Platinum-Based Fuel Cell Adoption in Future EV Powertrains
Refinitiv

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AGENDA

1. Hydrogen Value Chain and Economy
2. Fuel Cell Vehicles Characteristics and Competitiveness
3. Fuel Cell Vehicle Production & Implications on Platinum Market
4. Concluding Remarks
Hydrogen Value Chain and Economy
HYDROGEN VALUE CHAIN

Source: H2FCSUPERGEN, Mitsubishi
NEW APPLICATIONS FOR HYDROGEN

Transport
- Taxi Fleet in Paris France
- Class 8 Trucks Japan, US
- Trains Germany

Outside of transport:
- Power systems
- Green Ammonia Technology
- Steel production
- Etc…
DIRECTLY SUPPORTING HYDROGEN DEPLOYMENT BY TARGET APPLICATION

GOVERNMENT RD&D BUDGETS FOR HYDROGEN AND FUEL CELLS

Source: IEA, The Future of Hydrogen
HYDROGEN PRODUCTION AND USES

Source: IEA, The Future of Hydrogen
HYDROGEN PRODUCTION AND CHARACTERISTICS

Grey, Blue or Green?

**GREY HYDROGEN**
Currently, 96% of hydrogen is produced from fossil fuels via carbon intensive processes.

- **Main production routes**
  - Steam Methane Reforming (SMR)
  - Coal Gasification

**Characteristics**
- Intensive CO₂
- Low cost
- Social acceptance

**BLUE HYDROGEN**
Grey hydrogen whose CO₂ emitted during production is sequestered via carbon capture and storage (CCS).

- **Main production routes**
  - SMR + CCS
  - Coal gasification + CCS

**Characteristics**
- Low CO₂
- Expensive
- Social acceptance

- Grey h2, high Co2 but low cost and low social acceptance.
- Blue h2 supposedly improved CO2 due to carbon capture, but higher costs and acceptance
- Green h2, no CO2, but very expensive but also high consumer acceptance.
MAIN TYPES OF WATER ELECTROLYSIS

Summary of Efficiency and Operational Range of AEL, PEMEL and SOEL in Water Electrolysis for H2 Production

Source: Buttler A., and Spliethoff, H; Renewable and Sustainable Energy Reviews
ELECTROLYSER CAPACITY ADDITIONS

Development of electrolyser capacity additions for energy purposes and their average unit size, 1990–2019

Source: IEA, The Future of Hydrogen
DEALING WITH EXCESS ENERGY GENERATION THROUGH USE OF H2

CALIFORNIA POWER GENERATION ISSUES

- Nuclear
- Out-Of-State Imports
- Hydro-Electric
- Natural Gas
- Solar

Energy Use

EXCESS RENEWABLES

Natural Gas

Hydro-Electric

Out-Of-State Imports

Solar

Wind

EXCESS RENEWABLES

NATURAL GAS

IMPORTS

WIND

BIOMASS/GAS GEOTHERMAL

SOLAR

EXCESS RENEWABLES

HYDRO

KQED

Edit presentation title on Slide Master using Insert > Header & Footer
DATA STORAGE EXAMPLE
WHERE DO YOU STORE IT?

Onboard in Tanks

Stationary Storage

Large Underground Storage

Source: Change
Fuel Cell Vehicles
Characteristics and Competitiveness
DISECTED FUEL CELL VEHICLE TOP VIEW

- High-pressure hydrogen tanks
- FC stack
- Power control unit
- Drive battery
- FC boost converter
- Motor
POWER CONVERSION
BEV and FCEV Power Conversion Example

Source: Psycho.org
Comparison of current vehicle running characteristics:

<table>
<thead>
<tr>
<th>Type</th>
<th>Fuel cost per km ($)</th>
<th>Range (km)</th>
<th>Refuel / charge time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>7.5c</td>
<td>500</td>
<td>5</td>
</tr>
<tr>
<td>Diesel</td>
<td>6.0c</td>
<td>600</td>
<td>5</td>
</tr>
<tr>
<td>FCV</td>
<td>20c</td>
<td>500</td>
<td>5</td>
</tr>
<tr>
<td>BEV</td>
<td>2.5c</td>
<td>300-500</td>
<td>75-720</td>
</tr>
</tbody>
</table>

Source: Mitsubishi from PWC, US DOE, EU FCJU; LMC Automotive
ELECTRIFICATION AND FUEL CELLS VEHICLE RANGE

Segment

- SUVs/Trucks
  - Land Rover Defender
  - Mercedes-Benz
  - NIO ES8
  - Tesla Model Y
  - Audi e-tron

- Sports cars
  - Toyota Supra
  - Porsche 911

- Sedans
  - Tesla Model S
  - Toyota Mirai

- Hatchbacks
  - Kia Rio
  - Honda Fit
  - BMW 3 Series

- Runabouts
  - Smart Fortwo
  - BMW i3

- Small vans
  - SAIC Maxus EV80

FCV
- Audi
- BMW
- Daimler
- Honda
- Hyundai
- Kia
- Nissan
- Renault
- Toyota
- Lexus

BEV
- BEV (China and India only)

BEV (China and India only)

REFINITIV DATA IS JUST THE BEGINNING
### 2018 EV COST COMPARISON MODEL

<table>
<thead>
<tr>
<th>Cost Savings</th>
<th>Up Front Car Cost Adder &gt; 10 year Gas Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$5,000</strong></td>
<td><strong>$15,000</strong></td>
</tr>
<tr>
<td><strong>$25,000</strong></td>
<td><strong>$45,000</strong></td>
</tr>
</tbody>
</table>

#### 2018 Electrification Cost Model

<table>
<thead>
<tr>
<th>No. California</th>
<th>EU</th>
<th>USA Ave.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro to Mild Hybrids</td>
<td>Hybrids</td>
<td>PHEV's</td>
</tr>
<tr>
<td>#2</td>
<td>#1</td>
<td>#3</td>
</tr>
</tbody>
</table>

*Base ICE Engine (midsize)*

- Hybrids lowest TCO: better TCO than gas
- BEC 3rd, best play for short distance
- FCEV:
  - Highest cost by far
  - New green electrolyzed H2 will alter cost curve
  - Low vol drives up front cost adder
Assume:
- Doubling gas price
- Power price doubles
- E-gallons doubles
- H2 retail price -50% with electrolysis
- FCEV become place 4, positive return, 10 year gas savings higher than up front cost adder
- Make FCEV more viable alternative on high volume, moving from premium segment to main market LDV
At volume, total cost of ownership become similar to BEVs ($25,000) and only a little higher than ICEs ($20,000). As upfront costs come down, zone of adoption will grow to mid range and volume type.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>Short</th>
<th>Mid</th>
<th>Long</th>
<th>Very long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>BEV</td>
<td>BEV</td>
<td>FCV?</td>
<td>FCV</td>
</tr>
<tr>
<td>Premium</td>
<td>BEV</td>
<td>BEV</td>
<td>FCV</td>
<td>FCV</td>
</tr>
</tbody>
</table>

Source: Mitsubishi from PWC, US DOE, EU FCJU
“In 2040, I picture autonomous BEVs being used in cities while passenger FCEVs are used for weekend trips. Trains, buses, ships and long-range vehicles will also use fuel cells. 2040 may be too early for airplanes, but things may accelerate due to stringent regulation on emissions from air transport.”

KATSUMI HIROSE, TOYOTA MOTOR CORPORATION

When working on the design of production units, you clearly see that hydrogen and batteries are complementary. Batteries ensure fast-response and hydrogen complement on a longer period of time. To store large excess of power, hydrogen is fit for purpose. And it can be transformed again into power thanks to fuel cells or injected into the gas grid.

MICHELE AZALBERT, ENGIE
Fuel Cell Vehicle Production & Implications on Platinum Market
HISTORICALLY FUEL CELL SALES REMAIN LOW, BUT CONTINUE TO GROW
YTD SALES FOR 2019 ARE UP 82%

Annual passenger car FCV sales, 2015-2018

Units sold

2015 2016 2017 2018

7m YTD passenger car FCV sales, 2018-2019

Units sold

7m 2018 7m 2019

Source: Rho Motion, Marklines
FUEL CELL PRODUCTION IS CONCENTRATED TO EAST ASIA
BUT SALES STILL ECLIPSED BY PLUG-IN HYBRID

Source: Rho Motion, Marklines
LDV PRODUCTION FORECAST

LDV production with FCEV Modification

Source: LMC Automotive
LDV FUEL CELL PRODUCTION
Growth rates huge coming from low base and easing over time

LMC: Conservative

Source: LMC Automotive

PMCM: Progressive

Source: Precious Metals Commodity Management
EVOLUTION OF FUEL CEL APPLICATIONS
Transport to evolve in dominating fuel cell applications

Source: E-4tech
EVOLUTION OF MW BY FUEL CELL TYPE

PEMFC to become the dominant technology

Source: E-4tech
PLATINUM DEMAND

Transport Dominates Pt consumption and within transport its LDV
Trains and busses less efficient because often there are secondary systems operating for the HVAC and other electrical systems.

Pt loadings to come down further on latest Toyota Mirai model launches.
### Table 1A

<table>
<thead>
<tr>
<th>Market Penetration</th>
<th>Consumption of Pt in fuel cells in LDV, Moz</th>
<th>Loading Thrifting, gr/vehicle (100 kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td>110 M units</td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>2%</td>
<td>1.7</td>
<td>1.4</td>
</tr>
<tr>
<td>5%</td>
<td>4.3</td>
<td>3.4</td>
</tr>
<tr>
<td>10%</td>
<td>8.6</td>
<td>6.8</td>
</tr>
</tbody>
</table>

### Table 1B

<table>
<thead>
<tr>
<th>Market Penetration</th>
<th>Consumption of Pt in fuel cells in LDV, % of total market supply</th>
<th>Loading Thrifting, gr/vehicle (100 kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td>8.5 Moz</td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td>10%</td>
<td>8%</td>
</tr>
<tr>
<td>2%</td>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td>5%</td>
<td>50%</td>
<td>40%</td>
</tr>
<tr>
<td>10%</td>
<td>101%</td>
<td>81%</td>
</tr>
</tbody>
</table>
MARKET BALANCE BASE CASE

Market remaining in surplus throughout the forecast.
MARKET BALANCE WITH PENETRATION RATES

Market switching to deficit in 1% and 2% penetration rate by 2025
Above ground platinum stocks reduce on higher penetration rate
Concluding Remarks
CONCLUDING REMARKS

- Hydrogen fuel available but investment and dedication required to go into electrolysis process to make carbon neutral.
- AWE established technology but PEMEL likely to increase share rapidly in coming years.
- FCEV many challenges present, but promising powertrain along side BEV and other options.
- Breakthrough has been in the making for many years, but developments are accelerating.
- Interesting proposition for other segments in transport, particularly HDV, range and torque.
- FC still need platinum which will move to 10gr/vehicle in the forecast horizon.
- Taking a more progressive approach shows units rapidly accelerate towards 250k+ units. LDV will account for approx. 80% of that, equivalent to 200koz.
- Pushing penetration rate to 1% and 2% would demand approx. 350-750koz.
- Demand shock would push market balance in deficit and quickly start running down ABS.
- Is there enough short term supply available to feed that need in the case it occurs?
- What will happen to the price/market dynamics? Supply (mine and recycling) and price response
Thank You

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