Application of Hydrogen Fuel Cells in Transportation

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Ballard Power Systems Inc.

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Our Vision

We deliver fuel cell power for a sustainable planet
Hydrogen Mobility Driving Forces

**Macro Trends**
- Urbanization
- Climate change
- Digital world (E-commerce)

**Market Drivers**
- Air pollution impact
- GHG emission reduction targets
- Freight increase (+40% by 2040)

**Technology evolution**
- New vehicle utilization (car share, autonomous)
- Electrification of transport (battery technology)
- Autonomous vehicles

**Macro Trends**
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Extreme weather from climate change is the world’s greatest threat.
COP21 Paris Agreement will result in decarbonization.
Hydrogen Council formed in 2017
Fuel cell technology is needed for deep decarbonization of transportation
Many cities are committing to clean transportation
Increasing world wide regulations against fossil fueled vehicles

Electric vehicle targets have also been set by Austria, China, Denmark, India, Ireland, Japan, London, Los Angeles, Netherlands, S.Korea, Paris, Portugal, Spain, 8 U.S. States
Electrification of powertrain is already disrupting the automotive industry
Battery electric and fuel cell technologies are complementary
Roadmap for hydrogen mobility

- **2018**: >15,000 fuel cell forklifts in daily operation
- **2020**: >350 FCEBs on the road in Europe (JIVE)
- **2025**: 5,000 fuel cell buses and trucks in service
- **2030**: 10 to 15 million fuel cell cars and 500,000 trucks on the road

**Japan road map**: 40,000 vehicles on the road in Japan by 2021

**China road map 2018**: 5,000 FC vehicles on the road in China by 2020

**Europe H2Bus Project**: +600 FCEBs on the road in Europe

**China road map 2018**: 5,000 FC vehicles on the road in China by 2020

**Japan roadmap**: 1 in 10 trains on non-electrified tracks

**Korea road map 2019**: 6 million FC car produced by 2040

**Hydrogen Council vision**: 10 million FC vehicles on the road in China by 2030
What is driving the momentum behind hydrogen mobility?
1. Accelerating improvement on product cost and performance
Fuel cell technology is following adoption curves of Solar and Wind.
Dramatic price reduction with scale

Source: Bloomberg
2. Early adoption in medium and heavy duty motive applications
Value proposition of FCEVs

FCEV – Fuel Cell Electric Vehicles

Fuel cells delivers a significant value proposition to heavy duty vehicles

1. FCEV powertrains for trucks are cost competitive with BEV from 100 km range

2. Hydrogen refueling is 15 times faster than fast charging
   After 10 minutes refueling/recharging time
   \[ \frac{90\%}{10\%} \] of ~1000 km range

3. Recharging infrastructure...
   \[ 10-15x \] less space and creates flexible instead of peak load

Source
3) The China Factor
# National & Local Subsidies

## 2019 national subsidies for FCVs

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Subsidy Standard (RMB)</th>
<th>Upper limit of subsidy (RMB)</th>
<th>Rated power of fuel cell system</th>
<th>NDRC</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell Passenger vehicle</td>
<td>6000/kW</td>
<td>200,000/car</td>
<td>≥10kW</td>
<td>300km</td>
<td>0.3 ≤ r &lt; 0.4, 0.4 ≤ r &lt; 0.5, r ≥ 0.5</td>
</tr>
<tr>
<td>Fuel Cell Light Duty Bus &amp; Truck</td>
<td>N/A</td>
<td>300,000/car</td>
<td>≥30kW</td>
<td></td>
<td>0.8x</td>
</tr>
<tr>
<td>Fuel Cell Heavy Duty Bus &amp; Truck</td>
<td>N/A</td>
<td>500,000/ar</td>
<td>≥30kW</td>
<td></td>
<td>0.9x</td>
</tr>
</tbody>
</table>

### Local subsidies for FCVs

- **1.0x**
  - Guangzhou
  - Foshan
  - Wuhan
  - Nanning
  - Shanxi province
  - Jiangmen
  - Wenzhou

- **0.5x**
  - Hainan province
  - Dongguan
  - Shanghai
  - Xi’an
  - Beijing
  - Chengdu
  - Nantong

Set out ambitious plan for FCV development, aiming to build 28 HRSs in 2019 and to put 1,000 FC buses into use.

Announced three-phrase development plans with a medium goal of building 50 HRSs, and having 20,000 FC PVs and 10,000 FC CVs on the road by 2025.
Major Regional Activities

**Yangtze River Delta**
- Plan: 5,000 vehicles & 40HRS by 2021; 50,000 vehicles & 200HRS by 2025 (Hydrogen Corridor Plan 2019-2030)
- Deployed vehicles: ~980
- HRS: 8 operating / 12 under construction
- Key Players: Re-Fire

**Guangdong**
- Plan: FC tram line, 1500 buses+ 4000 special vehicles by 2020
- Deployed vehicles: ~1800
- HRS: 10 operating / 14 under construction
- Key Players: Nation-Synergy, Re-Fire, Broad-Ocean

**Beijing/Hebei**
- Plan: 2500 vehicles by 2020 (Hebei)
- Deployed vehicles: ~280
- HRS: 2 operating / 5 under construction
- Key Players: Sinohytec, Vision Group

**Shandong**
- Plan: 2000 vehicles by 2021
- Deployed vehicles: ~100
- HRS: 6 operating / 1 under construction
- Key Players: Weichai Power, Broad-Ocean

**Shanxi**
- Plan: 700 vehicles by 2020, 3,000 vehicles by 2022
- Deployed vehicles: ~300
- HRS: 1 operating
- Key Players: Hydrav (Vision Group), Meijin Energy
4) Renewable \( \text{H}_2 \) will reach cost parity with certain fossil fuels
Unsubsidized Levelized Cost of Energy Comparison

Certain Alternative Energy generation technologies are cost-competitive with conventional generation technologies under some scenarios; such observation does not take into account potential social and environmental externalities (e.g., social costs of distributed generation, environmental consequences of certain conventional generation technologies, etc.), reliability or intermittency-related considerations (e.g., transmission and back-up generation costs associated with certain Alternative Energy technologies).

<table>
<thead>
<tr>
<th>ALTERNATIVE ENERGY</th>
<th>Levelized Cost ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV—Rooftop Residential</td>
<td>$138</td>
</tr>
<tr>
<td>Solar PV—Rooftop C&amp;I</td>
<td>$88</td>
</tr>
<tr>
<td>Solar PV—Community</td>
<td>$78</td>
</tr>
<tr>
<td>Solar PV—Cryogenic Utility Scale</td>
<td>$49</td>
</tr>
<tr>
<td>Solar PV—Thin Film Utility Scale</td>
<td>$46</td>
</tr>
<tr>
<td>Solar Thermal Tower with Storage</td>
<td>$119</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td>$306</td>
</tr>
<tr>
<td>Microturbine</td>
<td>$76</td>
</tr>
<tr>
<td>Geothermal</td>
<td>$79</td>
</tr>
<tr>
<td>Biomass Direct</td>
<td>$77</td>
</tr>
<tr>
<td>Wind</td>
<td>$32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONVENTIONAL</th>
<th>Levelized Cost ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Reciprocating Engine</td>
<td>$48</td>
</tr>
<tr>
<td>Gas Peaking</td>
<td>$101</td>
</tr>
<tr>
<td>IGCC</td>
<td>$94</td>
</tr>
<tr>
<td>Nuclear</td>
<td>$97</td>
</tr>
<tr>
<td>Cost</td>
<td>$60</td>
</tr>
<tr>
<td>Gas Combined Cycle</td>
<td>$48</td>
</tr>
</tbody>
</table>

Levelized Cost ($/MWh)
Renewable hydrogen will be a part of the energy mix

Source: World Economic Forum

Production of renewable hydrogen
The key process for renewable hydrogen production is electrolysis, which is the breakdown of water at low voltages to produce hydrogen and oxygen. It can also be used in remote geographical locations. The hydrogen produced is mainly used for transport and storage, feeding into fuel cells and fuel cell vehicles. Through its subsidiary StorEn, ENGIE is exploring solutions for storing hydrogen underground and on the surface, also contributing to the development of local hydrogen-based refineries.

Transport & Storage
As a gas, hydrogen is relatively easy to transport and store. The hydrogen produced via electrolysis can be integrated into the gas transmission and distribution network. Through its subsidiary StorEn, ENGIE is exploring solutions for storing hydrogen underground and on the surface, also contributing to the development of local hydrogen-based refineries.

Applications
Three key applications of hydrogen are mobility, industry, and energy storage. ENGIE aims to provide cutting-edge solutions in all three market segments.

In the quest for green mobility and transportation, hydrogen is seen as a solution for long-distance and heavy-duty trucks, zero-emission and zero-noise hydrogen vehicles, and hydrogen micro and mini power during off-peak times. Some cities have incorporated hydrogen into their fuel network, with hydrogen being delivered by water and hydrogen power being the mainstream market. Light-duty electric vehicles, fuel cell electric vehicles, and hydrogen generation for residential applications are on the rise.

Q2Vent is an expert in the design and operation of refueling stations. Hydrogen-powered cars can be filled up in around five minutes to achieve similar range to a conventional vehicle. ENGIE is also working on hydrogen at the front of several new technologies, including mobility, energy storage, and synthetic fuels.

Today, hydrogen is used in many industrial processes, such as ammonia synthesis and hydrocracking. It is becoming a green energy carrier, transforming into energy carriers. While hydrogen can have a significant impact on the sector's energy transition, it will likely take more than 50 years for hydrogen to dominate the market, even if it is required. Converting, storing, and distributing electricity, as hydrogen allows the energy system to operate with much greater flexibility, hydrocarbons can easily be reconverted into electricity or converted into hydrogen to store it for future use.

Renewable hydrogen: Making a 100% decarbonized world a reality.

Source: ENGIE
5) Total Cost of Ownership getting attractive
H2Bus Europe

**Single Deck - 12 m**
Price < €375k
Range >450 km* Extended >675 km*
*Dependent on duty cycle calculated at 10°C

**Double Deck - 10.9 m**
Price < €410k
Range >310 km* Extended >420 km*
*Dependent on duty cycle calculated at 10°C

**Articulated - 18 m**
Price < €465k
Range >520 km* Extended >750 km*
*Dependent on duty cycle calculated at 10°C
6) Expanding to other mobility applications
Enable electrification of rail without catenary wires
Enable zero-emission ferries
Enable zero-emission cruise ships docked in port
Enable higher productivity in warehouse material handling
Enable longer range and reliability for UAVs
Enable high asset utilization for autonomous vehicles and shared mobility
The clean transportation revolution in happening now
Commercialization Timeline

Source: FCHJU "Hydrogen Roadmap Europe" (Feb 2019)
What’s next?

- **2018**
  - 40,000 vehicles on the road in Japan by 2021
  - 2,000 fuel cell buses and trucks in service
  - 1000 FC trucks in Switzerland
  - >15,000 fuel cell forklifts in daily operation
  - 5,000 fuel cell cars on the road
  - 500+ fuel cell buses and trucks in service

- **2020**
  - >350 FCEBs on the road in Europe (JIVE)
  - 100 FCEBs at Tokyo 2020 Olympics

- **2025**
  - 5,000 FC vehicles on the road in China by 2020
    - China road map 2018
  - 50,000 FCVs in service in China, among which 10,000 units are FC commercial vehicles, and 40,000 units FC passenger cars by 2025
    - China road map 2018
  - 200 fuel station in California by 2025
  - +600 FCEBs on the road in Europe
    - H2Bus Project
  - 2,000 fuel cell buses and trucks in Shandong Province
    - Weichai
  - 10,000 FCVs in service, in China, among which 10,000 units are FC commercial vehicles, and 40,000 units FC passenger cars by 2025
    - China road map 2018
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  - >15,000 fuel cell forklifts in daily operation
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- **2030**
  - 1 million FC vehicles on the road in China by 2030
    - China road map 2018
  - 10 to 15 million fuel cell cars and 500,000 trucks on the road
  - 1 in 10 trains on non-electrified tracks
  - Hydrogen Council vision
  - 10 million Fuel Cell Vehicles
  - 6 million FC car produced by 2040
    - Korea road map 2019
  - 1000 FC trucks in Switzerland
  - 200 fuel stations in California by 2025
  - 25,000 Fuel Cell Vehicles
  - 200 fuel station in California by 2025
  - 500+ fuel cell buses and trucks in service
  - 5,000 FCV vehicles on the road in China by 2020
    - China road map 2018
  - >15,000 fuel cell forklifts in daily operation
  - 5,000 fuel cell cars on the road
  - 500+ fuel cell buses and trucks in service

**Japan roadmap**

**China road map 2018**

**H2Bus Project**

**Hydrogen Council vision**
5th Ave, NYC, Easter 1900
Where is the car?
5th Ave, NYC, Easter 1913

Can you spot the horse?
“Disruptive Technology should be framed as a marketing challenge, not a technological one.”

– Clayton Christensen
Thank you