The Future for Low Carbon Vehicles, Hybrid and Electric Vehicles?

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Content

- Ricardo commitment to powertrain electrification
- Market outlook for powertrain electrification – Drivers & Enablers
- What electrification may mean to the market
- Ricardo electrified powertrain technology response
Ricardo commitment to deliver powertrain electrification

Our electrification team delivers attribute led engineering through the product lifecycle

Target Setting - Concept Feasibility - Design - Prototype Build - Test & Validation - Launch – Production

Ricardo Electrification Team

Vehicle Attributes

- NVH
- Vehicle Dynamics
- Thermal Management
- Performance, Economy, Driveability
- Aerodynamics
- Architecture Integration (Package)
- Safety
- Climate Control
- Weight

Electrified Powertrain

- 48V, PHEV, REEV engines solutions
- eMachines concept & design
- Transmission & Driveline design
- System simulation, modelling & DOE

Powertrain Sys. Integration

- Air Intake & Exhaust Systems design
- Fuel systems development
- Cooling system design & testing
- Complete CAE tools, system optimization

Chassis

- Full suspension system design
- Subframes & Mounts incl. brackets
- Steering System (HPS/EHPS, EPS)
- Braking System, Wheels & Tyres

Energy storage & management

- Chemistry options & cell selection
- Electro-mechanical battery pack design
- CFD & Thermal modelling
- BMS & Controls, FMEA verification

Electrical & Electronics

- Network topology & EDS integration
- Power Electronics concept & design
- Diagnostics & EOL, MIl, HiL, SiL testing
- Functional Safety / ISO26262

Body structural adaptation

- Body systems impact analysis & trade-off
- Mech, Interfaces & assembly strategy
- CAE overall structural perf. validation
- Full vehicle DVP

Functional System Engineering

Powertrain Control and Calibration
Why electrification?
Big drivers of change are favouring the Battery Electric Vehicle (BEV) over the Internal Combustion Engine (ICE) Vehicle

- Increased urbanisation & air quality issues leading to predicted ICE bans in cities
- Global warming driving CO₂ emissions reduction legislation
- Energy security / supply – decreasing oil reserves / new oil fields
- Cultural & demographic changes – consumer shifts & attitudes
- Technology & Autonomy – Technological advances making electric vehicles more attractive

CO₂ Emissions Regulations (Past and Future)
Major Cities Driving Radical City Legislation

Future city over-population concerns surrounding congestion, pollution, parking, air quality, safety and affordability is driving talk of radical city legislation (Incentives, Penalties & Bans).

- UK, London congestion charge discourages cars entering the city and will further penalizing older cars from Oct 2017.
- Germany, There is a national framework of low emission zones in Germany. A number of cities also have transit bans on heavy duty vehicle through-traffic.
- France; Paris vehicle classification tag, bans diesel cars registered before 1997 and some pre 2000 from the city between 8am and 8pm on weekdays, and plan for general Diesel ban from 2020, and free parking for EV in Paris city center
- Norway to ban petrol and diesel cars and even hybrids in the next decade, Law wouldn’t ban existing ICE cars it would stop new car sales.
- Netherlands; talk of banning all sale of new ICE-powered models starting in 2025; even hybrids and plug-in hybrids. Amsterdam is to ban cars in the city centre on Saturdays, one of a series of initiatives aimed at reducing motor traffic and pollution
- The mayors of Paris, Madrid, Athens and Mexico City announced plans to take diesel cars and vans off their roads by 2025
**What will change to make Electrification of vehicles viable**
Battery Electric Vehicles had a false start – but the key issues will be addressed in the not too distant future

## BEV Challenges and Solutions

<table>
<thead>
<tr>
<th>Today’s BEV challenges</th>
<th>Future BEV (2025)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries are too expensive</td>
<td>Battery system cost below $150/kWh</td>
</tr>
<tr>
<td>BEVs have a short range</td>
<td>&gt;400km (250miles) range will be standard</td>
</tr>
<tr>
<td>Charging infrastructure insufficient</td>
<td>Full coverage</td>
</tr>
<tr>
<td>BEVs take too long to charge</td>
<td>Public fast charging @ 20 minutes to 80% charge</td>
</tr>
<tr>
<td>BEVs mean customer compromises</td>
<td>Bespoke BEV, zero compromises, customer acceptance?</td>
</tr>
</tbody>
</table>
## Expected new EV Ranges to better 200 miles by 2018

Several vehicle manufacturers are developing new model EVs with battery capacities that support a driving range over 200 miles and are expected to use high power chargers.

<table>
<thead>
<tr>
<th>OEM</th>
<th>Model</th>
<th>Production</th>
<th>Range (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chevrolet</td>
<td>Bolt</td>
<td>2016</td>
<td>238</td>
</tr>
<tr>
<td>Hyundai</td>
<td>Ioniq</td>
<td>2017</td>
<td>110</td>
</tr>
<tr>
<td>Ford</td>
<td>Focus</td>
<td>2017</td>
<td>110</td>
</tr>
<tr>
<td>Fisker</td>
<td>E-Motion</td>
<td>2017</td>
<td>400</td>
</tr>
<tr>
<td>Renault</td>
<td>Zoe</td>
<td>2017</td>
<td>186</td>
</tr>
<tr>
<td>Tesla</td>
<td>Model 3</td>
<td>2017-8</td>
<td>200</td>
</tr>
<tr>
<td>Audi</td>
<td>e-tron SUV</td>
<td>2018</td>
<td>310</td>
</tr>
<tr>
<td>Aston Martin</td>
<td>Rapid E</td>
<td>2018</td>
<td>200</td>
</tr>
<tr>
<td>Jaguar</td>
<td>I-Pace EV</td>
<td>2018</td>
<td>220</td>
</tr>
<tr>
<td>Faraday Future</td>
<td>FF91</td>
<td>2018</td>
<td>378</td>
</tr>
<tr>
<td>Tesla</td>
<td>Roadster</td>
<td>2019</td>
<td>400</td>
</tr>
<tr>
<td>Tesla</td>
<td>Model S</td>
<td>2019</td>
<td>500</td>
</tr>
<tr>
<td>Mercedes</td>
<td>Generation EQ</td>
<td>2019</td>
<td>300</td>
</tr>
<tr>
<td>Volvo</td>
<td>full size</td>
<td>2019</td>
<td>200</td>
</tr>
<tr>
<td>Audi</td>
<td>A9 e-tron</td>
<td>by 2020</td>
<td>300</td>
</tr>
<tr>
<td>Nissan</td>
<td>Leaf</td>
<td>by 2020</td>
<td>200</td>
</tr>
<tr>
<td>Porsche</td>
<td>Mission E</td>
<td>by 2020</td>
<td>310</td>
</tr>
<tr>
<td>VW</td>
<td>I.D. Concept</td>
<td>by 2020</td>
<td>240</td>
</tr>
<tr>
<td>BMW</td>
<td>i5 SUV</td>
<td>2021</td>
<td>300</td>
</tr>
</tbody>
</table>

Source: carwow, inside evs, web
Charging Infrastructure Growth

By 2025, a charging infrastructure will be established with some super fast charging, however capacity is likely to be an issue. Home charging will be less important, with some regional harmonisation.

- There are a selection of formats and suppliers providing charging facilities across the UK & Europe; the picture is currently confusing for the uninformed consumer
  - Slow (up to 3kW) is best suited for 6-8 hours overnight
  - Fast (7-22kW) can fully recharge some models in 3-4 hours
  - Rapid AC and DC (43-50kW) 80% charge in 30 minutes
  - Super fast DC (120kW) 50-80% in 20 mins (Tesla)

- By 2020/25 a superfast (150kW) multi station charging network across Europe is proposed by major European OEMs to rival the current Tesla Superfast charging Network, however it is currently unclear how this will be financed.

Charging @ home

Fast charging

Charge @ work

Public charging
Charging – Ultra Fast charging
An Ultra fast (350kW) charging network requires significant technical and commercial challenges to be overcome i.e. New >4C capable cells, heat dissipation, cable sizing/cooling, and how will it be financed

- Joint venture to deploy a high-powered DC charging network for battery electric vehicles (BEV)
- 400 ultra-fast charging sites planned in Europe to cover long-distance travel routes
- Power levels up to 350kW
- Network to be based on Combined Charging System (CCS) standard technology

- US$4.5 Bn financial support for a national network of DC fast charging stations and longer term innovations:
  - Fast chargers up to 350kW DC, to charge a 200-mile range battery in 10 minutes
  - $50M funding over 5 years to develop a battery with 500kW/kg and capable of 1000 electric vehicle charge cycles and lower battery pack cost below $100/kWh

- CHAdeMO Association are developing a high power protocol for mass market EVs with larger batteries
  - It expects first 150kW standardised chargers to be deployed in 2017
  - It has also announced a technical study for 350kW chargers, putting CHAdeMO on a par with CCS Combo alliance plans
Electric Vehicle viability by 2025 & Consumer Acceptance by 2030?

BEV applicability for all use cases, once price, range, infrastructure and charging rate are comparable to internal combustion engine vehicles.

**Barriers removed**

- **Cost competitive:** with ICE Vehicles
- **Electric range** in D segment >400km (250miles)
- **Charging infrastructure:** Established (capacity challenges)
- **Super fast charging:** on key corridors (50-80% in 20 mins)

**Use Cases**

**Typical daily usage**
Commute to work, drive to shopping centre
>80% of all vehicles with daily mileages below 100km

**Long distance / high frequency**
Drive to holiday, sales representatives, taxi drivers, Up to ~1,500km per day
(Taxi: <350km ø daily mileage)
Fast charge: >80% in 20 minutes
→ ca. 4x en route charging for 1,500 km

Source: Ricardo analysis
Ricardo vision of what electrification means - a polarised powertrain

By 2025 BEV issues holding back EVs are predicted to be resolved - $150/kWh target cost, fast charging infrastructure, range will be ICE comparable (400km).

Powertrain paths

Today

- Internal combustion engine dominant

2030

- High efficiency internal combustion engine – mild/non-plug-in hybrid
  - Mild Hybridisation, e.g. 48V, or higher voltage without plug-in capability
  - Optimised gasoline ICE
  - CO2 neutral fuels

- PHEV
  - Plug in Hybrid
  - <50g CO2, >50km pure electric range
  - Transitional technology until BEV have reached sufficient consumer acceptance

- Battery electric vehicle
  - BEV
  - >400 km range, battery pack cost ~$150/kWh
  - Public / semi-public charging infra-structure in place

Source: RSC (Simon Schnuerrer)
Ricardo Interpretation of EU vehicle production forecasts

By 2025 xEVs are forecast with ~10% of EU LV production, while start-stop / mild hybridization of ICE will exceed 80% share from 2018, with 48V mild hybridization dominating by 2025

European LV Production Forecast by propulsion system, in million units

Data on future vehicle market derived from IHS forecasts which Ricardo view as sound but generally conservative where new technology is involved, therefore xEV forecasts are viewed as low

<table>
<thead>
<tr>
<th>Year</th>
<th>xEV</th>
<th>ICE</th>
<th>Micro &amp; Mild-Hybrid</th>
<th>Pure. ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>20.9</td>
<td>69%</td>
<td>29%</td>
<td>11%</td>
</tr>
<tr>
<td>2016</td>
<td>21.5</td>
<td>76%</td>
<td>21%</td>
<td>13%</td>
</tr>
<tr>
<td>2017</td>
<td>21.7</td>
<td>79%</td>
<td>18%</td>
<td>15%</td>
</tr>
<tr>
<td>2018</td>
<td>22.1</td>
<td>81%</td>
<td>15%</td>
<td>13%</td>
</tr>
<tr>
<td>2019</td>
<td>22.5</td>
<td>82%</td>
<td>13%</td>
<td>11%</td>
</tr>
<tr>
<td>2020</td>
<td>22.7</td>
<td>83%</td>
<td>11%</td>
<td>10%</td>
</tr>
<tr>
<td>2021</td>
<td>23.2</td>
<td>83%</td>
<td>10%</td>
<td>9%</td>
</tr>
<tr>
<td>2022</td>
<td>23.4</td>
<td>83%</td>
<td>9%</td>
<td>8%</td>
</tr>
<tr>
<td>2023</td>
<td>23.5</td>
<td>83%</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>2024</td>
<td>23.7</td>
<td>83%</td>
<td>8%</td>
<td>7%</td>
</tr>
<tr>
<td>2025</td>
<td>23.8</td>
<td>83%</td>
<td>7%</td>
<td></td>
</tr>
</tbody>
</table>

1) incl. HEV, PHEV, REV, BEV, FCEV
2) incl. Start/Stop (S&S)
3) Non electrified

Source: IHS, Ricardo analysis

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Ricardo view of the passenger vehicle electrified powertrain mix

By 2030, Ricardo fully expects ‘mass electrification’ for passenger car, penetration rates by powertrain type will vary by segment

Powertrain mix 2030 – developed markets – high BEV customer acceptance

Vehicle segment

<table>
<thead>
<tr>
<th>Vehicle segment</th>
<th>Powertrain mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoD Pod 1</td>
<td>Gasoline with mild hybridisation (MHEV, HEV)</td>
</tr>
<tr>
<td>MoD Pod 2</td>
<td>BEV</td>
</tr>
<tr>
<td>A</td>
<td>Diesel</td>
</tr>
<tr>
<td>B</td>
<td>PHEV</td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
<tr>
<td>SUV</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>FCEV</td>
</tr>
</tbody>
</table>

Source: Ricardo analysis

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Ricardo view of the passenger vehicle electrified powertrain mix

By 2030, Ricardo fully expects ‘mass electrification’ for passenger car, penetration rates by powertrain type will vary by segment

Powertrain mix 2030 – developed markets – Low BEV customer acceptance

Vehicle segment

- MoD Pod 1
- MoD Pod 2
- A
- B
- C
- D
- SUV
- E

Powertrain mix

- Gasoline with mild hybridisation (MHEV, HEV)
- Diesel
- BEV
- PHEV
- FCEV

Source: Ricardo analysis
Ricardo Electrified Powertrain Technology Response
R&D focus on expanding 48V systems application, advanced hybrid & EV battery systems, 800V power electronics development & novel e machine design, to improve performance / reduce cost

Mild Hybrid Technology Demonstrators
- Demonstrators for gasoline 12V plus and diesel 48V technologies leading UK-based LCVTP consortiums
- Hyboost - 46% CO\textsubscript{2} reduction 1.0L gasoline, with ‘12+x’V micro-hybrid, 6kW Belt Starter Generator, Electric Supercharger & ‘12+x’V supercapacitors
- Adept - 75 g/km CO\textsubscript{2}, 1.5L diesel, 48V mild-hybrid, 12.5kW Belt Starter Generator, advanced lead-carbon battery, 48V Ancillaries & electric turbine

European Competitiveness in Commercial Hybrid and AutoMotive Powertrains
- To achieve low cost, low weight, robust hybrid solutions for passenger cars & commercial vehicles
- Systems modelling & simulation
- Hybrid cooling systems design & optimisation
- Design & development of a 25kW 48V e m/c & power electronics for a commercial vehicle application

800V Power electronics for future EVs
- To achieve high performance, low cost, low weight, robust solutions for DC/DC converters, inverters and charging systems
- Testing, systems modelling & simulation of Silicon Carbide and Gallium Nitride semi conductors to match the correct technology to the appropriate application (800V\400V, Hybrid\EV)

EV and REEV Demonstrator Vehicles
- Technology demonstrators for EV and REEV, developed with UK-based LCVTP consortium
- Selection & integration (electrical, thermal, mechanical, EMC, charging) of EV components
- Design & analysis of generator for REEV
- Engine conversion, build & test for REEV
- Analysis & technology selection for HVAC & waste heat-recovery systems

Next Generation BMS & EV Battery Design
- Ricardo battery management system (BCM & VTBM) and Ricardo battery module design, build & test
- Using a highly accurate model based control to optimally manage cells
- New cell chemistry with higher specific energy compared to current Lithium Ion - LiS
- Better battery management and control to use more of available cell capacity (400Wh/kg and $250/kWh)

85kW design specification for passenger car traction
- Base speed: 3,700 rpm
- Torque at base speed: >200 Nm peak, >100Nm continuous
- Maximum speed: 15,000 rpm
- Novel synchronous reluctance rotor design to enhance mechanical strength and performance
Announcements of BEV penetration rates and sales targets are suggesting that the existing forecasts are conservative. However history suggests that there is often a difference between press releases and reality….

### BEV announcements

<table>
<thead>
<tr>
<th>Group</th>
<th>Announced EV target</th>
<th>Comment</th>
</tr>
</thead>
</table>
| VOLKSWAGEN | ● 25% BEV sales penetration by 2025  
● 50% BEV sales penetration by 2050  
● 30 BEV models by 2025  
● 2-3 million BEV sales p.a. in 2025 | ● Part of recently announced ‘TOGETHER Strategy 2025’                   |
| RENAULT NISSAN | ● 1.5 million of cumulative BEV sales by 2020  
● Nissan: 20% BEV sales penetration by 2020 in EU markets with right conditions | ● Recently more bullish about achieving 2020 target despite very slow start |
| DAIMLER    | ● 10 new BEV models launched until 2025  
● 15-25% BEV sales penetration by 2025 | ● Formally announced EQ sub-brand at Paris motorshow (2016)             |
| BMW Group  | ● 100k p.a. BEV sales by 2020 | ● Announced in 2014 (Reithofer)                                         |
| TESLA      | ● 500k p.a. BEV sales by 2020 | ● Strategic target set by Elon Musk                                      |
| VOLVO      | ● 1 million cumulative Plug-in sales by 2025  
● Two plug-in hybrids or battery electric vehicles per model | ● Announced in 2015 Corporate Sustainability Report issued 2016          |
Thank you for listening

Questions?