Future Propulsion Systems: Is Pure Electric the Only Way?

Future Powertrain Conference
National Motorcycle Museum
Birmingham
28th February 2019

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MAHLE Powertrain Limited
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Air Quality is of high importance

- We would all like to see this……

- And not this……

Need to meet local air quality targets – Careful not to displace emissions

Photo of Tower bridge: http://www.blueskyinvvm.com/burrfrim/

Photo of smog: https://www.itv.com/news/london/2012-12-10/up-to-9-of-londons-deaths-due-to-pollution/
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Extraction and processing

- Take care not to replace this…

- With this…

Always need to consider the ‘bigger picture’
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Air pollution over last 25yrs

- Clear downward trend

Defra report 2017

We are heading in the right direction, but need to accelerate…..
UN Convention on Climate Change 2015 (COP21), 197 countries agreed common climate policy targets

Paris Agreement central aims

- Strengthen global response to threat of climate change
- Aim to keep global temperature rise this century well below 2°C

Tough CO₂ targets are a necessity
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Passenger Car Electrification Challenges

- Number of charging points in the UK need to increase by 23x current numbers
- Grid infrastructure takes 70yrs to undergo levels of change required
- 6x Sizewell B sized power stations needed by 2040 to meet peak demand which take >5yrs to build and cost >£5bn each
- Technologies developed to counter this, but will the consumer accept?

Infrastructure investment is key to success in new technology
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Goods transportation electrification challenges

- This may be one of a number of solutions to decarbonise road transport
- SMART Motorways….M1 J13 – J16 **24 miles**, 4 years and **£373m**!!! (2300 miles of motorway total)
- Only **42%** of rail lines are electrified in the UK

13 June 2018 By **Joe Baker**

**Will the UK ever get electrification back on track?**

The National Audit Office has published the findings of its investigation into the **Department for Transport’s decision to cancel three rail electrification projects due to high costs**. The move was widely criticised at the time as a step backwards, when other major countries were rolling out national schemes.

We shouldn’t underestimate the investment required


Photo of train: Barrie C. Woods [https://visitpoulton-le-fylde.co.uk/about/getting-here/railway-line-electrification/](https://visitpoulton-le-fylde.co.uk/about/getting-here/railway-line-electrification/)
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Fleet CO₂ Limits

Update 17th December 2018

Increasing levels of hybridisation required

2030: 59 g/km

Pure electric mandatory before 2045?

2040

2045

Would require pure ICE vehicle engine cycle average brake thermal efficiency to double over next decade

But is a BEV really a ZEV? Is the comparison to an ICE being made on an even basis?

CO₂ targets are driving manufacturers towards increased electrification

Targets based on 1400 kg vehicle mass for “average vehicle”

Source: ICCT Nov 2017 Early Christmas present to the car industry, or lump of coal?
Tailpipe vs Whole lifecycle?

Typically only in use tailpipe emissions considered:

Complete system life-cycle analysis (LCA) required:

System Boundary Under Consideration

Need to consider the whole system lifecycle
Electricity Production – Snapshot of Europe

Great Britain: 277 g/kWh

Netherlands: 492 g/kWh

France: 73 g/kWh

Sweden: 50 g/kWh

Estonia: 911 g/kWh

Germany: 366 g/kWh

Source: www.electricitymap.org
Snapshot for 21st February 2019

A complex and changing picture
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Battery Embedded CO₂

Battery & system lifecycle analysis is not straightforward

Mean value used for this study

Source: Dale & Hall, ICCT, January 2018
Battery Technology Advancement Requirements

- Lithium ion believed to be dominant technology for next two decades
- APC and Faraday Challenge set some demanding targets:

<table>
<thead>
<tr>
<th>Target</th>
<th>2017</th>
<th>2025</th>
<th>2035</th>
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<tbody>
<tr>
<td>Cost ($/kWh)²</td>
<td>280</td>
<td>150</td>
<td>100</td>
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<tr>
<td>Energy Density (Wh/l)</td>
<td>280</td>
<td>550</td>
<td>1000</td>
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<tr>
<td>Power Density (kW/kg)</td>
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<td>7.5</td>
<td>12</td>
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<tr>
<td>Pack Life (Years)</td>
<td>8</td>
<td>10</td>
<td>15</td>
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<tr>
<td>Recyclability (%)</td>
<td>10-50</td>
<td>75</td>
<td>95</td>
</tr>
</tbody>
</table>

APC Energy Storage Roadmap (Pack Level Targets)

Target: power density increase of 300% by 2035

Battery development targets are challenging and require significant technology breakthroughs


Roadmaps Explored – Understanding the battery challenges from chemistry to recycling: [https://www.apcuk.co.uk/news/roadmaps-explored-understanding-battery-challenges-chemistry-recycling/](https://www.apcuk.co.uk/news/roadmaps-explored-understanding-battery-challenges-chemistry-recycling/)
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Lifetime CO$_2$ is Directly Related to Battery Pack Size

Lifetime CO$_2$ is directly related to battery pack size. The range of CO$_2$ emissions is illustrated in the diagram.

- **Battery CO$_2$ break-even**: Range of ~300 km* on NEDC
- **Range of ~600 km* on NEDC**: Baseline gasoline, BEV72 - UK grid, BEV72 - Renewable, BEV36 - UK grid, BEV36 - Renewable

LCA for 1400kg vehicle
- 15,000 km per annum
- Analysis based on NEDC
- 10 year vehicle life
- No credit for vehicle recycling

Fascination with EV Range!

1) Scharrer et al. EVS30, Stuttgart, 2017
2) Gasoline WTT 12g/MJ from Eriksson and Ahlgren, ISSN 1654-9406, 2013
3) Dale & Hall, ICCT, January 2018
4) Av. UK grid for 2017 from www.electricity.info.org
Battery Sizing

- Ideally battery should be sized for average daily usage.

- Hard to beat the energy density of gasoline or diesel, so why try?

- Longer excursions could utilise other on-board energy source:
  - Plug-in hybrid with:
    - Conventional engine
    - Gasoline range extender
    - Bio-fuel engine
    - Hydrogen fuel cell

Example fleet daily usage distribution

Are we overspecifying the battery to get equivalance to ICE vehicles?
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PHEV – Optimum EV Range

Optimal battery size

- Grid CO2
- Tail-pipe weighted CO2
- Vehicle embedded CO2
- Combined PHEV life CO2

Battery cost

Optimum battery size = 100km Range = lowest lifecycle CO₂

Estimates based on 1400 kg vehicle mass for “average vehicle”
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Optimum solution?
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MAHLE Modular Powertrain

“MAHLE Dedicated Hybrid Engine” + “MAHLE Integrated Electric Powertrain” eAxle plus generator = MODULAR POWERTRAIN
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**MAHLE Modular Powertrain**

- **Simplified, high-efficiency, ICE**
- Electric drive enables ICE power to be reduced to ~1/3 of conventional

- **High-efficiency, ICE**
- Advanced pre-chamber combustion
- BSFC < 200g/kWh

- **Compact, high-power, traction motor and power electronics** provides fully electric drive capability. Removes transients from ICE

- **Multi-speed transmission**

- **Dual operating mode**
  - Series/parallel modes
  - Series hybrid mode

Hybridisation enables ICE power to be reduced and reduction of transient operation
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MAHLE Modular Powertrain

Estimates for PHEV with 15 kWh battery pack:

- Highly efficient ICE and recuperation lead to low un-weighted vehicle CO$_2$ of ~70 g/km
- Total vehicle LCA of ~90 g/km

Ability to downsize and optimise ICE with full electric driveline leads to a highly efficient system

Estimates based on 1400 kg vehicle mass for “average vehicle”
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Fleet CO₂ Limits – Where Are We on an LCA Basis?

Targets based on 1400 kg vehicle mass for “average vehicle”

LCA: BEV72 today achieves 152 g/km CO₂
LCA: Pure ICE vehicle today achieves 173 g/km CO₂ (NEDC basis)
LCA: PHEV15 today achieves 120 g/km CO₂
Pathway for reducing vehicle LCA to almost 1/3rd of current levels

Bioethanol could bring significant benefits to existing ICE fleet

LCA: Pure ICE vehicle on bioethanol achieves 83 g/km CO₂
LCA: BEV72 on fully renewable grid achieves 120 g/km CO₂
LCA: PHEV15 with optimised driveline and renewable grid achieves 66 g/km CO₂

Optimised PHEV is an attractive option

Sources:
ICCT Nov 2017
Early Christmas present to the car industry, or lump of coal?
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Technology dilemma

- Strict air quality and CO$_2$ targets need to be met
- Infrastructure investment is a necessity
- Should no longer consider just the vehicle
- Pure gasoline and diesel powertrains will be banned
- Carbon neutral fuels need to be considered
- PHEV looks attractive compromise

- Let’s not put all of our eggs in one basket!!

Combination of technologies need to be pursued
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- Thank you for your attention
- Come and see us on our stand