Powertrain Evolution in the Passenger Car and Commercial Vehicle Sectors

Andy Walker, Technical Marketing Director
February 27th, 2019
Contents

- Introduction

- Regulations and other Key Market Drivers in the Passenger Car Market

- Powertrain Evolution in the Commercial Vehicle Market

- Conclusions
Innovation in Automotive Systems

**ICE**
- Emission Control Catalysts
- TWC / GPF
- DOC / LNT / CSF / SCR / SCRF / ASC

**BEV**
- Li-Ion Battery Materials
- Lithium Iron Phosphate
- Nickelate Materials
- High Voltage Spinel
- Lithium Titanate

**PHEV**
- Emission Control Catalysts
- Li-Ion Battery Materials

**FCEV**
- Hydrogen Catalysts
- On-Board Reforming
- Proton Exchange Membranes
- Coated Catalyst Systems
- Membrane Electrode Assemblies
- Li-Ion Battery Materials
Contents

• Introduction

• Regulations and other Key Market Drivers in the Passenger Car Market

• Powertrain Evolution in the Commercial Vehicle Market

• Conclusions
European Passenger Car CO\(_2\) Regulation Proposal Evolution

1. European Commission Proposal

<table>
<thead>
<tr>
<th>Year</th>
<th>CO(_2) Target vs 2021 Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td>-15%</td>
</tr>
<tr>
<td>2030</td>
<td>-30%</td>
</tr>
</tbody>
</table>

Low (PHEV) and Zero Emission Vehicle benchmark targets of 15% in 2025 and 30% in 2030
OEMs who exceed these levels would have a less stringent CO\(_2\) fleet target

2. European Parliament Amendment

<table>
<thead>
<tr>
<th>Year</th>
<th>CO(_2) Target vs 2021 Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td>-20%</td>
</tr>
<tr>
<td>2030</td>
<td>-40%</td>
</tr>
</tbody>
</table>

OEMs to ensure Low and ZEV are 20% of OEM fleet in 2025, and 35% in 2030
From 2025, OEMs to report the Life Cycle CO\(_2\) Emissions of new vehicles, using a common protocol

3. European Council General Approach

<table>
<thead>
<tr>
<th>Year</th>
<th>CO(_2) Target vs 2021 Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td>-15%</td>
</tr>
<tr>
<td>2030</td>
<td>-35% for cars</td>
</tr>
<tr>
<td>2030</td>
<td>-30% for vans</td>
</tr>
</tbody>
</table>

Low (PHEV) and Zero Emission Vehicle benchmark targets of 15% in 2025 and 35% in 2030
OEMs to report measured (instead of declared) CO\(_2\) emissions – OEMs typically declare higher levels for COP

4. Trilogue Discussion Conclusions

<table>
<thead>
<tr>
<th>Year</th>
<th>CO(_2) Target vs 2021 Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td>-15%</td>
</tr>
<tr>
<td>2030</td>
<td>-37.5% for cars</td>
</tr>
<tr>
<td>2030</td>
<td>-31% for vans</td>
</tr>
</tbody>
</table>

Low (PHEV) and Zero Emission Vehicle benchmark targets of 15% in 2025 and 35% in 2030
OEMs who exceed these levels have a less stringent CO\(_2\) fleet target – eg 40% ZLEV in 2030 = 1.05 x CO\(_2\) target
OEMs to report measured and declared CO\(_2\) emissions
Evolution of Global PC CO₂ Regulations – Significant Incoming Reductions

- **Confirmed**
- **Proposed (under review)**
- **Scenario**

**EPA 2 cycle**
- US: based on GHG reduction targets for transport sector by EU

**NEDC (WLTP from 2021)**
- EU: 15% reduction from 2021 levels in 2025
- EU: 37.5% reduction from 2021 levels in 2030
- US: 4% annual reduction assumed after 2025
- China: convergence with EU targets expected

**EU Regulations to 2030:**
- 15% reduction from 2021 levels in 2025
- 37.5% reduction from 2021 levels in 2030

Source: ICCT, European Commission, ACEA
The EU has a binding GHG target of 30% below 1990 levels in 2030. The sectors covered by EU Emissions Trading System (ETS) must deliver 43% GHG reduction (compared to 2005 levels) by 2030. The non-ETS sectors, which include transport, must deliver a 30% reduction (also compared to 2005 levels).
There are Many Projections on How the EV Market Will Grow

Source: Bloomberg New Energy Finance, Long Term Electric Vehicle Outlook, May 2018

Regulations
Infrastructure
Cost
TCO
OEM offerings
Range concerns

ICE
BEV
PHEV
sales

All EVs
% of sales

million vehicles

2% 3% 11% 28% 43% 55%
2015 2020 2025 2030 2035 2040
Projected Evolution of Battery Pack Prices

<table>
<thead>
<tr>
<th>Key Market Drivers: Consumer Sentiment and Concerns</th>
<th>Belgium</th>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>UK</th>
<th>China</th>
<th>India</th>
<th>Japan</th>
<th>South Korea</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Infrastructure</strong></td>
<td>20%</td>
<td>16%</td>
<td>20%</td>
<td>44%</td>
<td>22%</td>
<td>18%</td>
<td>25%</td>
<td>23%</td>
<td>34%</td>
<td>22%</td>
</tr>
<tr>
<td><strong>Price/Cost</strong></td>
<td>28%</td>
<td>32%</td>
<td>22%</td>
<td>19%</td>
<td>24%</td>
<td>9%</td>
<td>14%</td>
<td>31%</td>
<td>22%</td>
<td>26%</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>31%</td>
<td>31%</td>
<td>35%</td>
<td>4%</td>
<td>26%</td>
<td>25%</td>
<td>14%</td>
<td>18%</td>
<td>10%</td>
<td>24%</td>
</tr>
<tr>
<td><strong>Charging Time</strong></td>
<td>9%</td>
<td>11%</td>
<td>11%</td>
<td>18%</td>
<td>13%</td>
<td>12%</td>
<td>11%</td>
<td>11%</td>
<td>17%</td>
<td>10%</td>
</tr>
<tr>
<td><strong>BEV Safety</strong></td>
<td>5%</td>
<td>4%</td>
<td>5%</td>
<td>7%</td>
<td>6%</td>
<td>22%</td>
<td>22%</td>
<td>9%</td>
<td>11%</td>
<td>8%</td>
</tr>
<tr>
<td><strong>No BEV in Preferred Model</strong></td>
<td>2%</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>3%</td>
<td>11%</td>
<td>7%</td>
<td>3%</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Favoured OEM Doesn’t Make BEVs</strong></td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
<td>3%</td>
<td>4%</td>
<td>3%</td>
<td>7%</td>
<td>3%</td>
<td>1%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Some interesting differences in perceived BEV concerns by country

Source: Deloitte Global Automotive Consumer Survey 2018
Key Market Drivers: Infrastructure – Electric Charging

- EU Alternative Fuels Infrastructure directive sets a target of 1 public charging point for every 10 EVs

Good growth continues in European BEV public charging infrastructure

Source: eafo, Energy Efficient End-Use Equipment Technology Collaboration Program, IEA Global Outlook 2018
http://www.eafo.eu/electric-vehicle-charging-infrastructure
Key Market Drivers: Infrastructure – Electric Charging – the UK Picture

- EU Alternative Fuels Infrastructure directive sets a target of 1 public charging point for every 10 EVs
  - Today there are around 155k EVs on the UK’s roads

- Lack of domestic charging infrastructure could be potential headwind limiting BEV uptake in areas with limited off-road parking
  - 72% of UK vehicle owners have access to off-street parking
  - this falls in major cities: 48% in London, 61% Edinburgh and Cardiff, 65% Manchester

Source: https://www.zap-map.com/statistics, IEA Global Outlook 2018
The UK’s Road to Zero Ultra Low Emission Vehicle Targets, and Implications

“We want to see at least 50%, and as many as 70%, of new car sales and up to 40% of new van sales being ultra low emission by 2030”

Source: UK Government: “The Road to Zero”, July 2018
Intelligent materials design maximises nickel content and energy without compromising performance.

Key areas of enhancement compared to other high-nickel materials:
- Higher energy density
- Better cycle life

Efficient use of cobalt gives stability and power whilst keeping overall content of all JM grades <8 wt%.
Contents

• Introduction

• Regulations and other Key Market Drivers in the Passenger Car Market

• **Powertrain Evolution in the Commercial Vehicle Market**

• Conclusions
Electrification of the Transit Bus Market Today

- 385k Electric Transit Buses in 2017 (13% of the global fleet)

- Over 380k of these are in China (supported by incentives), with around 1.5k in EU and 0.4k in US

- Shanghai and Shenzhen buy only electric buses

- Shenzhen fleet is 100% electrified – around 16.5k buses
  - 510 bus charging stations; 8k charging points
  - $500M subsidy for buses and charging infrastructure

Source: BNEF “Electric Buses in Cities” March 2018
Projected Penetration of E-Buses into Urban Bus Market

- Electric bus market already strong in China
- Expect increased penetration in Europe and US/NA
- London to increase its BEV fleet from 120 to 300 by 2020
- Oslo committed to fossil fuel-free public transport by 2020
Electrification of the CV Truck Market

Europe electrifies first, based on Diesel fuel price differential vs electricity. LDT leads MDT, with HDT line haul cost parity being beyond 2030, if ever....

Source: McKinsey New Reality: electric trucks and their implications on energy demand, September 2017
Projected Penetration of BEVs into LDT/MDT

Electric LDT

Electric MDT

Some LDT and MDT systems can reach price parity with diesel today, by right-sizing battery pack
Europe electrifies first, based on Diesel fuel price differential vs electricity
Relatively low adoption in China due to low cost of diesel LDT/MDT

Weight class definitions:

US: MDT: Class 4-7 (6.4-15t); LDT: Class 2-3 (3.5-6.4t)
EU: MDT: 7.5-16t , LDT: 3.5-7.5t
CN: MDT: 6-14t , LDT: 1.8-6t

Source: McKinsey New Reality: electric trucks and their implications on energy demand, September 2017 and JM analysis
Projected Penetration of BEVs into HDT

Electrification looks promising for City Bus, LDT and MDT
But how do we decarbonise HD Trucks?

Source: McKinsey New Reality: electric trucks and their implications on energy demand, September 2017
Possible Approaches to Decarbonise Long Haul HDD Trucks

**Catenary Electric Drive**
- Overhead cabling with pantograph
- Scania/Siemens trials ongoing in Stockholm
- ~ 80% efficient (twice as high as diesel freight)
- Suitable for heavily travelled freight corridors?
- Expensive?
- Global/cross regional alignment of standards?

**Inductive Charging in the Road**
- Less mature technology
- Major infrastructure investment required

**Fuel Cell**
- High efficiency (over 50% cf ~40% HDD engine)
- Quick refuelling
- Can use H₂ from renewable sources
- Long range, but requires hydrogen infrastructure
- Renewable H₂ expensive; fuel cells relatively expensive
- Nikola field trials starting this autumn
JM and Fuel Cells

JM’s key product is the MEA (Membrane Electrode Assembly)

A sandwich of two sheets of carbon paper, two catalyst layers and a membrane

Making good MEAs requires skills in materials science, chemistry, physics and catalysis

Technical focus on reducing Pt loadings to drive costs down

The cell is completed by two conducting plates that distribute gas over the outer surfaces of the MEA sandwich

A fuel cell stack is simply a stack of cells

The current is determined by the area of the MEA and the voltage is determined by the number of cells stacked together
Key Market Drivers: Range and Rapid Refuelling

- Diesel/gasoline tank charge rate: 25 MW
- H₂ tank charge rate: 5 MW
- BEV charge rate: 0.007-0.12 MW
- BEV future ultra fast charging: 0.35 MW

Public Chargepoint type | Power Output | Charging Time | Chargepoint Cost
--- | --- | --- | ---
Slow | Up to 3.5 kW AC | Full charge in 6-12 hours | €500
Fast | 7-22 kW AC | Full charge in 3-4 hours | €5,000
Rapid | 43 kW AC or 50 kW DC | 80% charge in 30 minutes | €35,000
Tesla Supercharger | 120 kW | 80% charge in 40 minutes | €150,000
Ultra Fast | 350 kW | 80% charge in 15 minutes | Unknown

More rapid charging (and longer range) with ICE and FCEV – range anxiety still a concern with BEVs

Honda Clarity FCEV fuelled at Beaconsfield could drive to Edinburgh on a single tank of H₂

Source: https://www.zap-map.com/charge-points/connectors-speeds/
Global H₂ Refuelling Station Development and FCEV Targets

Nordic Hydrogen Corridor
Zero emission transportation between the capitals of the Nordic countries:
• 8 HRSs by 2020
• Zero GHG transportation – H₂ from renewables

Each HRS can service up to around 1k vehicles or so

<table>
<thead>
<tr>
<th>Country/State</th>
<th>Today</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan HRS</td>
<td>90</td>
<td>160</td>
<td>320</td>
<td>900</td>
</tr>
<tr>
<td>Japan FCEVs</td>
<td>2,000</td>
<td>40,000</td>
<td>200,000</td>
<td>800,000</td>
</tr>
<tr>
<td>China HRS</td>
<td>30</td>
<td>&gt; 100</td>
<td>&gt; 300</td>
<td>&gt; 1,000</td>
</tr>
<tr>
<td>China FCEVs</td>
<td>1,500</td>
<td>5,000</td>
<td>50,000</td>
<td>&gt; 1M</td>
</tr>
<tr>
<td>S Korea HRS</td>
<td>20</td>
<td>310 (2022)</td>
<td>520</td>
<td></td>
</tr>
<tr>
<td>S Korea FCEVs</td>
<td>16,000</td>
<td></td>
<td></td>
<td>1.8M</td>
</tr>
<tr>
<td>California HRS</td>
<td>35</td>
<td>94</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>California FCEVs</td>
<td>23,600 (2021)</td>
<td>47,200 (2024)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France HRS</td>
<td>20</td>
<td>100 (2023)</td>
<td>700 (2028)</td>
<td></td>
</tr>
<tr>
<td>France FCEVs</td>
<td></td>
<td>5,200 (2023)</td>
<td>36,000 (2028)</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>43</td>
<td>100</td>
<td>400 (2023)</td>
<td>1000</td>
</tr>
<tr>
<td>UK</td>
<td>14</td>
<td>31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Projected Fuel Cell Cost Reduction with Economies of Scale

The Scale of Production has a significant Impact on the Cost of Fuel Cell Stacks

<table>
<thead>
<tr>
<th>Production Volume</th>
<th>1k</th>
<th>10k</th>
<th>30k</th>
<th>80k</th>
<th>100k</th>
<th>500k</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Cost ($/kWnet)</td>
<td>216</td>
<td>103</td>
<td>84</td>
<td>62</td>
<td>60</td>
<td>53</td>
</tr>
<tr>
<td>Stack Cost ($/kWnet)</td>
<td>154</td>
<td>61</td>
<td>49</td>
<td>31</td>
<td>30</td>
<td>26</td>
</tr>
</tbody>
</table>

Annual Production Rate (Systems/Year)

Cost ($/kWnet)

JM Membrane Electrode Assembly development focused on reduction of Pt loading, along with improved performance and durability.
Some Fuel Cell Truck Offerings: Nikola

- Nikola Truck with up to 1,600 km range
- Nikola business model leases the truck to users, with H₂ as part of the lease
- Claims 15% lower TCO than diesel trucks
- PowerCell supplying FC stacks
- Bosch will jointly develop powertrain systems, and worked with Nikola to develop the truck’s “eAxle,” which houses the electric motor, transmission and power electronics
- Ryder System Inc. will serve as Nikola’s exclusive provider for distribution and maintenance nationwide

800 ordered by Annheuser Busch, expected to be in service by end of 2020

Nikola/Nel to build 28 H₂ stations to support this fleet

Nikola/Nel to build up to 700 H₂ stations across the US by 2028
Conclusions

Regulations
• Increased focus on urban air quality and global CO₂ emissions continue to drive towards Zero Emission Vehicles in the PC and CV sectors
• CO₂ regulations continue to drive the uptake of EVs

Other Passenger Car Drivers
• Consumer concerns around EV infrastructure, vehicle price and range
  – Charging infrastructure continues to develop at pace, but more to do!
  – EV prices are dropping and ranges are increasing as new battery chemistries are introduced

Commercial Vehicle Powertrain Evolution
• E-Bus widely present in China today, and on the way elsewhere
• LDT and MDT electrification starting – new CO₂ HDD regs will increase uptake
• Fuel Cells a very good fit for long-range cars and HDD trucks
• Technology and volume required to drive down FCEV costs
• Plans in pace to expand H₂ fuelling infrastructure