, hydropower, or geothermal with biomass gasification systems.

These tasks relate to barriers A, B, C, D, F, G, H, & I.
Approach

• This project examines the evolution of hydrogen technologies and a hydrogen infrastructure that meets the objectives laid out in the DOE’s *Hydrogen, Fuel Cells & Infrastructure Program Multi-year Plan* to realize energy security, environmental, and economic benefits. The analysis:
  – Takes an integrated approach, considering the entire chain of hydrogen from energy resource to production to distribution to end-use.
  – Considers the use of hydrogen as a transportation fuel as well as a fuel for use in stationary applications.
  – Takes a long-term perspective, constructing plausible scenarios by which hydrogen could expand in a gradual and orderly manner until it comprises the majority of transportation fuel use.
  – Accounts for the important spatial aspect of infrastructure development, using a GIS analysis to create realistic infrastructure development scenarios to 2050 for four cities: Denver, Houston, Boston, and Seattle.
  – Quantifies the greenhouse gas benefits deriving from various integrated technological pathways.
  – Relies on techno-economic assumptions of the hydrogen analysis community, research literature, and technology developers.
  – Places the analysis against an energy and policy backdrop derived from the National Energy Modeling System (NEMS) of the DOE.
Project Safety

As a technological analysis, this project has no direct safety requirements, targets, or objectives. However, it is designed to take into account safety requirements in its examination of the evolution of a hydrogen infrastructure. It is based on techno-economic parameters and assumptions that are consistent with appropriate safety regulations and standards with respect to technologies and operating procedures, which affect underlying assumptions regarding labor, materials, etc. This is particularly relevant to the estimated costs and performance of:

- transmission and distribution infrastructure (pipelines and tanker trucks),
- dispensing (refueling apparatus), and
- end-use (vehicles and stationary appliances)
**Project Timeline**

10/02 – 4/03  
5/03 – 10/03  
11/03 – 4/04  
4/04 – 5/05

<table>
<thead>
<tr>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
<th>Phase IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Techno-economic assessment (H₂ production, distribution, end-use)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Formulation of references cases and alternative scenarios</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Creation of analytical framework, integration of NEMS and LEAP models</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Acquisition of city-specific data and GIS information</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Finalizing techno-economic assumptions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Encoding data and creation of national and city scenarios</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Refining scenarios</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Finalizing results</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Overview

• Hydrogen Demand Assumptions
• Analysis framework – GIS analysis, H2 demand density, infrastructure elements, scenarios
• Major results (USA) – H2 demand, infrastructure required, CO2 emissions, delivered costs
• Major conclusions
Fuel Cell Penetration Schedule – 4 CMSAs & the USA
Hydrogen Refueling Stations – Boston Retail and Fleet Stations
CMSA - Hydrogen Supply Infrastructure Schematic
Cost-Effective H2 Delivery

Pipeline delivery cost versus % H-FCVs

- Transmission (100 km)
- Local distribution
- Total price

% of cars that are H-FCV: 0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

$ per gallon of gasoline equiv:
- $0.50
- $1.00
- $1.50
- $2.00
- $2.50
- $3.00
H2 Demand Density over Time/Space

BOSTON 2000
H2 Demand Density over Time/Space

BOSTON 2010
H2 Demand Density over Time/Space

BOSTON 2020
H2 Demand Density over Time/Space
H2 Demand Density over Time/Space
H2 Demand Density over Time/Space
Hydrogen Demand - USA
Hydrogen Transmission Pipelines - USA
Hydrogen Distribution Pipelines - USA

![Graph showing hydrogen distribution pipelines in the USA over time with different scenarios: BAU, GHG, and SHOCK.](image-url)
Carbon Sequestration Pipelines - USA
Installed Central H2 Production Units - USA
Installed On-site H2 Production Units - USA

![Graph showing installed on-site H2 production units in the USA from 2000 to 2050. The graph compares BAU, GHG, HH2-BAU, HH2-GHG, and SHOCK scenarios.](image-url)
Carbon Emissions

The graph illustrates the projected carbon emissions in kilotons (kt) C-equivalent from 2000 to 2050, with different scenarios including BAU, GHG, HH2-BAU, HH2-GHG, HH2-BAU (seq), HH2-GHG (seq), and SHOCK. The emissions are projected to increase significantly by 2050.
CO₂ per H₂ Produced

The graph shows the CO₂ per kg H₂ produced from 2025 to 2050, with labeled scenarios 'HH2-BAU', 'HH2-GHG', and 'SHOCK'. The y-axis represents kg CO₂-equivalent per kg H₂, while the x-axis shows the years from 2025 to 2050.
1. Hydrogen FCVs are unlikely to be cost competitive with gasoline ICEVs (even at a sustained $40/barrel).

⇒ A transition toward hydrogen would have to be motivated by GHG, air pollution, energy insecurity, not solely by profit.

2. Electric vehicles and biofuels are (strong) contenders.

⇒ Hydrogen is not the only option to address these problems.

3. On an energy basis alone, hydrogen is not that compelling (owing to energy losses in conversion and distribution).

⇒ It is only when coupled with zero-carbon supply options that hydrogen becomes interesting.
4. The only sources of zero-carbon hydrogen are:
   a. biomass (gasification/reforming)
   b. fossil (gasification/reforming) w/ CO2 capture & sequestration
   c. renewable and nuclear electricity

First two options require centralized production and pipeline delivery. (LH2 tankers & GH2 tube trailers have negligible long-term role.) Third option does not require pipelines (it can be done on-site), but this is pointless for cogen and limited value for transport until very high penetration (which is bounded by technical, cost and resource considerations.).

5. It only makes sense to use zero-carbon electricity to make hydrogen to displace gasoline (in hybrid vehicles) after coal-based power has been eliminated.
Observations and Conclusions (3)

6. Without pipelines, hydrogen cannot have any GHG benefit in cogeneration, and or significant benefit in transport sector.

7. Pipelines are only cost-effective when hydrogen demand density is fairly high (~200 cars/km² or ~20% of Boston car density). Eventually, a large fraction (>85%) of hydrogen demand would be in regions exceeding this threshold.
8. Getting there will take a long period of transition (~decades).
   a. more R&D (primarily storage & FC cost reduction)
   b. stock turnover in vehicles, auto manufacturing, energy infrastructure
   c. chicken-egg problem(s)

9. Transitional steps include:
   a. Fleet (e.g., buses) using centralized refueling
   b. On-site hydrogen production (from NG and grid electricity)
   c. Dual-fuel (gasoline/hydrogen) vehicles

10. Have to venture through some not so attractive options en route to clean hydrogen.
Observations and Conclusions (5)

Institutional and policy issues

1. Given that the drivers are not economic, but environmental/social,
   ⇒ a hydrogen transition would require public support and political will to address GHG emissions, pollution, and energy insecurity.

2. In the best case, hydrogen is a long-term solution with inevitable but potentially unsavory transitional implications.
   ⇒ Hydrogen should not edge out near term solutions. (E.g., gasoline hybrid-electric vehicles, NG cogeneration, grid-connected renewables, efficiency)

3. The energy system is highly inertial. A timely transition will require a lot of time.
   ⇒ Decisions must be made under some degree of uncertainty.
   ⇒ Other options (as in GHG Case) must be implemented in the meantime.
The “H₂A” group of hydrogen analysts convened by the DOE has provided a major source of interaction and technical exchange for this project. Technical inputs to this project have been checked for consistency with the cross-referenced to the products of the H₂A group.

Presentations on this work have been made at Harvard University, Boston University, Cornell University, and MIT.
Possible Next Steps

• Approach
  – Explore alternative strategies for deeper reductions
  – Examine costs/benefits/constraints of pure renewables strategies

• Modeling
  – Expand analysis to cover other h2 production technologies and h2 consuming technologies
  – Incorporate existing H2 production from industrial facilities into overall tallies
  – Fine-tune transmission and distribution pipeline module

• Marketing
  – Contact regional planning commissions - adapt H2M to other cities