H2A Delivery Analysis

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This presentation does not contain any proprietary or confidential information
Evolved from H2A Project

- Addresses MYPP Hydrogen Delivery Barriers:
  - A. H2 and H2-carrier infrastructure analysis (primary)
  - F. Hydrogen delivery infrastructure storage costs (secondary)

- FY05 Focus: Model building, coordination, quality control, peer review
  - Budget ~$350k, 60% complete
  - Partners
    - Argonne National Lab (ANL)
    - National Renewable Energy Lab (NREL)
    - University of California at Davis (UCD)
    - Pacific Northwest National Lab (PNNL)

- FY06 Focus: Model expansion & analysis (with Nexant team)
Objectives

- Develop methodology to understand contribution of individual delivery components and entire delivery infrastructure to H2 cost
- Develop tools for consistent and transparent analysis of hydrogen delivery within framework of the H2A Model
  - Delivery Component Model (Version 1.0 completed 3/05)
  - Delivery Scenario Model (Version 1.0 completed 5/05)
  - Build on past/current efforts and common analytical tools
    - Microsoft EXCEL based
    - Common building blocks from H2A Program
      - “First principles” approach
      - Discounted cash flow analysis
      - Common format, financial and energy assumptions
      - Above-ground storage, compression, “forecourt”
- Work with industry to validate assumptions and analysis approach
  - H2A Key Industrial Collaborators
  - Delivery Tech Team
H2A Delivery

Overall Approach

LH2 and GH2 Delivery Require Different Components; Analyses Require Component Modeling

Gaseous Delivery Path

Liquid Delivery Path
H2A Delivery

Overall Approach

With Component and Scenario Models Individual Pieces or Entire Delivery Paths Are Compared

- Define paths from plant gate to “forecourt” (“well” to “pump”) with associated components
- For each component, estimate:
  - Capital and operating cost, lifetime, operating profile, etc.
  - Size to satisfy scenario demand
  - Account for losses, efficiencies, new technologies, scale, “learning”
- Apply consistent financial and operating assumptions
  - Debt vs. equity, project lifetimes, ROI, etc.
  - Availability
- Link component results to estimate:
  - Delivery cost contribution and cash flow
  - Energy and GHG emissions associated with H2 delivery
  - Lower cost paths under alternative assumptions
Hydrogen Delivery Components Model

- Excel-based tool with separate tabs for each component
- Determines “generic” contribution to H2 cost by component
- Consistent assumptions for:
  - Discount Rate – 10%
  - Dollar Year – 2005
  - Startup Year – 2005
  - Depreciation Type – MACRS
  - Analysis Period – 20 years
  - Federal Taxes – 35%
  - State Taxes – 6%
  - Total Tax Rate – 38.6%

- H2 cost calculated in real dollars using fixed charge rate
Components Model Hierarchy

- Component Design Inputs
- Component Design/Scenario Calculations
- Component Scenario Inputs
- Component Capital Costs
- Direct/Indirect Capital Costs
- Operating and Maintenance Costs
- Financial / Economic Inputs
- Financial Analysis
- Component Cost ($/kg of Hydrogen)
- Replacement Capital
# H2A Delivery

## Technical Accomplishments:

### Components Model Features

<table>
<thead>
<tr>
<th>Delivery Components</th>
<th>Storage Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Truck – Tube Trailer</td>
<td>- Compressed Gas Tube System</td>
</tr>
<tr>
<td>- Truck - LH2</td>
<td>- Bulk Liquid Hydrogen System</td>
</tr>
<tr>
<td>- Pipeline</td>
<td>- Geologic</td>
</tr>
<tr>
<td>- Liquefier</td>
<td>- Forecourt</td>
</tr>
<tr>
<td>- Compressor (single &amp; multi-stage)</td>
<td></td>
</tr>
<tr>
<td>- Forecourt Compressor</td>
<td></td>
</tr>
<tr>
<td>- Terminals (gaseous and liquid)</td>
<td></td>
</tr>
</tbody>
</table>

- Yes/no toggle switches for user input or H2A defaults
- Error messages alert user to input errors
- MACRS depreciation options
- Color-coded to facilitate user input

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

Information
H2A Delivery

Technical Accomplishments

Components Model Illustrative Results: Compressed Gas Truck (Tube Trailer)

- Tube trailer dropped off at forecourt
- One tractor and sufficient number of trailers to maximize tractor utilization
- 20 yr analysis period
- 180 atm (2760 psia) maximum pressure
- 100 kg/d station demand

![Graph showing hydrogen cost ($) per kg versus roundtrip distance (km)]
Delivery Scenarios Model

Version 1.0 contains three pathways with pre-defined demand based on market, penetration and modal efficiencies. Delivery is by a single user-defined mode. Loading, packaging and storage are inside the plant gate.

- **Compressed Gas (CG) Truck**
- **Liquid Hydrogen (LH) Truck**
- **Pipeline**
Delivery Scenarios Defined by Urban Area Size and Interstate Highway Traffic Density

- Interstate highways = 1% of rural roads but 23% of rural travel (FHWA 2003)
- Traffic density = <1000- >50,000 vmt/mi/d
- Fuel use = 700 kg/d avg ~50-2000 kg/mi/d range

75% of population in urbanized areas
Urban areas large and clustered E of Mississippi & on W coast
Urban areas smaller & more dispersed in Plains
Most of the Great Plains and Mountain States are within 200 highway miles (320 km) of smaller urban areas
Delivery Scenario Variables

- **Urban areas**
  - Population, land area, vehicle density
  - Distance from central H2 production

- **Intercity/rural travel**
  - Highway miles
  - Travel density, fuel demand

- **Hydrogen-fueled vehicles**
  - Number, fuel economy, utilization

- **H₂ stations (forecourts)**
  - Number, capacity, avg. kg dispensed
  - Distance between stations
  - Ratio to gasoline stations

- **LH₂ and GH₂ trucks**
  - Fuel economy, losses, capacity, delivery volume
  - Speed, load/unload time, drops/trip
  - Physical & economic life

- **Pipelines**
  - Inlet, city gate, forecourt pressure
  - Transmission, distribution, service length
  - Circuity factors
  - Physical & economic life
  - Ratio to capital cost of natural gas pipelines
## Technical Accomplishments

**V 1.0 Models 32 Scenarios Defined by Market, Penetration and Delivery Mode**

<table>
<thead>
<tr>
<th>Penetration Market</th>
<th>1%</th>
<th>10%</th>
<th>30%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large urban</td>
<td>CG Truck</td>
<td>LH Truck Pipeline</td>
<td>LH Truck Pipeline</td>
<td>LH Truck Pipeline</td>
</tr>
<tr>
<td>Small urban</td>
<td>CG Truck</td>
<td>LH Truck Pipeline</td>
<td>LH Truck Pipeline</td>
<td>LH Truck Pipeline</td>
</tr>
<tr>
<td>Intercity – long segment</td>
<td>---</td>
<td>CG Truck LH Truck Pipeline</td>
<td>CG Truck LH Truck Pipeline</td>
<td>CG Truck LH Truck Pipeline</td>
</tr>
<tr>
<td>Intercity – short segment</td>
<td>---</td>
<td>CG Truck LH Truck Pipeline</td>
<td>CG Truck LH Truck Pipeline</td>
<td>CG Truck LH Truck Pipeline</td>
</tr>
</tbody>
</table>
Technical Accomplishments

Preliminary Results That Follow Are **NOT** Based on Fully Integrated Model

- Not based on detailed financial analysis
- Intended to illustrate:
  - Types of analyses being conducted
  - Types of comparisons being made
  - Types of conclusions that might be drawn
- Fully integrated model completed after slide preparation
**Technical Accomplishments**

**Illustrative Results:** Depending on Volume, Delivery Cost Can Vary by 2-3 for Current Technologies

- Pipeline delivery cost can be double in small urban markets yet still be below LH2 delivery.
- Even at high volume LH2 delivery to interstate stations is expensive.
- $/kg excludes forecourt compression, storage & dispensing.
Illustrative Results: Depending on Geometry, Service Lines May Account for Increasing Share of Pipe Delivery

- For 1-ring system, service lines account for 60 to 87% pipeline cost
- For 2-ring system, service lines account for 27 to 62%
- 1-Ring system less costly below 30% penetration
- Lowest cost 2-ring mileage achieved at 40% penetration
Planned Model Enhancements and Applications

- **Remainder FY05**
  - Beta testing by KIC members, implementation of recommendations
  - Forecourt model
  - Mixed pathways (e.g., pipeline to GH2 terminal)
  - Mixed demands/markets (e.g., combining multiple urban areas and urban with interstate demand)
  - Additional scenarios (e.g., larger urban area, 2-trailer dropoff)
  - Technology improvements (e.g., 10,000 psi storage)
  - Energy efficiencies and CO₂ emissions

- **FY06**
  - Sensitivity analyses (service ratio, service lines, storage/compression tradeoffs, etc.)
  - Novel solid/liquid hydrogen carriers
  - Tradeoffs between system options (e.g., pressure vs. storage)
Additional Members of Project Team
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Publications and Presentations


Ringer, Matt, *Analysis of Hydrogen Pipeline Delivery and Other Hydrogen Storage and Delivery Systems*, Presented at the ASME 5th International Pipeline Conference, Calgary, Alberta, Canada (October 5, 2004)

There is no significant hydrogen hazard associated with this project.

This project is conducted in a typical office setting. No experimental work is involved.
No safety measures beyond normal office procedures are required.