H2-W
The producers value of Water in a Hydrogen Economy

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Project ID # AN7

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Overview

Timeline

- Start: Sept 07
- End: Oct 08
- Percent Complete: 75%

Budget

- Total project funding
  - DOE $440K
- Funding received in FY07
  - $200K
- Funding for FY08
  - $240K

Barriers

- Future Market Behavior (A) Market Transformation
- Inconsistent data, assumptions and guidelines (C)
- Unplanned Studies (E) - Resource Requirements and Availability

Partners/Collaborators

- UC Davis ITS (Model Parameterization)
- LBNL (L. Dale)
- Sandia (M. Hightower)
- NREL (M. Ruth)
Project Objectives

- Characterize the water requirements for hydrogen production
  - Assess the water requirements inside the H2 plant
    - Water intensity
    - Water quality
    - Impact of water on H2 costs
  - Assess external water requirements in support of H2 Production
    - Embedded water of input resources
    - Source reliability (quantity and quality)
    - Regional water influences
- Develop framework for assessing the impact of water in hydrogen production
- Comparative analysis with water use for other fuel options
- Evaluate regional conditions that may impact adoption hydrogen production for a particular region
Approach: Background

Frame problem of water requirements as a decision opportunity for a hydrogen producer

• Balance Energy - Water tradeoffs
  – Design plant assuming water “may” be a critical resource
  – Regional dependent problem

• Broaden scope of planning problem to infrastructure not typically included
  – Similar to a Wheel-To-Wheels (WTW) approach with the added complexity of water reuse.
  – Assess water withdrawal, consumption and reuse vs. return

• Decision variables:
  – Production method
  – Electric source
  – Cooling technology
  – Water reuse
Assumptions

• Hydrogen production at scale requires development of supporting infrastructure (e.g. electricity generation, water pre and post-treatment, water conveyance and acquisition) that is not required for small scale

• Electricity can be produced by a variety of methods

• Water value and cost and may be different in different regions of the country and might influence the choice of technologies
Approach: H2-Water-Balance

Withdrawn Water

Consumed Water

Embedded Water

Source Water

Extraction Water

Process Water

Feedstock Fuel

Process Water

Water Cooling

Electricity

Process Water

Water Cooling

H2 Production Technology

Transportation

End use

Distribution Method

Embedded Water

Consumed Water

Withdrawn Water


\[ E = \text{Electricity Generation Technology} \]
\[ \alpha_p = \text{Process Water Coefficient} \] t
\[ F = \text{Fuel Type} \]
\[ \alpha_{cw} = \text{Cooling Water Technology Coefficient} \] t
\[ P = \text{Hydrogen Production Technology} \]
\[ t_s = \text{Water Treatment Coefficient} \] t

H2-W - Hydrogen - Water Nexus Model
The Hydrogen-Electricity-Water Pathway

• Significant quantity of electricity is needed for input to electrolysis process
• Cooling water in electricity generation can be large
• Hydrogen producers have choice of electricity source
• Opportunity for water savings utilizing newer technology
**H2 Pathways Examined:**

### Fuel Production Intensities

<table>
<thead>
<tr>
<th>Technology</th>
<th>Process Water $Q_p$ (gal/kg)</th>
<th>Process Electricity $E_p$ (kWh/kg)</th>
<th>Process Fuel $F_p$ (MMBTU/kg)</th>
<th>Process Cooling $Q_{cw}$ (gal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMR Forecourt Air Cooled</td>
<td>1.1 - 1.3</td>
<td>3.7</td>
<td>0.17</td>
<td>n/a</td>
</tr>
<tr>
<td>SMR Forecourt Water Cooled</td>
<td>1.1 - 1.3</td>
<td>3.2</td>
<td>0.19</td>
<td>123</td>
</tr>
<tr>
<td>SMR Central</td>
<td>1.0 – 1.3</td>
<td>0.55 - 0.8</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Electrolysis Forecourt</td>
<td>2.4 - 2.7</td>
<td>55 - 81</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>1 - 2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Source Water Treatment Efficiencies

<table>
<thead>
<tr>
<th>Water Treatment Technology</th>
<th>Coefficient $t_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Osmosis Brackish</td>
<td>1 - 1.5</td>
</tr>
<tr>
<td>Reverse Osmosis Saline</td>
<td>2 - 9</td>
</tr>
<tr>
<td>Ion Exchange</td>
<td>1:1</td>
</tr>
</tbody>
</table>

### Power Plant Cooling Parameters

<table>
<thead>
<tr>
<th>Cooling Type</th>
<th>Requirement $Q_{cw}(E)$ (gal/kWh)</th>
<th>Coefficient $\alpha_{cw}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once Through</td>
<td>0.1 - 0.5</td>
<td>60 - 200</td>
</tr>
<tr>
<td>Wet</td>
<td>0.18 - 1.4</td>
<td>1 - 1.5</td>
</tr>
<tr>
<td>Dry</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Sources:
- GE Manufacture Specification: Personal communication
- Source: Energy Demands on Water Resources: Report to Congress on Interdependency of Energy and Water 2006:
**Water Intensity Preliminary Results:**

- **Electricity Source:** Bio-Fuel, Gasoline, SMR, Electrolysis
- **Cooling Type:** Wet, Fresh, Dry, Brackish, Saline
- **Source Water:** Withdrawal

<table>
<thead>
<tr>
<th>Electricity Source</th>
<th>Cooling Type</th>
<th>Source Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-Fuel</td>
<td>Wet</td>
<td>Fresh</td>
</tr>
<tr>
<td>Gasoline</td>
<td>Dry</td>
<td>Brackish</td>
</tr>
<tr>
<td>SMR</td>
<td>Wet</td>
<td>Saline</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>Wet</td>
<td>Fresh</td>
</tr>
</tbody>
</table>

**Water Requirements (gal H2O / gge):**

- Irrigation
- Electric Cooling
- Process

- NGCC
- Nuclear
- Solar
**Water Intensity Preliminary Results:**

Big variations in water intensity are driven by choice of electricity.

*Irrigation consumption not included.
H2-W

Hydrogen Water Economics
Preliminary Results:

Water Intensity of electricity can be reduced with minimal impact on H2 price

- Changing a 500 MW NGCC from Wet cooling to Dry cooling plant has annualized change in producers cost of electricity of +3% $/kWh

- Change in retail electric price would be more due to mark-ups

- Change in cost of hydrogen production
  - 2% for Electrolysis
  - >1% for SMR

Cost of Water Supply
- Regionally/source dependent cost
- $0.2 - $8 per 1000 gal minimum requirement

Equivalent Cost of Water (i.e. cost of recycling)
- $3.3 - $6.1 per 1000 gal in CEC study
- Regionally and climatically dependent
- Compare technologies with this method

Residual Imputation
- VOW = Revenue - Non-water costs
- Requires assumption about hydrogen demand
- Under development

*Improved estimates of the value of water will improve decisions regarding water dependent technology investment*
Regional geography influences how water can be utilized in fuel production

Assume ..

\[ Q_F(\text{Existing}) = Q_F(\text{Hydrogen}) \]

but..

\[ \text{Cost}(Q_F(\text{Existing})) \neq \text{Cost}(Q_F(\text{Hydrogen})) \]

In California, Forecourt Hydrogen generation will have different water requirements than the current petroleum infrastructure.

21 Oil refineries (CEC 2006)

~1,000 Potential H2 stations (10% of all CA retail stations (CEC 2003) (Currently <30)
Current Progress

Tasks:
1) Develop analysis of water requirements
   Literature Search, Systems models development
2) Determine engineering parameters and commercial constraints
   Assess data quality and inconsistencies across previous studies
3) Determine preliminary economics
   Assess value of alternative technologies, sensitivity analysis
4) Assess key regional scenarios and solutions
   Regional analysis water supply cost curves
5) Assess and identify climate change concerns.
Proposed Future Work

Tasks:
1) Develop analysis of water requirements
2) Determine engineering parameters and commercial constraints
3) Determine preliminary economics
4) Assess key regional scenarios and solutions
5) Assess and identify climate change related concerns

X) Integration with MSM
Y) Data collection through coordinated metering
Z) Regional Geographic Hydrogen-Water Benchmarking Scorecard

<table>
<thead>
<tr>
<th>07</th>
<th>FY 08</th>
<th>FY 09</th>
<th>FY 10+</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FY 09</td>
<td>FY 10+</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>FY 09</td>
<td>FY 10+</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>FY 09</td>
<td>FY 10+</td>
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<td>FY 09</td>
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<tr>
<td>5</td>
<td>4</td>
<td>FY 09</td>
<td>FY 10+</td>
</tr>
</tbody>
</table>

X
Y
Z
Summary

• The H2-W framework extends the bounds of water impacts in the hydrogen production life cycle
• Electricity can be the biggest water user in the hydrogen production life cycle
• Hydrogen-water intensity can be kept low with new technology at small cost relative to cost of hydrogen
• Price, Value, and Availability of water to a producer will be dependent on the geographic location
• Water can be recycled more easily than other resources like gasoline, or CO2