Design, Optimization and Fabrication of Home Hydrogen Fueling System

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Lynntech Inc.
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Overview

Timeline

• Start – July 2009
• Finish – April 2010
• Phase I completed.

Barriers

• Barriers
  — Cost
  — Safety
• Targets – Home H₂ production and dispensing

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2015</th>
<th>Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ cost $ per kg*</td>
<td>3-7</td>
<td>2-6</td>
<td>2-3</td>
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Budget

• Total project funding
  > DOE - $100,000

Partners

• None for Phase I
• Potential partner for Phase II reformer development – GTI, Innova Tek.
• Mid South Synergy

*http://www1.eere.energy.gov/hydrogenandfuelcells/storage/pdfs/targets_onboard_hydro_storage_explanation.pdf
Objectives

**Target**: Affordable hydrogen for fueling a PEM fuel cell vehicle for domestic daily consumer that speeds up commercialization and general awareness of fuel cell technology.

**Problem**: Lack of system integration study for producing \( \text{H}_2 \) at required quality and pressure.

**Phase I objectives**
- Develop a multivariate model for system integration and optimization for a Home Hydrogen Fueling device based on natural gas reformation.
- Identify best options for \( \text{H}_2 \) generation, purification and compression for home hydrogen fueling device and provide an optimized system design.
<table>
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<tr>
<th>Milestones</th>
<th>Progress Notes</th>
<th>Comments</th>
<th>% Comp</th>
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<tr>
<td>Identify requirements and specification for a reformer based Home H₂ Fueling Station</td>
<td>Identified safety codes and standards and developed operating guidelines.</td>
<td>Concise list of safety standards for individual subsystems (reformer, purifier and compressor) have been reviewed to create a user oriented safety instructions guidelines.</td>
<td>100</td>
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| System optimization analysis                                   | **Constructed a user friendly multivariate model** and identified best options for a Home Fueling Station for low H₂ production rates based on cost, CO₂ emissions and electricity consumption.                                | • Compressor and purifier are the capital cost intensive systems driving H₂ cost at H₂ production rates < 5 kg/day (8 hr operation).  
• Identified the least cost system design as a function of production rate.  
• Provided sensitivity analyses for the system designs.                                                                 | 100    |
| Complete system design with the optimized design approach      | Preliminary system design calculations completed.                                                                                                                                                                                                                       | Preliminary designs for individual subsystems identified are completed. Off-the-shelf components identified for the Phase II prototype.                                                                 | 100    |
| Target for the Phase II prototype development                  | **Go/No Go milestones** for Phase II for the optimized system fabrication are identified.                                                                                                                                                                                | Specific target parameters identified to achieve the H₂ cost targets for the identified compression and purification technologies.                                                                  | 100    |
Multivariate Optimization Example

Optimal Home $H_2$ Fueling Reformer System

Identify relationships and constraints

Identify variables and parameters of interest

Identify system components

Risk Analysis
Optimization

@RISK analysis
Lynntech’s Home Hydrogen Reformer Component matrix

Natural Gas
Propane

Pre-Treatment
Sulfur Scrubber
O₂ Concentrator

H₂ Generation
Steam Reforming
CPOx with WGS
Autothermal Reforming with WGS

H₂ Purification
High Temperature Electrochemical Membrane
PSA
Pd Membrane

H₂ Compression
Mechanical Compressor
Metal Hydride
Electrochemical pump

Delivery to car

CO₂/Emissions
System selection analysis (Weighting factors)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weightage</th>
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<tbody>
<tr>
<td>Cost</td>
<td>50 %</td>
</tr>
<tr>
<td>Safety</td>
<td>12.5 %</td>
</tr>
<tr>
<td>Technological maturity</td>
<td>12.5 %</td>
</tr>
<tr>
<td>Ease of operation</td>
<td>10 %</td>
</tr>
<tr>
<td>Maintenance</td>
<td>10 %</td>
</tr>
<tr>
<td>Ease of integration</td>
<td>5 %</td>
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- The analysis is strictly for low hydrogen production rates of 0.5 kg/day to 5 kg/day.
- Cost was assumed the main driver for the technology.
- Pre-treatment options were not critical in final system analysis.
System integration choices

**System 1:**
- NG
- H₂O
- Steam Methane Reforming
- Electrochemical Membrane
- Electrochemical Compressor
- H₂ for Dispensing

**System 2:**
- NG
- H₂O
- Steam Methane Reforming
- PSA
- Electrochemical Compressor
- H₂ for Dispensing

**System 3:**
- NG
- H₂O
- Steam Methane Reforming
- PSA
- Mechanical Compressor
- H₂ for Dispensing

**System 4:**
- NG
- H₂O
- Steam Methane Reforming
- Electrochemical Membrane
- Mechanical Compressor
- H₂ for Dispensing
Cost of hydrogen vs. System Designs (single system assumed)

- Purification and compression are the critical cost components at low hydrogen production rates.
- Capital cost of Electrolyzers depend strongly on H₂ production rate as compared to Reformer systems.
- Electrochemical techniques for purification and compression can be scaled down in a cost effective way as compared to conventional PSA and mechanical compressor options.

Capital cost of fuel processors (excluding compression)
Effect of electricity price

Natural gas price, 7 $/GJ

Effect of electricity price

Electricity price, cents per kWH

H2 cost, $ per kg

Electrolyzer
Reformer System 1

Effect of natural gas price

Electricity price, 5 cents/kWH

Natural gas price, $ perGJ

H2 cost, $ per kg

Electrolyzer
Reformer System

H₂ production

0.5 kg/day

3 kg/day

5 kg/day
• For hydrogen production variation, System 1 and Electrolyzer have the least variation in the cost.

• As expected, the impact of variation in cost of electricity is pronounced for Electrolyzer and followed by the Reformer Systems with more electrochemical technologies.

• Effect of natural gas on the four Reformer Systems is comparable and low.
Collaborations

- Partners
  - Potential collaboration for Reformer reactor development in Phase II:
    - Gas Technology Institute (GTI)
    - Innova Tek Inc.
  - Mid South Synergy for field testing of prototype that will be developed in Phase II.
Future work (Phase II)

- Develop and demonstrate cheap (low capital cost) electrochemical membrane purifier technology for hydrogen reformate purification.
- Develop and demonstrate cheap (low capital cost) electrochemical compression technology for hydrogen.
- Development and/or fabrication of fuel processor (subcontract to reformer partner).
- Integrate the systems to produce a prototype.
- Field testing of the system with the help of Mid South Synergy, a local electrical co-operative.
Conclusions

• A multivariate model was developed for system optimization of home hydrogen fueling systems.

• Model Results for 0.5 to 5 kg/day hydrogen production rate
  ➢ Reformation of natural gas is the cost effective way to produce hydrogen gas as compared to water electrolyzers.
  ➢ Capital cost of purification and compression are the critical cost drivers for the reformer based hydrogen production systems.
  ➢ Electrochemical purification and compression technologies offer the most cost effective route as compared to conventional PSA and mechanical compression technologies.
  ➢ Combination of reformation for H₂ production with electrochemical purification and compression offers the most economical system design.

• Fundamentally new information has been uncovered on how to design small hydrogen refueling stations.

• The commercial benefits are multiple and include
  1. Small scale hydrogen refueling stations offering significant cost and process advantages over existing designs and
  2. Modeling and simulation tools for implementation of future hydrogen economy equipment items and infrastructure.
Project summary

- **Relevance:** The Phase I project identified the critical components for an affordable home hydrogen fueling device and identified critical technology pathways to achieve the best $\text{H}_2$ cost.

- **Approach:** Develop a multivariate model to identify and optimize the reformer based home hydrogen fueling system.

- **Technical Accomplishments and Progress:** Identified the critical technologies for a cost and energy effective home hydrogen fueling system through a multivariate optimization approach.

- **Technology Transfer/Collaborations:** Active communication with GTI and Innova Tek for reformer development in possible Phase II effort. Support from Mid South Synergy for field testing of Phase II prototype.

- **Proposed Future Research:** Develop cheap technologies for purification and compression of hydrogen.

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