Community Energy:
Analysis of Integrated Distributed Energy Systems for Power and Transportation (Draft)
Darlene Steward
November 15, 2012
Objective

The HTAC committee is charged with evaluating the benefits of hydrogen as an enabler of renewables. The potential benefits of integration of renewable electricity generation with transportation fueling is one aspect of this mandate and the focus of this presentation.

An analysis of hydrogen for community-scale electricity storage was completed previously.
Grid-Independent Renewable Energy Vehicle Fueling System Schematic

Electricity load for a community of about 100 houses

- Electricity from the solar panels goes to supply the building load or to supply fuel for vehicles
- Transformer and distribution lines must have enough capacity to supply the peak building load

When solar output is less than building load, the grid supplies the difference.

- All load for vehicle fueling is supplied by PV system
  - Electrolysis for hydrogen production
  - Battery for electric vehicle charging

Electricity from the solar panels goes to supply the building load or to supply fuel for vehicles.
Grid-Independent Renewable Energy Vehicle Fueling System Schematic

Building demand: Maximum = 125 kW, ~573,000 kWh/year

Three example PV system sizes cover a range from about ½ the yearly building load to approximately 2X the building load:
- 1,200 m² (146 kW peak output); 287,000 kWh/y
- 4,000 m² (490 kW peak output); 760,000 kWh/y
- 7,000 m² (850 kW peak output); 1.3M kWh/y

Case 1 – PV output in excess of building load to vehicle refueling
Case 2 – PV output before noon and output in excess of building load to vehicle refueling
Electrolyzer sized to maximum difference between PV output and building load

Compressor sized to peak hourly hydrogen flowrate

Hydrogen Storage assumed daily full cycling of storage system (no multi-day storage)

H2 Dispenser: One assumed in all cases. 350 bar dispensing.
Renewable Energy Electric Vehicle Fueling System Schematic

<table>
<thead>
<tr>
<th>Battery</th>
<th>Vehicle</th>
</tr>
</thead>
</table>

**Zinc Air Battery**
Battery sized to maximum kWh in storage + 50% assuming full discharge of the battery daily (i.e., no multi-day storage)

**Level I charging**
Assume home vehicle charging (comparable to 350 bar hydrogen system).
Example building, PV and vehicle load – 4,000 m² PV system

Building load is based on a small hotel, which has a similar load profile to residential housing.

Peak load = ~125 kW, 573,000 kWh/year
Example building, PV and vehicle load

Hydrogen and electric vehicles would have similar charging profiles. Daily profiles are identical, but total daily demand is matched to available PV electricity.
Example building, PV and vehicle load

PV output is based on hourly data from Boulder, Colorado and realistic current PV technology.
Example building, PV and vehicle load

Hydrogen (or electricity to battery) produced when PV system output exceeds the building load.
Overview of Results

The hydrogen system including an electrolyzer, compressor, storage and hydrogen dispensing is about 2X the cost of a battery system.

For both hydrogen and electric vehicles, diverting more electricity from the PV system improves the economics, but the effect is more pronounced for the hydrogen system.

Best case hydrogen cost is for the 7,000 m² PV system Case 2.
• About 90% of the PV output goes to hydrogen production or battery storage for EV charging
• 28% of the building load is supplied by the PV system
• The electrolysis system produces about 32,000 kg/year (~90 kg/day) or supply for 160 vehicles
• **Hydrogen cost is about $11/kg or ¢19/mile**
Full System Costs are Dominated by the PV Panels

Hydrogen System – PV System is the largest cost item, followed by the hydrogen storage system.
Hydrogen System Costs for Case 1 are Dominated by the Electrolyzer Costs

Hydrogen System – Case 1

Hydrogen Production and Dispensing System Cost Distribution (Excess PV Electricity)

PV Array Size

- 1200 m² (~150 kW max)
- 4000 m² (~600 kW max)
- 7000 m² (~1070 kW max)

Thousands

- Indirect cost (site preparation, engineering, contingency)
- Hydrogen dispensers
- Hydrogen system balance of plant
- Hydrogen storage compressor
- Hydrogen storage tanks
- Electrolyzer
Comparison of Case 1 and Case 2 for Hydrogen

Hydrogen System – Case 2 storage systems are slightly larger

<table>
<thead>
<tr>
<th></th>
<th>Millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect cost</td>
<td></td>
</tr>
<tr>
<td>Hydrogen dispensers</td>
<td></td>
</tr>
<tr>
<td>Hydrogen storage tanks</td>
<td></td>
</tr>
<tr>
<td>Storage system balance of plant</td>
<td></td>
</tr>
<tr>
<td>Electrolyzer</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0</td>
<td>$0</td>
<td>$1</td>
<td>$1</td>
<td>$2</td>
<td>$2</td>
</tr>
<tr>
<td>$0</td>
<td>$0</td>
<td>$1</td>
<td>$1</td>
<td>$1</td>
<td>$1</td>
</tr>
<tr>
<td>$0</td>
<td>$1</td>
<td>$1</td>
<td>$1</td>
<td>$1</td>
<td>$1</td>
</tr>
<tr>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
</tbody>
</table>
Hydrogen System Costs as a Percentage of the Total

Hydrogen Production and Dispensing System Cost Distribution (Excess PV Electricity)

Percent of Hydrogen Production and Dispensing System Costs

Indirect cost (site preparation, engineering, contingency)
Hydrogen dispensers
Hydrogen system balance of plant
Hydrogen storage compressor
Hydrogen storage tanks
Electrolyzer

PV Array Size

1200 m²
4000 m²
7000 m²

0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
## Overview of Results

<table>
<thead>
<tr>
<th>Hydrogen</th>
<th>PV System Size (% of total building load)</th>
<th>Case 1 - Excess Electricity (kg H2/year)</th>
<th>Number of vehicles</th>
<th>$/kg</th>
<th>¢/mile</th>
<th>Case 2 - Morning Output + Excess Electricity (kg H2/year)</th>
<th>Number of vehicles</th>
<th>$/kg</th>
<th>¢/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>1200 m² (~50)</strong></td>
<td>1,804</td>
<td>8</td>
<td>34</td>
<td>63</td>
<td>3,541</td>
<td>17</td>
<td>24</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td><strong>4000 m² (~170)</strong></td>
<td>14,564</td>
<td>71</td>
<td>13</td>
<td>22</td>
<td>16,985</td>
<td>83</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td><strong>7000 m² (~300)</strong></td>
<td>29,274</td>
<td>143</td>
<td>12</td>
<td>20</td>
<td>31,898</td>
<td>156</td>
<td>11</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Full Electric Vehicle (EV)</th>
<th>PV System Size</th>
<th>Case 1 - Excess Electricity (kWh/year)</th>
<th>Number of vehicles</th>
<th>$/kWh</th>
<th>¢/mile</th>
<th>Case 2 - Morning Output + Excess Electricity (kWh/year)</th>
<th>Number of vehicles</th>
<th>$/kWh</th>
<th>¢/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>1200 m²</strong></td>
<td>61,726</td>
<td>15</td>
<td>$1.04</td>
<td>35</td>
<td>121,936</td>
<td>30</td>
<td>0.45</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td><strong>4000 m²</strong></td>
<td>500,755</td>
<td>123</td>
<td>$0.41</td>
<td>14</td>
<td>585,475</td>
<td>145</td>
<td>0.40</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td><strong>7000 m²</strong></td>
<td>1,008,212</td>
<td>249</td>
<td>$0.39</td>
<td>13</td>
<td>1,100,877</td>
<td>272</td>
<td>0.39</td>
<td>13</td>
</tr>
</tbody>
</table>
Conclusions

This analysis does not present a very compelling case for community-scale hydrogen fueling. However;

• The system allows us to have a fully renewable fueling scenario
• The system allows us to have higher PV penetration without reverse power flow and voltage fluctuations.
• The analysis shows that the number of vehicles supported are comparable to the number expected for the number of residences represented by the building load.
• The storage system for hydrogen is more flexible than the battery – e.g., an additional kWh of H2 is cheaper than additional kWh of battery storage
• 100 mile range for electric vehicle may not fully support the needs of every resident.
Recommendations for Further Work

Perform sensitivity analysis to determine what hydrogen system component costs would have to be to be competitive with the battery system.

Explore more realistic scenarios for dealing with seasonal variation in PV output.
Thank You
# Hydrogen Refueling

**Hydrogen compression, storage and dispensing costs adapted from the H2A forecourt models**

<table>
<thead>
<tr>
<th>System</th>
<th>Design Calculations</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Compressor – One compressor assumed for both low pressure storage and cascade storage</td>
<td>Compressor design calculations taken from H2A forecourt model</td>
<td>~ 2.4 kW compressor power/(kg/h) H2 flowrate~$6,000 /kW (for comparison, at 1500 kg/day the cost is ~1,800/kW, $3,900/kg/h)</td>
</tr>
<tr>
<td>Dispenser</td>
<td>Source: H2A forecourt models</td>
<td>~$64,000 installed</td>
</tr>
<tr>
<td>Cascade storage – One cascade system assumed</td>
<td>Total volume 65 kg H2 (in 3-tank system)</td>
<td>~$1,700 per kg</td>
</tr>
<tr>
<td>Low pressure storage</td>
<td>Volume varies by application</td>
<td>~$1,040 per kg</td>
</tr>
</tbody>
</table>
# Electric Vehicles

## Battery and Electric Vehicle information

<table>
<thead>
<tr>
<th>System</th>
<th>Design Calculations</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc Air Battery</td>
<td>Design based on maximum kWh in “storage” at any time during the year</td>
<td>$315/kWh installed</td>
</tr>
<tr>
<td>Electrical Upgrades and Charging Stations</td>
<td>5% of installed batter cost</td>
<td></td>
</tr>
<tr>
<td>All Electric Vehicle based on the Nissan Leaf</td>
<td>100 mile all electric range</td>
<td>12,000 miles per year</td>
</tr>
<tr>
<td>PHEV</td>
<td>20 mile all electric range 40% of yearly miles traveled are all electric</td>
<td>12,000 miles per year</td>
</tr>
</tbody>
</table>
Building Load Statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand maximum (kW)</td>
<td>125.3</td>
</tr>
<tr>
<td>Demand minimum (kW)</td>
<td>28.4</td>
</tr>
<tr>
<td>Demand average (kW)</td>
<td>65.4</td>
</tr>
<tr>
<td>Demand Stdev (kW)</td>
<td>22.8</td>
</tr>
<tr>
<td>Demand total (kWh/year)</td>
<td>572,518</td>
</tr>
</tbody>
</table>