Hydrogen Fuel Cells for Cars, Trucks, and Buses

Western Washington State
Clean Cities Webinar

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Tim Lipman – Bio Overview

• BA in Environmental Studies - Stanford (1990); MS in Transp. Technology and Policy - UC Davis (1998); PhD in Ecology - UC Davis (1999)
• Co-Director of UC Berkeley TSRC Since 2006
• Research Affiliate with the Berkeley Lab
• Chair of TRB Committee on Alternative Transportation Fuels and Technologies (ADC80)
• Member of U.S. DOE Hydrogen and Fuel Cell Technical Advisory Committee
• Member of BAAQMD Advisory Board
Outline

• UC Berkeley TSRC Research Areas
• Low Carbon Hydrogen Production
• Hydrogen Station Status in California
• Hydrogen Fuel Cell EVs – Now Here
• Questions?
Transportation Sustainability Research Center (TSRC) Locations

• Main office is at Berkeley Global Campus - Richmond
TSRC Program Areas

• **Advanced Vehicles and Fuels**
  Electric-drive vehicles and infrastructure; lifecycle analysis of biofuels, tar sands and other non-traditional fuels, hydrogen, and electricity; transportation-related emissions; and feebates

• **Energy and Infrastructure**
  Smart grid integration, advanced fuel infrastructure, intelligent transportation systems applications, ecodriving for private vehicles

• **Goods Movement**
  AB 32 and goods movement, smart parking for trucks, ecodriving for trucks

• **Transit and Travel Connections**
  Smart parking for transit, carsharing, bikesharing, and ridesharing

• **Mobility for Special Populations**
  Non-traditional modes, transit and non-motorized travel
Plug-in Hybrid Electric Vehicles

• Many years of research on various aspects of EVs
• 2010-11 Toyota-sponsored project included 10 conventional hybrid Priuses and 10 plug-in hybrid Priuses
Lots of New Electric Car Models!
Hydrogen Fueling Facility

• High pressure (700 bar = 10,000 psi) hydrogen fueling facility at UC Berkeley - Richmond
  – In operation since May 2011 (first 700-bar station in N. Cal) with more than 2,000 kg of hydrogen dispensed
Transportation and the Env’t - GHGs

Emissions by Economic Sector

- Transportation: 37%
- Industrial: 24%
- Residential: 6%
- Commercial: 5%
- Agriculture: 8%
- Electricity Generation (Imports): 8%
- Electricity Generation (In State): 12%
- Not Specified: <1%

2014 Total CA Emissions: 441.5 MMTCO2e

Source: California Air Resources Board, 2016
https://www.arb.ca.gov/cc/inventory/data/data.htm
GREET Example – Key Features

Key GREET features

- Emissions of greenhouse gases
  - CO₂, CH₄, and N₂O
- Emissions of six criteria pollutants
  - Total and urban separately
  - VOC, CO, NOₓ, SOₓ, PM₁₀ and PM₂.₅
- Energy use
  - All energy sources
  - Fossil fuels (petroleum, NG and coal)
  - Petroleum
  - Coal
  - NG
Lifecycle Emissions Reductions of Adv. Vehicles

**Overall, Emissions from Plant Construction Are Negligible Compared to Fuel- and Vehicle-Cycle Emissions**

<table>
<thead>
<tr>
<th></th>
<th>Gasoline ICEV</th>
<th>H₂ FCEV</th>
<th>BEV 100</th>
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<tbody>
<tr>
<td>Fuel Economy (mpgge)</td>
<td>23</td>
<td>54</td>
<td>80*</td>
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*from wall outlet (assuming 85% charging efficiency)

Source: ANL, 2013

Note: BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; ICEV = internal combustion engine vehicle
The GREET model shows that the California mix of hydrogen in an FCEV reduces GHGs by more than half compared to gasoline in a combustion vehicle. The “California mix” includes 33% of hydrogen from renewable as state regulations currently require. Regulations also require that 33% of electricity come from renewable by 2020.

In a transit bus, real-world data shows that fuel cell buses reduce GHG emissions by half compared to natural gas buses—even when the hydrogen is produced from natural gas.

Source: CaFCP, 2014
Hydrogen Production Strategies

Hydrogen Production - Strategies

Technology Readiness of DOE Funded Production Pathways

Note: CCS = carbon capture and sequestration; PEC = photo-electrochemical; STCH = solar thermo-chemical
2015 HTAC ANNUAL REPORT SUMMARY

This Annual Report of the United States (U.S.) Department of Energy (DOE) Hydrogen and Fuel Technical Advisory Committee (HTAC) highlights worldwide advances and challenges with regard to hydrogen and fuel cell commercialization, policy, regulations, standardization, financial, climate, and research and development (R&D) during 2015.

Hydrogen and fuel cell technologies continued to advance rapidly during 2015. Significant commercial progress and new technical milestones for fuel cell systems and hydrogen production, delivery, and storage were achieved. This growth has come despite the persistent drag in all places that may have slowed incremental gains in the past. Moreover, the DOE Hydrogen & Fuel “Big Idea” project this year illustrated green power potential for hydrogen and fuel cell technology. These technologies are uniquely valuable in that they can enable dynamic greenhouse gas (GHG) emissions reductions across many sectors and applications simultaneously. This makes them critical to achieving the Nation’s goal to significantly reduce GHG emissions.

Key highlights from 2015 include:

- Toyota released the Mirai fuel cell electric vehicle (FCEV) to selected customers in the U.S., following up on a late 2014 debut in Japan, pledging to make FCEVs a key component of its future vehicle development strategy.
- FuelCell Energy and Falls Energy Peak LLC announced what would be the world’s largest stationary fuel cell power plant designed in Connecticut, with 63.3 megawatts of ultimate capacity, and commissioning scheduled for start in 2016.
- Honda continued to sell commercial FCEVs in Asia, Europe, and the U.S., with a new FCX fuel cell vehicle launched in Japan, France, and announced an automobile FCEV during trials in the U.S.
- Honda announced that the 2016 Clarity FCEV is to go on sale in Japan in March 2016, with U.S. (California) and European introductions late in 2016.

California continues to lead the U.S. in hydrogen fueling infrastructure development, with 12 open stations, 12 additional stations contracted or under construction, and 25 additional stations in planning or permitting at the end of 2015.

This compares to the largest deployment of hydrogen fueling stations in Japan, which has about 45 retail stations as of the end of 2015. Germany, meanwhile, had 30 open retail stations at the end of 2015 and a goal of 400 stations by the end of 2020.

Hydrogen announced a first supply deal with Chiyoda Corporation that includes transport, the largest to date, via 1,000 ton vessels of different types over the next 5 years, and includes heavy-duty fuel cells and fueling stations.

Japan’s FRESS-FARDC project achieved a total of over 140,000 users of stationary and cell systems in residential applications.

Despite these encouraging steps, key challenges for the hydrogen and fuel cell industry remain. Individual regions have their specific challenges, including:

- Europe suggests that the U.S. is not on track to meet the 2020 goals for hydrogen FCEVs and enabling infrastructure set by the U.S. Energy Policy Act of 2005 (EPAF) Title VIII. It is, therefore, important that an urgent plan, including measurable progress milestones, be put in place by 2016-2017 that ensures this goal will be successfully achieved.
- Developing a sufficient and robust hydrogen refueling infrastructure for FCEVs is an ongoing challenge, given unfavorable economics, until the vehicle reaches further development.
- Stationary fuel cell power remains numeric, compared to other forms of distributed power generation, at about $4,000-$7,000 per kilowatt, but offers higher operational efficiency and lower noise emissions than conventional-based guarantees.

Overall, 2015 was an important and encouraging year for hydrogen and fuel cell system development. Much progress is being made, but greater momentum is needed for these technologies to provide the large benefits that they are capable of in 2020 and beyond. More specifically, continued investment in research and infrastructure, and R&D, hydrogen and fuel cells can create additional energy diversity leading to greater energy security and economic efficiency.
New Hydrogen Fuel Cell EVs

Introducing the
**TUCSON FUEL CELL**

$499 / month
36-month lease, $2,999 due at lease signing
Including fuel and maintenance

Toyota Mirai

Hyundai Tucson

Honda Clarity – Coming early 2017
Application Space

Source: GM
Proton-Exchange Membrane (PEM) Fuel Cells Operation
Hydrogen Fuel Cell Development
Hydrogen Fuel Cells – Cost Improvement

Fuel Cell Cost Reductions Enabled by R&D

Fuel Cell Cost Reductions

- 50% from 2006
- 30% from 2008
- 5X Platinum Catalyst

Fuel Cell System Cost* Cost Breakdown

- 5% Bipolar Plates
- 11% Membranes
- 24% Catalyst + Application
- 11% GDLs
- 46% MEA Frames/Gaskets
- 6% Balance of Stack

Catalyst accounts for >45% of total system cost

Fuel Cell Cost Status and Goal

- $55/kW* for high volume
- ~$280/kW† for low volume
- $40/kW by 2020 is the goal

*SA: bottom-up analysis of model system manufacturing cost, 500,000 sys/year with next-gen lab technology.
†TORNI, top-down analysis based on OEM input, 20,000 sys/yr. with current technology.

Catalyst remains key challenge and opportunity to lower cost

*For PEMFC Stack cost, 500,000 units per yr.
Cost is shows as $/kW-net.
Hydrogen Station Progress
Hydrogen Station Progress

Photo: T. Lipman – Hayward, CA - 9/29/16
UC Berkeley TSRC – FCEV Test Program

- UC Berkeley TSRC has been conducting technical and social/behavioral research with several hydrogen FCEVs since late 2005
- Drivers drive the vehicles for a month at a time, filling out “before” and “after” surveys about their attitudes, demographics, and experiences with the vehicles
- Drivers are trained to refuel by themselves after a few assisted fills
- The Toyota Highlander FCHV-adv vehicle study has now concluded with “n=54” test drivers
- The program is continuing with the Hyundai Tucson FCEV and possible additional commercial FCEVs
- Findings/results paper is under review for publication
Hydrogen Fuel Cell Buses – Progress

- Fuel cell buses in operation at AC Transit since 2005
- Current fleet of 12 buses (240 miles range)
- Lead fuel cell bus with 20,000+ hours of operation
- Nearly one million miles of service for AC Transit and over 3 million passengers carried
- Emeryville station has dispensed over 100,000 kg of fuel
- Oakland station now online
Hydrogen Fuel Cell Trucks – Long Haul

• Major announcements in 2016 by Toyota and Nikola for Class 8 long-haul trucks powered by hydrogen/FCs
• Nikola One – FC/battery powered:
  • Nikola One weighs 2,000 pounds lighter than a conventional diesel semi truck
  • Lease for $5,000-$7,000 a month for 72 months with 1 million miles of free hydrogen fuel
  • Nikola intends to build 364 hydrogen fueling stations across the U.S.
  • 320 kWh battery pack integrated into the rails of the big rig
  • Electric motors that churn out 1,000 horsepower, 2,000 pound-feet of torque
  • Cruising range of up 1,200 miles
  • Nikola One will return the equivalent of 15.4 miles per gallon
Hydrogen Fuel Cell Trucks – Short Haul
“Zero Emission Cargo Transport”

Using existing ElecTruck developed in ZECT I project as a platform...

Build an extended range zero-mission truck using fuel cell technology

Hydrogenics HyPM™ Fuel Cell
Several demonstration projects for short-haul, zero-emission port drayage trucks (battery or fuel cell “dominant”)

CEC awarded $2.4M to SCAQMD for a demo of seven FC port trucks in LA/Long Beach in 2015 – partners include TransPower, Kenworth, US Hybrid

Requirements of CEC grant vehicles:
  • Pull 80,000 pounds GVWR
  • Climb 6% grades
  • 100 miles operation between fueling
  • Operate at freeway speeds

TransPower is working with Hydrogenics to use 30 kW FC range extender for electric-drive trucks

TSRC hopes to provide project evaluations for similar proposed FC truck projects at the Port of Oakland
Conclusions

• Transportation is a significant contributor to climate change and other environmental problems
• Both PEVs and FCEVs are improving rapidly and ramping up in market launch and production volume
• Key challenges are now mainly around the supporting infrastructure:
  – Providing PEV charging in settings available to broad range of consumers, not just single family home owners
  – Relatively high cost and difficulty of siting hydrogen fueling stations
• Fuel cell technology may ultimately be most well suited to heavier duty vehicles, but much remains to be learned as time goes on and various technologies continue to improve