Hydrogen and Fuel Cells Overview: Opportunities for Ports & Maritime Applications

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U.S. Department of Energy

CHBC & CHFCA Ports Workshop
Vancouver, Canada – May 21, 2019
Progress
Fuel Cell Shipments - Growth by Application

Fuel Cell Power Shipped (MW)

- Approximately 68,500 fuel cell units shipped worldwide
- Approximately $2.3 Billion fuel cell revenue*

* Revenue from publicly available

Source: DOE and E4Tech
More than 6,800 fuel cell cars on the road

Fuel Cell Cars in the U.S.

Over 6,800
May 2019

Jun-14  Jun-16  Jun-18
Commercial Hydrogen Refueling Stations

Retail Hydrogen Stations in the U.S.

40 stations
Apr. 2019

More than 40 retail stations. Plans for many more.
Real World Applications – In the U.S.

Fuel cell delivery and parcel trucks starting deliveries in CA and NY

World’s first fuel cell for maritime ports in Hawaii

First fuel cell tow truck fleet at airport in Memphis

Photo Credit: UPS

Photo Credit: FedEx

Photo Credit: Sandia National Laboratories
Real World Applications – In the U.S.

**Industry demonstrates heavy duty fuel cell trucks**

Photo Credit: Toyota

**ZH2: U.S. Army and GM collaboration First of its kind**

Photo Credit: General Motors

**Fuel cell powered lights at Super Bowl**

Photo Credit: Toyota

**Fuel cell buses in California surpass 20 million passengers**

Photo Credit: NREL
Real World Applications – Growing Opportunities

Hydrogen fuel cell powered drones and UAVs- markets taking off

Thousands of fuel cell forklifts in warehouses and stores in the U.S.

Photo Credit: MMC

Thousands of fuel cells for backup power and stationary power for resilience

Hydrogen fuel cell trains in passenger service in Germany

Photo Credit: Hydrogenics and Alstom
Hydrogen in the United States Today

U.S. annual hydrogen production
10 million metric tons

Largest Users in the U.S.

- Petroleum Processing: 68%
- Fertilizer Production: 21%

Hydrogen Production Units in the United States (Gaseous, metric tons/day)
- 0 – 50
- 50 – 100
- 100 – 200
- 200 – 400
- 400 – 800

H₂@Scale concept
Enable affordable, reliable, clean and secure energy across sectors
H$_2$@Scale: Enabling affordable, reliable, clean, and secure energy across sectors
H2@Scale Consortium

Over 20 projects with DOE Labs, Industry, States

Source: Elgowainy, et al, ANL
Requests from Industry: Work with National Labs on...

- Techno economic Modeling and Analysis
  - Approx. 16,000 jobs today in the fuel cell car sector in the U.S.
  - Over 300,000 potential jobs in the future with fuel cell cars in the U.S.
  - Manufacturing: Approx. 120,000 jobs
    - Multiple industries/manufacturing: professional services, chemicals, medical equipment, etc.
    - 50% in industrial central regions
  - Distribution and Sales: Approx. 200,000 jobs
    - Multiple industries/distribution: consumer goods, retail, transportation, etc.
    - 60% in industrial central regions

- Hydrogen Materials R&D
  - Friction & wear
  - Pressure cycle aging
  - Fundamental property changes

- Grid simulation and Testing R&D

- Safety and Infrastructure R&D
Versatility

Volume

Value Proposition
Hydrogen Energy Storage is Scalable

Image: Hydrogen Council

One hydrogen cavern could provide ~ 100 GWh energy storage

Hydrogen can be used to monetize surplus electricity from the grid, or remote, off-grid energy feedstock (e.g. solar, wind) for days to months.
Example: Addressing Grid Needs

Preliminary study shows electrolyzers can reduce amplitude of power fluctuations by up to 65% in a grid with high renewables.

Source: D. Murphy, et al, NREL and INL. Specific case with high solar penetration and electrolyzers used to compensate for power fluctuations.
H₂@Scale: Supply and Demand Assessment

Assessing resource availability - most regions have sufficient resources

Red: regions where projected industrial & transportation demand exceeds supply for given scenario

This analysis represents potential generation from utility-scale photovoltaics and onshore wind resources minus total hydrogen demand from the industrial sector, refineries, biofuels, ammonia and natural gas systems (metals are not included) and the transport sector: light duty vehicles and other transport. The data has been normalized by area at their respective spatial scales, and then summarized by county.

Data Source: NREL analysis

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Nicholas Gilroy, March 27, 2017
Scenario Analysis for Hydrogen Fueling Station Rollout

Modeling the optimal size and placement of hydrogen stations over time under various scenarios

Tiers represent clusters of sequential FCEV introduction, based on early adopter metrics, industry input, and geographical considerations.

State Success 2050

- Denver-Aurora, CO
  - Total Stations: 91
  - Ave Cap (kg/d): 1,853

- Kansas City, MO
  - Total Stations: 27
  - Ave Cap (kg/d): 689

- Minn.-St. Paul, MN
  - Total Stations: 57
  - Ave Cap (kg/d): 1,031

- Chicago, IL
  - Total Stations: 366
  - Ave Cap (kg/d): 1,953

- Columbus, OH
  - Total Stations: 18
  - Ave Cap (kg/d): 736

- Seattle, WA
  - Total Stations: 248
  - Ave Cap (kg/d): 1,937

- Portland, OR
  - Total Stations: 157
  - Ave Cap (kg/d): 1,896

- Sacramento, CA
  - Total Stations: 158
  - Ave Cap (kg/d): 1,782

- Los Angeles, CA
  - Total Stations: 1,519
  - Ave Cap (kg/d): 1,951

- Las Vegas, NV
  - Total Stations: 122
  - Ave Cap (kg/d): 1,580

- Boston, MA
  - Total Stations: 346
  - Ave Cap (kg/d): 1,880

- New York, NY
  - Total Stations: 1,627
  - Ave Cap (kg/d): 1,959

- Atlanta, GA
  - Total Stations: 217
  - Ave Cap (kg/d): 1,331

- Houston, TX
  - Total Stations: 302
  - Ave Cap (kg/d): 1,944

- Miami, FL
  - Total Stations: 129
  - Ave Cap (kg/d): 1,870

Number HRS: 11,800
Pop. Enabled: 126 M
H2@Ports to Scale up Hydrogen

H₂@Rail and H₂@Ports Initiatives

- U.S. DOE in collaboration with:
  - Dept. of Transportation (DOT)-Federal Railroad Administration
  - DOT-Maritime Administration

Data Centers and Energy Storage Applications
Examples of Intermodal Routes in the U.S.
Collaboration with multiple project partners was essential to success of the project.

<table>
<thead>
<tr>
<th>Partner</th>
<th>Project Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>(logo removed)</td>
<td>DOE Sponsorship, steering</td>
</tr>
<tr>
<td>DOT/MARAD</td>
<td>Sponsorship, steering, and facilitation</td>
</tr>
<tr>
<td>Young Brothers &amp; Foss Maritime</td>
<td>Site preparations, prototype operation and routine maintenance</td>
</tr>
<tr>
<td>Hydrogenics (sub w/ cost share)</td>
<td>Design, engineer, build, commission, and support prototype unit</td>
</tr>
<tr>
<td>HNEI</td>
<td>Hydrogen supply logistics facilitation</td>
</tr>
<tr>
<td>HCATT</td>
<td>Hydrogen provider</td>
</tr>
<tr>
<td>ABS</td>
<td>Prototype design to maritime product standards</td>
</tr>
<tr>
<td>US Coast Guard</td>
<td>Review and acceptance of prototype design and operation</td>
</tr>
<tr>
<td>PNNL H₂ Safety Program</td>
<td>Prototype and project safety review by HSP; Hydrogen Emergency Response Training for First Responders</td>
</tr>
<tr>
<td>Sandia</td>
<td>Mgmt. and coord., H₂ materials, systems, risk expertise, H₂ supply logistics, tech/biz data collection and analysis</td>
</tr>
</tbody>
</table>
Fuel Cell and Diesel Engine Efficiency Examples

Diesel engines at ports: Typically sized for max load. Poor efficiency at part load.


Sandia National Lab. Figure based on commercial diesel system.  
In collaboration with U.S. MARAD, developed and tested hydrogen fuel cell power generator

Source: Sandia National Laboratory, 2017

Model analysis validated in field experiment testing: ~30% energy efficiency gain over diesel engine at part loads

Next Step
Maritime fuel cell generator will be field tested at Scripps Institution of Oceanography in San Diego for cold ironing application

Example: Annual Fuel Cost for Port Application

Annual fuel cost for six 300 kW generators in port application

Hydrogen fuel at roughly $5/kg can offer fuel savings compared to diesel and zero emissions
“Clustering” FCEVs Can Drive H2 Demand in Port-Based Distribution Complexes

Representative Port-Based Industrial Complex with Hydrogen Cost < $6/kg
“Hub and Spoke” H2 Fueling Stations Connected by Pipelines
## Examples of Applications and Specifications

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Power Required</th>
<th>Run Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Typical</td>
<td>Low</td>
</tr>
<tr>
<td>Harbor Tug</td>
<td>100 kW</td>
<td>7.5 kW</td>
</tr>
<tr>
<td>Tug-Barge</td>
<td>115 kW</td>
<td></td>
</tr>
<tr>
<td>Fishing Trawler</td>
<td>200 kW</td>
<td>75 kW</td>
</tr>
<tr>
<td>Bulk</td>
<td>200 kW</td>
<td>150 kW</td>
</tr>
<tr>
<td>Tanker (steam pumps)</td>
<td>700 kW</td>
<td>550 kW</td>
</tr>
<tr>
<td>Auto/RoRo</td>
<td>800 kW</td>
<td>700 kW</td>
</tr>
<tr>
<td>Container</td>
<td>1.4 MW</td>
<td>500 kW</td>
</tr>
<tr>
<td>Reefer</td>
<td>3 MW</td>
<td>900 kW</td>
</tr>
<tr>
<td>Cruise</td>
<td>6 MW</td>
<td>3.5 MW</td>
</tr>
<tr>
<td>Tanker (elec. pumps)</td>
<td>7.8 MW</td>
<td></td>
</tr>
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**Examples of applications under assessment:**
- Container ships at berth at the Port of Tacoma and/or Seattle
- Tugs at anchorage near the Port of Oakland
- Powering refrigerated containers on-board Hawaiian inter-island transport barges

Source: Sandia National Laboratory, 2014
Example - Hydrogen Potential at the Port of Tacoma

<table>
<thead>
<tr>
<th>Fuel Use Category</th>
<th>Subcategory</th>
<th>CO2e Tons</th>
<th>Gallons Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>OGV</td>
<td>Hotelling</td>
<td>2,796</td>
<td>249,643</td>
</tr>
<tr>
<td>OGV</td>
<td>Maneuvering</td>
<td>65</td>
<td>5,804</td>
</tr>
<tr>
<td>OGV</td>
<td>Subtotal</td>
<td>2,861</td>
<td>255,446</td>
</tr>
<tr>
<td>CHE</td>
<td>Subtotal</td>
<td>12</td>
<td>1,071</td>
</tr>
<tr>
<td>Locomotives</td>
<td>Subtotal</td>
<td>1,166</td>
<td>104,107</td>
</tr>
<tr>
<td>HDV</td>
<td>On-Terminal</td>
<td>28</td>
<td>2,500</td>
</tr>
<tr>
<td>HDV</td>
<td>Subtotal</td>
<td>28</td>
<td>2,500</td>
</tr>
<tr>
<td>Port</td>
<td>Total</td>
<td>4,067</td>
<td>400,276</td>
</tr>
</tbody>
</table>
State and Industry Project:
Hydrogen Fuel Cell Ferry to be Built Soon

Funded by the State of California Air Resources Board (CARB)

The first commercial hydrogen fuel cell ferry in the western hemisphere.
- Aluminum catamaran
- 70’ long
- 84 passenger (reconfigurable)
- 22 knot top speed
- On the waters of SF Bay Fall of 2019.

Project Lead

Funding & Administration

This project is supported by the “California Climate Investments” (CCI) program
Collaboration & Resources
Example of International Government Collaboration

The International Partnership for Hydrogen and Fuel Cells in the Economy
Enabling the global adoption of hydrogen and fuel cells in the economy

www.iphe.net

Working Groups: Education & Outreach
Regulations, Codes, Standards & Safety

Find IPHE on Facebook, Twitter and Linkedin
Follow IPHE @The_IPHE

Formed 2003
Over 20 Countries
Collaboration: New H₂ Safety Partnership

new global partnership to promote collaboration on safety

www.aiche/chs
Summary and Next Steps

Using H₂ for large scale applications aligns with H2@Scale and can enable energy security, economic value and environmental benefits. Maritime applications can play a role.

Next Steps

• Conduct analysis on H₂ and fuel cells maritime applications.
  – TCO, impact potential (petroleum, emissions reductions, etc.)
• Develop technical and cost targets.
• Identify barriers and opportunities for RD&D and addressing regulations, codes and standards
• Focus on global collaborations to accelerate progress.
Opportunities for outreach and to increase awareness

Celebrate National Hydrogen & Fuel Cell Day
October 8 or 10/08
(Held on its very own atomic-weight-day)

Information and Training Resources to Increase Awareness

Learn more at: energy.gov/eere/fuelcells

Save the Date: May 18-21 2020
Annual Merit Review
Washington DC

H2tools.org
Thank You

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