NextSTEPS White Paper: The Hydrogen Transition

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Talk Outline: H2 White Paper Highlights

• **Intro**: A Comeback for H2? What are drivers?

• **Tech status for FCVs and H2 supply**

• **Near and long term transition issues**
  – Managing Risk in Early FCV Rollout
  – Getting to “Green H2”
  – H2 Transition Costs in Perspective

• **Current status of the Global Hydrogen FCV Rollout**
  – FCV Commercialization
  – H2 Infrastructure
  – Rise of Public/Private Partnerships

• **Hydrogen Policy**
  – Public funding trends
  – Policy Review

• **Conclusions and Recommendations**
Comeback for Hydrogen?

- Enthusiasm for H2 FCVs in early 2000s. Lots of R&D, investment by stakeholders.
- By late 2000s it appeared that battery PEVs might be quicker route to zero emissions. H2 seen by some as too difficult, decades away, if ever.
- Early 2010s. New factors emerging, re-accelerating H2 FCV Rollout.
- Next 2-3 years will see concerted efforts to introduce 100s of H2 stations capable of supporting 10,000s of FCVs in selected regions worldwide, backed by $100s millions in public funds, $billions in private investment.
- If these efforts succeed, H2 FCVs might be just a few years behind PEVs in commercialization process, not decades.
New (& some Old) Factors Accelerating H2 FCV Rollout

• Automakers continued commitment to FCVs as zero emission vehicles “without compromise”: good performance, larger size, fast refuel, 300+ mile range. (synergy w/ PEV technologies)
• H2 infrastructure planning more sophisticated, workable, network thinking. Plans w/ stakeholder buy-in. Automakers partner with energy suppliers.
• Rise of Regional and National public private partnerships
• Public Funding, policy support generally trending upwards (mixed in US).
• Good prospects for low cost, plentiful H2. Shale gas boom.
• Success of H2 FCs in stationary, CHP and forklift markets
• H2 FCV recognized as key tech for low-C energy future
• Interest in H2 as energy storage for intermittent renewable energy
• Transition costs appear manageable. Long term benefits >> costs
• At least 3 regions where expertise, stakeholders, funding are at the right scale for successful rollout.
Progress in FC Technologies

At 100% technology meets goal for FCV commercialization


NRC 2013 study analyzed technical potential for efficiency. Plug-in EVs & H2 FCVs reach first cost parity with highly efficient (80 mpg+) ICEVs c. 2035-2045.

**FIGURE 2.8** Car incremental cost versus 2010 baseline ($26,341 retail price)—Midrange case.

Studies => H2 Long Term Potential: Key Tech for 2 Degree Scenario

**Key point**

In the Improve case, electric, PHEV and FCEVs together account for nearly three-quarters of new vehicle sales in 2050.

Source: International Energy Agency Energy Technology Perspectives 2012
Studies => H2 Long Term Potential: Flexible Storage for Renewables

Versatility of Hydrogen is a key advantage for energy storage

<table>
<thead>
<tr>
<th>Announced</th>
<th>Partners</th>
<th>Source</th>
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</table>
## FCV Market Intro. Dates Announced by Automakers

<table>
<thead>
<tr>
<th>Company</th>
<th>Previous demos</th>
<th>Commercialisation dates</th>
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<tbody>
<tr>
<td>BMW</td>
<td>7 generations of H₂ ICE saloons</td>
<td>Before 2015</td>
</tr>
<tr>
<td>Daimler</td>
<td>&gt;100 B-Class vehicles</td>
<td>Before 2015</td>
</tr>
<tr>
<td>Honda</td>
<td>&gt;100 FCX clarity (C-Class FC car)</td>
<td>2015-2016</td>
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<tr>
<td>Hyundai</td>
<td>Now deploying a fleet of ix35 SUV’s</td>
<td>2015-2016</td>
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<tr>
<td>Nissan</td>
<td>30 X-Trail SUV in US/Japan</td>
<td>2017-2018</td>
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<tr>
<td>Toyota</td>
<td>~100 SUV vehicles US/Japan/Germany</td>
<td>2019-2021</td>
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</tbody>
</table>
H2 Stations Worldwide: ~220 operational, 100s planned

Source: Ludwid Bolkow Systemtechnik,
Rise of Regional public-private partnerships
Mix of Partner Organizations varies by region
Early Market Dynamics: Stakeholder Roles in CA

Government
- Secure Funding (AB8)
- Maintain Strong ZEV Program
- ZEV Action Plan
- Conduct FCEV Projection Survey
- Create Govt Incentive Plan & Vision

Building Market Confidence

Automakers
- Support ZEV program
- Input into network build-out
- Outreach to station developers
- Advertise, announce; prep dealers

Station Developers
- Deliver stations on time
- Maximize uptime
- Build positive customer experience
- Keep stations open beyond 3 yrs

New thinking emerges on H2 infrastructure

• H2 infrastructure planning more sophisticated.
• 1-of-a-kind demos => system thinking/network concepts.
• Realistic Plans w/ stakeholder buy-in.
• More experience building infrastructure
CA H2 Highway (2004) Locate stations every 20 miles along the interstates.

**Problem**: This did not adequately serve H2 vehicles in cities where most people live.

**Solution**: Focus infrastructure mostly in cities w/ a few stations along the interstates to allow intercity travel.


**Problem**: For good access need H2 at 10-30% of gas stations. In LA this is ~400 stations just to get started.

**Solution**: Regional “Cluster” Strategy” (current paradigm)

FCVs, H2 stations placed together in “clusters” ID’d by stakeholders as early market sites. “Connector” stations added to facilitate regional travel

How many stations needed? Where should they be located?
Might FCVs follow similar path to HEVs and PEVs?

HEVs cum. US sales ~1 million in 2007 (8 years after market intro.), 2 million c. 2010 (11 years). Comparable to US goals (if FCVs ~ 50% of 3.3 million ZEV goal in 2025–11 years after FCV intro).
## H2 Network Scenario (78 sta., 34K FCVs in yr 7)

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
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<tr>
<td># FCVs in fleet</td>
<td>197</td>
<td>240</td>
<td>347</td>
<td>1161</td>
<td>12106</td>
<td>23213</td>
<td>34320</td>
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<td>H2 demand (kg/d)</td>
<td>137</td>
<td>168</td>
<td>250</td>
<td>800</td>
<td>8500</td>
<td>16000</td>
<td>24000</td>
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<tr>
<td>Total sta. capacity (kg H2/d)</td>
<td>400</td>
<td>400</td>
<td>1080</td>
<td>3580</td>
<td>11580</td>
<td>21580</td>
<td>31580</td>
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<td>Number of new stations/y by size, type</td>
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<td>Tot.# sta.</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>18</td>
<td>38</td>
<td>58</td>
<td>78</td>
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Scenario for Regional H2 FCV Rollout Years 1-12

Number of FCVs in fleet and FCV sales (vehicles/yr): Regional Scenario

- FCV sales/yr
- #FCVs in fleet
At first, network capacity factor low, as stations are built ahead of vehicle deployment. In first few years stations small, located to provide coverage for early adopters.
Investment to launch regional H₂ fuel supply

$100-200 million capital investment for ~100 stations (serving 50,000 FCVs) to reach H₂ <$7/kg, Assumes FCV market grows rapidly.
Buydown Cost for FCVs in US ($million/y)

H2 Transition Costs $10s B over 10-15 yr (mostly vehicles)
Transition costs << $flow in energy system

Diff Veh (gas-FCV)  Diff fuel (gas-FCV)
Diff TOT (gas-FCV)  Cum TOTAL (millions)

Analysis includes Private costs only.
Un-taxed fuel costs;
Long Term Benefits >> Transition Cost (NRC 2013)

FIGURE 5.24 Present value cost and benefits of a transition to hydrogen fuel cell vehicles using midrange technology assumptions, fuel cell vehicle subsidies and additional incentives, and a low-GHG infrastructure for the production of hydrogen.

Long Term Transition: Getting to “Green H2”

H2 SUPPLY SCENARIOS:
Deeper Cuts In Carbon Emissions => Higher H2 Cost (+$1/Kg) and More Renewable Electrolysis

WTW C cut 2050
90%

Coal w/CCS

Coal w/CCS

Natural Gas

80%

65%

H2 Supply Cost ($/kg)

H2 Levelized Cost ($/kg)

30% Coal, no CCS

2010 2015 2020 2025 2030 2035 2040 2045 2050

Trends in public funding for H2 and FC

Global Total Public Funding: ~$1B/y
Upward Trend except US
Leverages 6-9 X in private funding (USDOE)
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<th>Category</th>
<th>Policy</th>
<th>Canada</th>
<th>USA</th>
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<td><strong>Vehicle “Perks” (HOV lanes, free parking, etc.)</strong></td>
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<td><strong>Subsidy stationary power FCs</strong></td>
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<td><strong>Other</strong></td>
<td><strong>Public/private partnerships for H2/FCVs</strong></td>
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<td><strong>Nat’l Goals #FCVs</strong></td>
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<td><strong>Goal to end fossil fuel use by 2050</strong></td>
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Conclusions

• We seem to be tantalizingly close to the beginning of a hydrogen transition. Is it different this time?

• Workable strategies for H2 infrastructure rollout emerging with buy-in from key stakeholders: and public funding to support building early stations, overcoming first mover disadvantage.

• Our estimates => perhaps 50,000 FCVs in a region with 100 stations would be enough to bring H2 fuel costs to competitiveness. The station investment cost would be $100-200 million.

• At least 3 regions where expertise, stakeholders, funding are coming together

• If these regional rollouts are successful, hydrogen FCVs may be just a few years behind battery EVs, not decades.

• It appears that these efforts may jump start the hydrogen economy at last.
NextSTEPS Consortium Sponsors

Thank you for your financial and intellectual contributions.
# Compressed gas truck delivery

H2 Station Cost Assumptions: 700 bar dispensing.

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Capital Cost</th>
<th>Annual O&amp;M cost $/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1 (&lt;2013)</strong></td>
<td></td>
<td></td>
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<tr>
<td>100 kg/d -&gt; 170 kg/d</td>
<td>$1 million</td>
<td>$100 K (fixed O&amp;M) + 1 kWh/kgH2 x kg H2/yr x $/kWh (compression elec cost)</td>
</tr>
<tr>
<td>250 kg/d (has more ground storage)</td>
<td>$1.5 million</td>
<td>+ H2 price $/kg x kg H2/y (H2 cost delivered by truck)</td>
</tr>
<tr>
<td><strong>Phase 2 (2014)</strong></td>
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<tr>
<td>100 -&gt; 170 kg/d</td>
<td>$0.9 million</td>
<td>Same as above</td>
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<tr>
<td>250 kg/d</td>
<td>$1.4 million</td>
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<td><strong>Phase 3 (2015+)</strong></td>
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<td>100 -&gt; 170 kg/d</td>
<td>$0.5 million</td>
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<td>250 kg/d</td>
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<td>400 -&gt; 500 kg/d</td>
<td>$1.5-2 million</td>
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Number of FCVs in fleet and FCV sales (vehicles/yr): Regional Scenario (assume year 0 ~ 2014)