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Hybrid Powertrain Technology Roadmap

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Summary

By 2025 significant reductions in vehicle carbon dioxide (CO_2) emissions will need to be achieved to meet legislative requirements, increasing the interest in hybrid and electric vehicle technologies.

Building on previous research projects, focused on the design of a dedicated range extender (REx), heavily downsized internal combustion engines and lean combustion system developments, MAHLE Powertrain propose a possible hybrid technology pathway for developing a family of hybrid powertrains optimised for the future global automotive market targeted to meet emissions and CO_2 targets for 2030 and beyond.

Keywords: EREV (extended range electric vehicle), gasoline engine, ICE (internal combustion engine), LCA (Life Cycle Assessment), PHEV (plug in hybrid electric vehicle)

1 Introduction

Vehicle manufacturers are facing increasing pressure by legislation and economics to reduce vehicle emissions and deliver improved fuel economy. By 2025 significant reductions in carbon dioxide (CO2) emissions will need to be achieved to meet these requirements whilst at the same time satisfying the more stringent forthcoming Euro7 emissions regulations. Since September 2017 Real Driving Emissions (RDE) testing has been adopted as part of the regulatory approval regime [1] to ensure a correlation between emissions in real world driving conditions and those achieved under controlled laboratory test conditions. With the introduction of RDE testing the engine operating region that is under scrutiny during compliance testing has significantly increased. Furthermore, manufacturers may be required to disclose their engine base emissions strategy (BES) and any auxiliary emissions strategy (AES), which may preclude the use of fuel enrichment for component protection in future engines [2]. These combined demands increase the focus on the emissions performance of engines over their entire operating map.

Because electric vehicles (EVs) do not generate local pollutants during usage, and they can potentially rely on energy provided by a selection of renewable sources, they are the focus of much current interest. However, due to the present limitations of battery technology (in terms of size, weight and cost) the overall range of such a vehicle is limited in comparison to an equivalent gasoline or diesel fuelled vehicle. An additional consideration is the embedded CO_2 content of large battery packs and their recyclability.

Plug-in hybrid electric vehicles (PHEVs) partly overcome the limitations of current battery technology by retaining an internal combustion engine (ICE). The engine can directly provide motive power when the battery is depleted. Extended range electric vehicles (EREVs), have a REx unit that converts a fuel, such as gasoline, into electrical energy whilst the vehicle is driving, without a mechanical link to the vehicle wheels (series hybrid). This enables the traction battery storage capacity to be reduced, though still maintaining an acceptable vehicle driving range. MAHLE has developed a dedicated REx engine to identify the requirements and challenges faced in the development of components for such future engines [3].

Gasoline engine downsizing is also an effective technology for CO_2 reduction and is the process whereby the engine operating load point is shifted to a higher, more efficient region, through the reduction of engine swept volume, whilst maintaining the full load performance of the original engine through pressure charging. Further improvements in fuel economy are possible through increased levels of downsizing [4].

The present study draws on the experience gained through the development of the downsizing and REx demonstrator engines and examines the powertrain requirements to meet the needs of passenger cars in the 2030 timeframe, and beyond. Legislative drivers are examined and the ability of current internal combustion engines to meet these requirements is evaluated for a range of vehicle sizes. The technology steps needed to meet anticipated future legislative targets are discussed.

2. MAHLE Range Extender Engine

MAHLE has developed a dedicated range extender (REx) engine to identify the requirements and challenges faced in the development of the components for such future engines, shown in Fig. 1. The MAHLE REx was specifically developed for B and C-segment passenger car EREV applications (having a kerb weight of around 1200-1500 kg). During the concept phase the key attributes for the REx unit were considered, and a full assessment of a wide array of alternative engine architectures was undertaken. After careful analysis, the specifications of the MAHLE REx unit were developed. The specifications of the resulting REx unit are summarised in Table 1 [3].

Figure 1: The MAHLE range extender unit [3]

The overall engine design is targeted at maintaining the lowest production cost to achieve the performance targets within the smallest possible package volume. The engine achieves a maximum power output of 30 kW at a maximum engine speed of 4000 min^{-1}. Given the low rated speed, and moderate specific power output requirements, the engine only requires 2 valves per cylinder. Similarly, port fuel injection is employed for low cost. In order to minimise overall package, the generator is fully integrated into the engine structure. One further feature of note is the ability of the engine to be installed at any angle from vertical to horizontal (exhaust side down) with only minor hardware changes. This feature was included to enable the engine to be applied to various EREV layouts. With an EREV, the engine is not mechanically connected to the wheels of the vehicle and thus can be mounted anywhere within a vehicle.

Table1: MAHLE REx specifications

Technical specifications	
Layout	2-cylinder, 4-stroke
Engine displacement	0.9 litres
Generator	Permanent magnet axial flux generator
Maximum power	30 kW at 4000 rev/min
Peak torque	72 Nm between 2000 and 4000 rev/min
Dimensions	327 x 416 x 481 mm
Dry weight	50 kg (70 kg with generator)

In order to enable development and refinement of the REx system, it was installed into a modified production vehicle. The conventional ICE driveline was removed and the vehicle was fitted with an electric drive-line and the MAHLE range extender engine. The resulting vehicle was intended to reflect likely near to market steps for EREVs.

As a subsequent development of the REx demonstrator vehicle, MAHLE Powertrain developed control software which can intelligently manage the use of the battery energy through the combined use of global positioning system (GPS) and road topographical data [5]. Advanced knowledge of the route prior to the start of a journey enables the software to calculate the state of charge (SOC) of the vehicle battery throughout the journey and pre-determine the optimum operating strategy for the REx to enable best charging efficiency and minimize NVH. Real-world testing showed that the GPS based controller could typically reduce the fuel consumption of the EREV by 5 %.

A timeline for the MAHLE range extender project, indicating the timeframe for the development of the REx unit, demonstrator vehicle and GPS based control system, is shown in Fig. 2.

3. MAHLE Downsizing Engine

In order to conduct research into the requirements for advanced downsizing engines and their components, MAHLE Powertrain previously developed a demonstrator engine, which was intended to represent 50 % downsizing of a naturally aspirated 2.4 litre engine [6, 7]. The resulting heavily downsized engine was a direct injection, 1.2 litre, 3-cylinder inline, turbocharged, gasoline engine (referred to colloquially as the MAHLE Di3). A timeline of the main MAHLE downsizing engine development steps is summarised in Fig. 2.

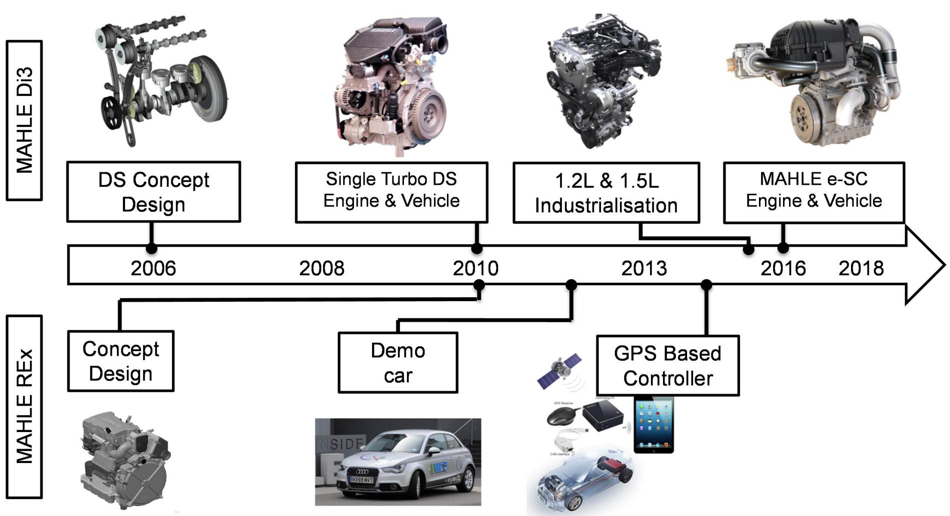


Figure 2: Timeline summarising the major development steps of the MAHLE REx and Di3 projects

Equipped with a single stage turbocharger, the resulting engine achieved a peak brake mean effective pressure (BMEP) of 30 bar. The peak power output of the engine was 120 kW (100 kW/litre) from 5000 min^{-1}. Stoichiometric fuelling (lambda = 1.0) could be maintained over a wide proportion of the engine operating map [6]. A key target during the development of the single-stage turbocharged engine was to ensure that the transient response remained acceptable. The engine was installed into a D-segment (1500 kg kerb weight) demonstrator vehicle, which features stop-start capability. Testing confirmed that the vehicle achieves a fuel consumption figure of 5.8 l/100 km (CO_2 emissions of 135 g/km) over the new European drive cycle (NEDC) [8].

In order to explore the limits of the potential benefits achievable through engine downsizing, further developments of this engine, including the addition of an electric supercharger, enabled the specific brake mean effective pressure of the engine to be further increased to 35 bar BMEP (between 1500 to 4000 min^{-1})

and the specific power increased to 161 kW/litre (193 kW, 262 PS) [9]. This engine was then fitted into a VW Golf GTi, replacing the standard 2.0 litre turbocharged, gasoline direct injection (GDI), engine. The resulting vehicle demonstrated 15 % reduction in fuel consumption over the NEDC, purely due to downsizing [10]. Further benefits from the 48 V mild-hybrid system are possible, and with the right level of recuperation this could be as much as a further 15 % [11].

3.1 Industrialised Version of the MAHLE Di3

MAHLE Powertrain has also been engaged in the development of an industrialised version of the original downsizing engine, shown in Fig. 3. Two 3-cylinder engine variants, based on the original MAHLE Di3 engine, have been developed with capacities of 1.2 and 1.5 litres, sharing maximum commonality. The 1.2 and 1.5 litre variants of the engines are rated at 30 bar BMEP and 100 kW/l and 28 bar BMEP and 94 kW/litre respectively and both variants are also capable of achieving these outputs whilst operating on 92 RON gasoline [12]. The very high-specific outputs enable greater use of the downsizing effect to reduce pumping losses and improve fuel economy at low loads. Through careful detailed design of the engine and combustion system excellent knock mitigation characteristics have been achieved which enable a high compression ratio, for the specific output, of 9.25:1 to be maintained. With this compression ratio, operation at up to 30 bar BMEP and over 70 kW/l power output can be achieved whilst running under stoichiometric operating conditions. The advanced combustion system is combined with a low-friction base engine design and optimized thermal management which combined enables the engines to be capable of delivering competitive real-world economy.

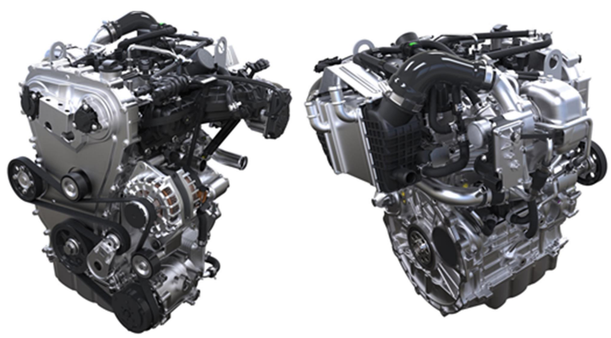


Figure 3: MAHLE industrialised 3-cylinder downsizing engine [12]

The key engine specifications for the 1.2 and 1.5 litre variants are shown in Table 2. The specific power and torque targets for the 1.5 litre variant are slightly reduced from those of the 1.2 litre variant to enable the performance to be achieved whilst using the same common exhaust, after-treatment and intake systems.

Table2: Key characteristics of the MAHLE 1.5 litre and 1.2 litre engines

Parameter	1.5 litre	1.2 litre
Displaced volume [cc]	1497	1199
Stroke [mm]	92.2	73.9
Bore [mm]	83	83
Compression ratio	9.25:1	9.25:1
Number of Valves/Cylinder	4	4
Power	141 kW @ 5000 min^{-1}	120 kW @ 5000 min^{-1}
Torque	334 Nm @ 1600-3500 min^{-1}	286 Nm @ 1800-3500 min^{-1}
Fuel Injection System	Central DI	
Variable Valve Timing	Inlet & Exhaust with 60 °CA Authority	
Turbocharger	BMTS Technology with electronic waste gate actuation	

The Lambda map, minimum brake specific fuel consumption (BSFC) point and maximum BMEP curve for the 1.5 litre variant, operating on 95 RON fuel (with a lower heating value (LHV) of 42 MJ/kg), is shown in Fig. 4. The over-fuelling region in the upper right hand corner of the engine operating map is where additional fuel is supplied to the engine to prevent the exhaust gas temperature exceeding the 950 °C turbine inlet temperature limit of the turbocharger used on the engine. Figure 4 also shows a reduced output operating line (24 bar BMEP from 1500 min^{-1} to 3600 min^{-1}) and a peak specific power output of 80 kW/litre. This line indicates the limits of the operating region within which the engine could operate at lambda 1 across the entire map, with only a modest increase in turbine inlet temperature limit to 970 °C. The minimum BSFC level of the engine, at 233 g/kWh is excellent for such a heavily downsized engine that has been designed to be have a relatively low production cost.

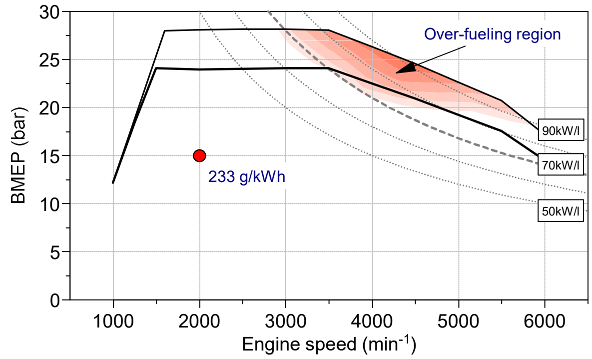


Figure 4: Lambda map and minimum BSFC point for the 1.5 litre industrialised version of engine running on 95 RON fuel. Also showing maximum BMEP curve and suggested reduced BMEP curve for full map lambda 1 operation

4. Powertrain Family

In this study, the powertrain requirements for a range of vehicles have been analysed using some simple assumptions. A fleet of vehicles have been considered in this study, with kerb weights ranging from 1000 kg to 2000 kg. Vehicle performance targets have been defined and these have been used to establish the power required from the drivetrain, as summarised in Table 3. The vehicle data used in this study is based on EPA dynamometer coefficients [13] for a range of vehicles from a number of manufacturers, to establish a generic fleet. The fleet of vehicles has been analysed over the NEDC, as although this is no longer used for vehicle emissions certification, it still forms the basis for the fleet averaged CO_2 targets.

Table 3: Fleet of vehicles analysed, performance targets and required power

	Units	Compact car	Hatchback	Family car	SUV	4x4
Vehicle segment	(-)	B	C	D	Compact SUV (J)	Large SUV (J)
Kerb mass	(kg)	1000	1200	1500	1800	2000
Maximum speed	(km/h)	180	200	200	210	220
0-100 km/h time	(s)	11.0	10.0	10.0	9.5	8.5
Engine power	(kW)	72	96	112	154	163

4.1 Conventional powertrain family

The industrialised version of the MAHLE Downsizing engine [12] has been considered as a prime mover for the fleet of vehicles considered in Table 3. As described above, this engine can readily achieve 80 kW/litre with stoichiometric fuelling. To meet the power requirements for the fleet of vehicles considered, 3 engine capacities are required; a 2.0 litre 4-cylinder, a 1.5 litre 3-cylinder and a 1.2 litre 3-cylinder, as summarised in Fig. 5a. All engines share a common architecture, and power-cell unit. The 1.2 and 1.5 litre engines can also share a common engine block. Even with the modest technology level included for this engine, the individual vehicles of the fleet meet current CO_2 targets, as seen in Fig. 5b.

4.2 Advanced powertrain family

In order to meet the CO_2 emissions levels required for 2020 additional technologies need to be applied to the vehicle fleet. The technology package applied to the fleet, along with resulting NEDC achieved CO_2 emissions, are shown in Fig. 6a.

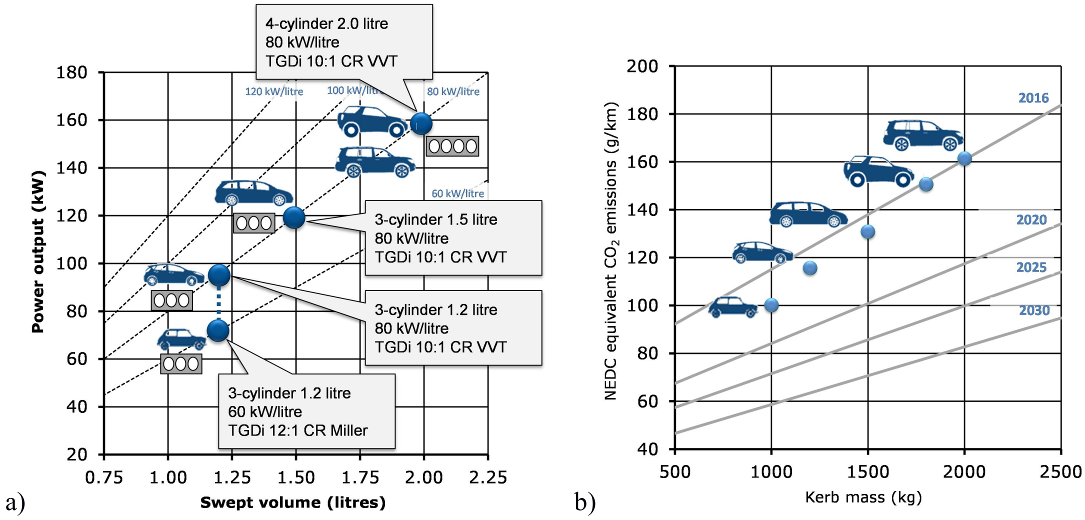


Figure 5: Conventional powertrain applied to the vehicle fleet; a) Engine family required; b) NEDC equivalent fuel CO_2 emissions achieved by this fleet with the conventional powertrain

Figure 6b summarises the enhanced technology powertrain family required for the fleet of vehicles. For the two heavier vehicles, the 2.0 litre engine can be replaced by a higher specific output variant of the 1.5 litre 3-cylinder engine; this is enabled by the addition of an EGR system, enabling lambda 1 operation up to 100 kW/litre. The ability of high-pressure EGR to enable lambda 1 operation up to a specific power output of 100 kW/litre was demonstrated previously using the MAHLE Di3 engine [14].

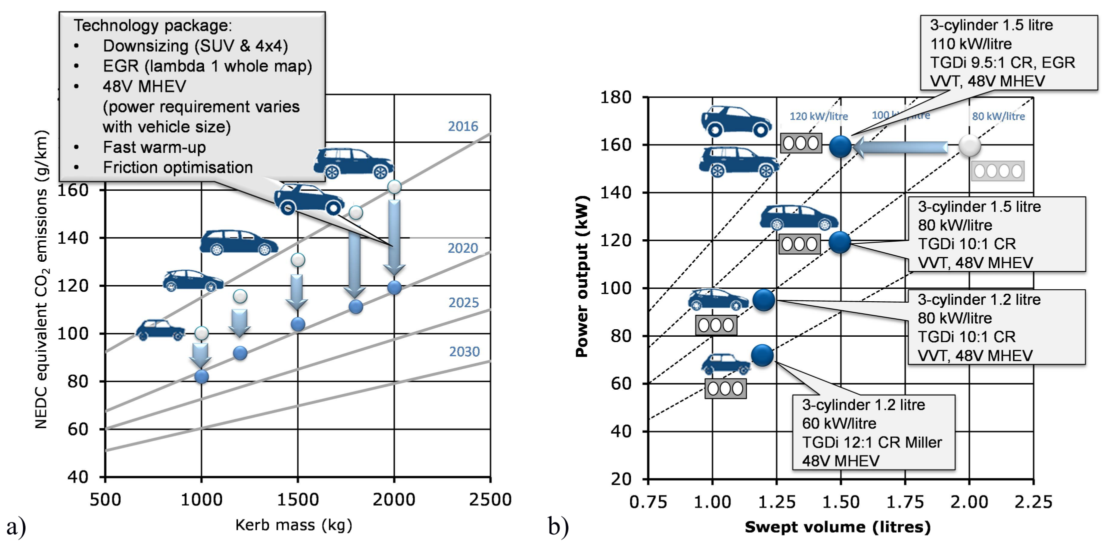


Figure 6: Enhanced conventional powertrain; a) NEDC equivalent fuel CO_2 emissions achieved by the enhanced conventional powertrain when applied to the vehicle fleet; b) Enhanced conventional powertrain engine family applied to the vehicle fleet

The engine family for the entire vehicle fleet can now be supported by a common 3-cylinder engine architecture, with two swept volumes of 1.5 and 1.2 litres. Additional technologies are required to enable the vehicles to meet the required CO_2 levels. The ones employed to generate the vehicle level results shown in Fig. 6b include a 20 % reduction in engine warm-up time, which would need to be achieved by reduced engine thermal mass or smart control of the engine coolant. Additionally, a 20 % reduction in engine friction level has been assumed, which would need to be achieved through detailed design changes to the base engine. Finally, 48 V mild-hybridisation has also been applied to the vehicles. The three larger vehicles require a P2 driveline architecture and reasonably high power recuperation capabilities (15 to 20 kW). The two smaller vehicles require below 10 kW of recuperative power. For the smallest vehicle a P0 hybrid architecture is sufficient.

5. Future Hybrid Powertrain Requirements

Beyond 2020 the individual vehicle CO_2 levels are extremely challenging without a significant degree of plug-in hybridisation, to enable the vehicles to be eligible to apply CO_2 weighting factors for plug-in hybrid vehicles, as specified in UN/ECE Regulation 101 [15]. This regulation enables a vehicle with pure electric driving capability to apply a scaling factor to the measured drive-cycle charge sustaining CO_2, based on the pure electric driving range over the cycle. This variation of this CO_2 weighting factor, as a function of electric driving range (as established driving repeated NEDCs) is shown in Fig. 7, where it can be seen that with zero electric driving capability the weighting factor is unity (i.e. un-weighted). As the electric driving range of the vehicle increases, the weighting factor diminishes quickly to 0.5 at a driving range of 25 km, and then begins to flatten out. The weighting factor for plug-in hybrid vehicles tested using the WTLP shows a similar trend. These weighting factors are based on statistical data for typically daily driving distances and are founded on the assumption that the user will recharge their vehicle every night, thus the weighting factor adjusts the measured tail-pipe CO_2 to allow for the fuel consumption displaced by electric driving.

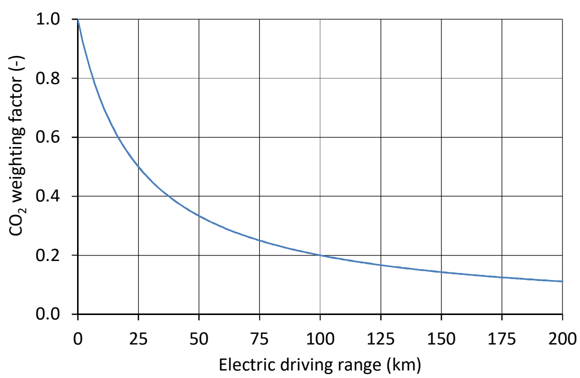


Figure 7: Carbon dioxide weighting factor for hybrid electric vehicles with off-vehicle charging capability [15]

In reality, many manufactures will achieve their fleet CO_2 targets through the sale of a range of vehicles that have a mix of technologies including conventional ICE, mild-hybrids, plug-in hybrids and full battery electric vehicles. The key factor then is to sell a sufficient percentage of the low emitting models to achieve the required fleet averaged CO_2 level to meet the targets. For the purposes of this analysis we have considered the technology requirement to meet the CO_2 target for each vehicle in the fleet on an individual basis.

Increasing the size of the battery of a PHEV enables the electric driving range to be increased, yielding a lower CO_2 weighting factor, and hence a lower vehicle CO_2 rating. However, currently vehicles are assessed on a tailpipe CO_2 emissions basis, and not on a total life cycle CO_2 equivalent basis. In future the total life cycle impact of the vehicle may come under scrutiny, and it is important (from an environmental, as well as legislative, perspective) that we consider the total life cycle impact of a vehicle – otherwise it is very difficult to compare ICE, PHEV and BEVs on an even basis. Of particular concern with a BEV or PHEV is the equivalent CO_2 impact of the battery generated during its production. Additionally, we need to consider the end of life vehicle (ELV) directive and the waste electrical and electronic equipment (WEEE) directive, as large vehicle battery packs may be challenging to recycle in a cost effective manner.

When we consider a conventional vehicle, the embedded CO_2 from mining, materials processing manufacturing and transportation, is about 5.6 tonnes equivalent CO_2 based on figures presented by Patterson *et al.* [16]. Assuming a useful vehicle life of 150,000 km, gives an embedded vehicle CO_2 equivalent to 37 g/km. Several studies have investigated the embedded CO_2 in producing battery packs and Dale and Lutsey [17] have presented a comprehensive survey of 10 recent studies, these are summarised in Fig. 8, where it can be seen that the battery production is associated with 56 to 494 kg of CO_2 per kWh of battery capacity. Dale and Lutsey emphasise that this summary simplifies the analytical findings of the studies considered and that the wide range of values observed indicates the degree of uncertainty in making a life-cycle assessment (LCA) for a vehicle battery pack. In their analysis of the LCA for PHEVs and BEVs, Dale and Lutsey [17] use a value of 175 g/kWh for the embedded CO_2 generated in in producing battery packs, which is the mid estimate of the study made by Romare and Dahllöf [18].

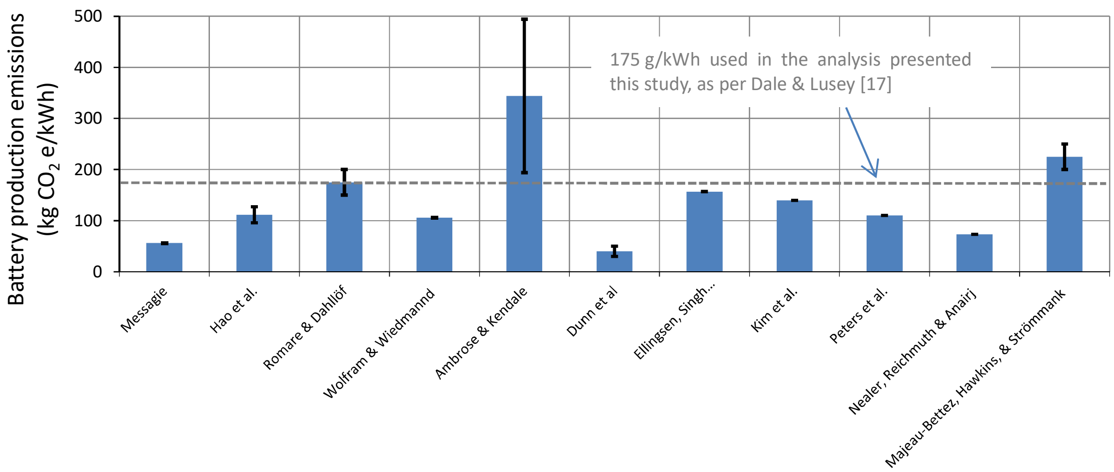


Figure 8: Comparison of the range of EV battery pack production emissions based on the studies analysed by Dale and Lutsey [17]

The carbon intensity of the electrical grid, used for recharging EVs and PHEVs, varies significantly from country to country. Some of the cleanest grids, for example Sweden which uses predominantly hydro-electricity, has an equivalent CO_2 intensity of 50 g/kWh [19], whereas Estonia which uses predominantly coal fired power stations has a value of 911 g/kWh. For this study the analysis is based on a grid CO_2 intensity of 292 g/kWh, which represents the UK average for 2017 [20].

Considering a contemporary C-D segment (1400 kg) passenger car which can achieve 120 g/km CO_2 emissions over the NEDC, and accept that the tail-pipe weighting factor for UN/ECE Regulation 101 [15] produces an appropriate weighting for PHEVs based on typical usage profiles, it can be estimated how the tail-pipe CO_2 of a PHEV varies with electric driving range, as shown in Fig. 9, where it can be seen to vary from 120 g/km at zero electric range and drop to 11 g/km for a 250 km electric driving range.

We can also compute the well to tank contribution of the fuel used by the vehicle as a function of electric driving range; again this is shown in Fig. 9. Additionally, we can compute the electrical energy required by the vehicle as the electric driving range increases, based on the inverse of the weighting factor shown in Fig. 7. We can then convert this into an equivalent CO_2 based on the electricity grid carbon intensity; again this is shown in Fig. 9. By assuming that the battery pack embedded CO_2 is simply supplemental to the embedded CO_2 from the conventional vehicle construction (assuming any addition for electric machines is offset by a reduction in ICE requirement), we can then consider the life-cycle CO_2 burden of vehicle production, as shown in Fig. 9 where it increases from 37 g/km at zero electric driving range to 75 g/km for a 250 km electric driving range, based on a 150,000 km vehicle life.

Finally, if we sum these contributions we get a curve that shows the LCA for a PHEV for varying electric driving range, again this is shown in Fig. 9. Interestingly, it can be seen that the LCA for the PHEV exhibits a minima for an electric driving range of 100 km. For comparison LCA values, based on the same assumptions outlined for the PHEV, for BEVs with 3 differing driving range capabilities are also shown in Fig. 9. It can be seen that the PHEV, with a 100 km electric driving range results in a very similar LCA to a

BEV with a 200 km driving range. As the BEV driving range is increased the embedded CO_2 in the battery pack increases the vehicle LCA proportionally. Based on these simplistic assumptions it would appear that for the majority of users (dependent on local electricity grid carbon intensity), a PHEV with a 100 km range represents a good solution for minimising environmental impact.

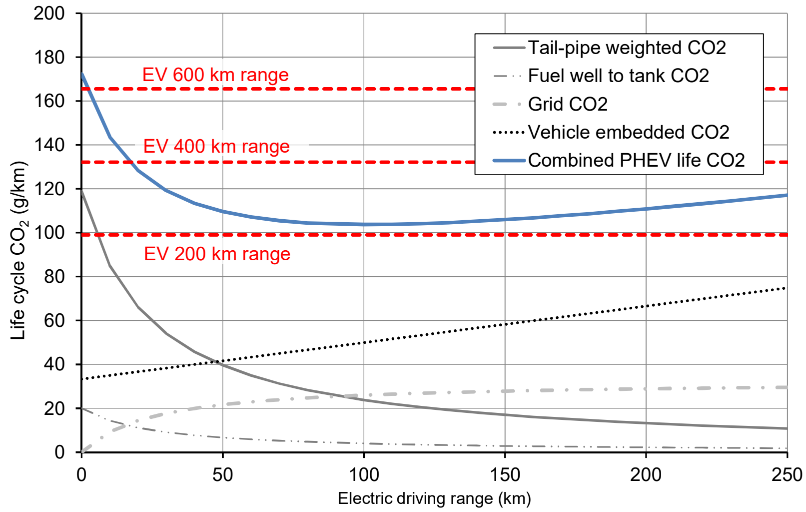


Figure 9: Comparison of the LCA for a PHEV with a range of pure EVs, with increasing electric driving range

Beyond 2025, plug-in hybridisation will be a key technology enabler to achieving fleet CO_2 targets. Once the vehicle has significant electric drive capability, it is possible to remove any dynamic loading from the engine. It can then operate in a much more steady-load manner, approaching the operation seen for range extender units, where the target is maintain battery SOC once the battery has become depleted. As the electric drive system is removing the entire dynamic load requirement from the engine, then the engine needs only to be sized to simply maintain battery state of charge during use. Previous studies have shown that the most critical parameter to consider when sizing such an engine is the steady state cruising conditions (both on a level road and whilst hill-climbing) considered for charge sustaining operation [21]. The charge sustaining power requirements for the vehicle fleet under consideration is shown in Fig. 10a, and equates to roughly a third of the motive power required to meet the dynamic capability of the vehicles shown in Table 3.

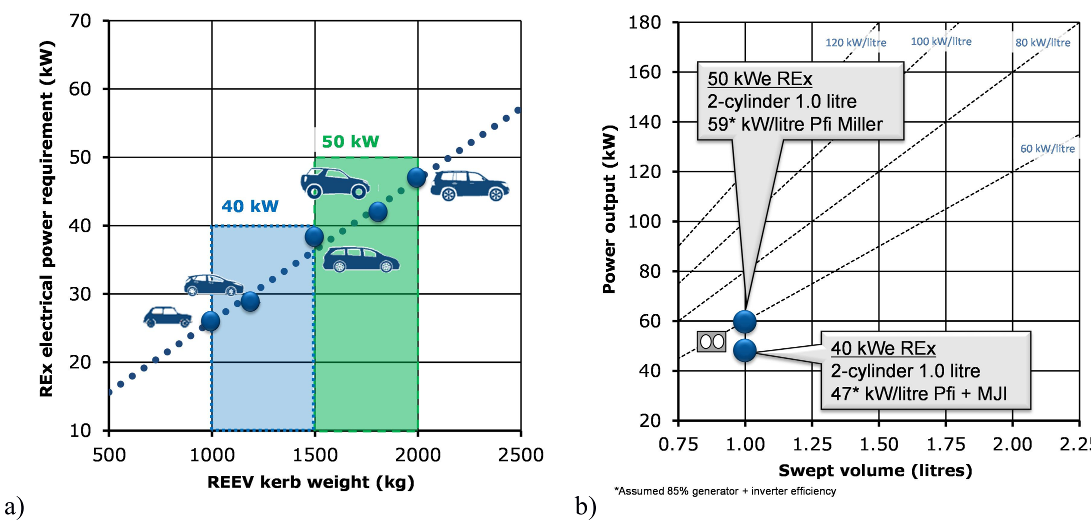
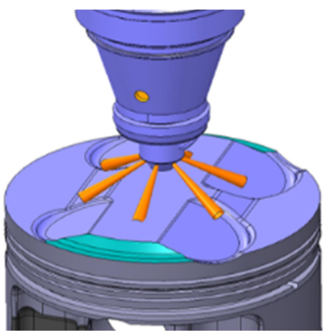


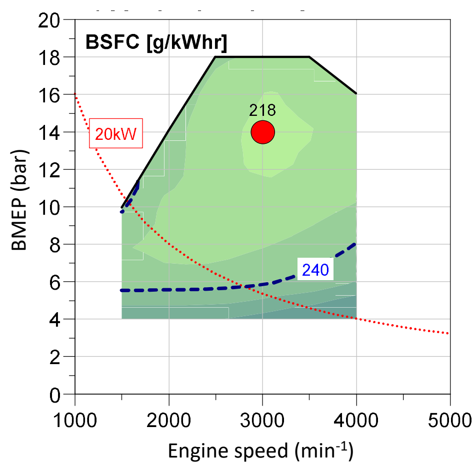
Figure 10: REx / PHEV powertrain; a) REx / PHEV powertrain power requirement for the fleet of vehicles considered; b) REx / PHEV powertrain family for the fleet of vehicles considered.

Based on the engine family already discussed, a simplified version of this engine can be used to achieve the power requirements shown in Fig. 10a, this low-technology family is shown in Fig. 10b (including additional power allowance for generator efficiency). It is envisaged that the engine can be significantly de-featured and whilst the architecture will retain many of the attributes of the serialised Di3 engine architecture, it will also contain many of the low cost design features that were used in the MAHLE REx engine. In particular the engine is envisaged to have a 2-cylinder layout and feature 2-valve per cylinder, a single camshaft, fixed valve event timing and port fuel injection. It is also anticipated that the engine will operate over a very limited speed range (1500 to 4000 min^{-1}) and up to about 18 bar BMEP.

However, to ensure that the efficiency of the engine is not compromised the engine will feature the MAHLE Jet Ignition (MJI®) system [22]. This is a pre-chamber based ignition system that enables very dilute mixtures to be initiated and burned in a stable manner. An image of the pre-chamber, including a depiction how the combustion jets propagate into the main combustion chamber, is shown in Fig. 11a. The rapid combustion enabled by this system also reduces the propensity of combustion end gases to spontaneously ignite ahead of the combustion front (knock), thus it also enables increased compression ratios to be used, further enhancing engine efficiency. Initial development of the combustion system for this PHEV application is well underway and initial results are very promising. Figure 11b shows initial fuel consumption measurements for the MAHLE Di3 running with a prototype MJI® combustion system, and it can be seen that all of the operating conditions above 20 kW power output have a BSFC of below 240 g/kWh and the minimum BSFC is below 220 g/kWh.



a)



b)

Figure 11: a) MJI ® pre-chamber assembly and combustion jet projections; b) Initial fuel consumption measurements for the low cost dedicated hybrid engine with MJI®.

It is envisaged that the driveline arrangement can also be simplified, as shown in Fig. 12a, with a traction motor driving the wheels directly via a fixed transmission ratio. By engaging a clutch, the engine can also be coupled to the wheels, via a differing fixed gear ratio, when required to sustain battery state of charge. At low vehicle speeds, when the direct drive ratio between the engine and wheels would mean that the engine would need to operate below the minimum desirable speed, the clutch can be opened and battery state of charge can be maintained by the engine via a low power ‘P1’ generator attached to the engine.

The CO_2 achieved for the fleet of vehicles under consideration is summarised in Fig. 12b. It can be seen that all of the vehicles readily meet the targets for 2030. This can be achieved by ensuring that the vehicles have an electric range that enables the CO_2 weighting factor to produce the weighted CO_2 figure required. It is anticipated that the electric driving range should be around 100 km to minimise the CO_2 LCA for the vehicle.

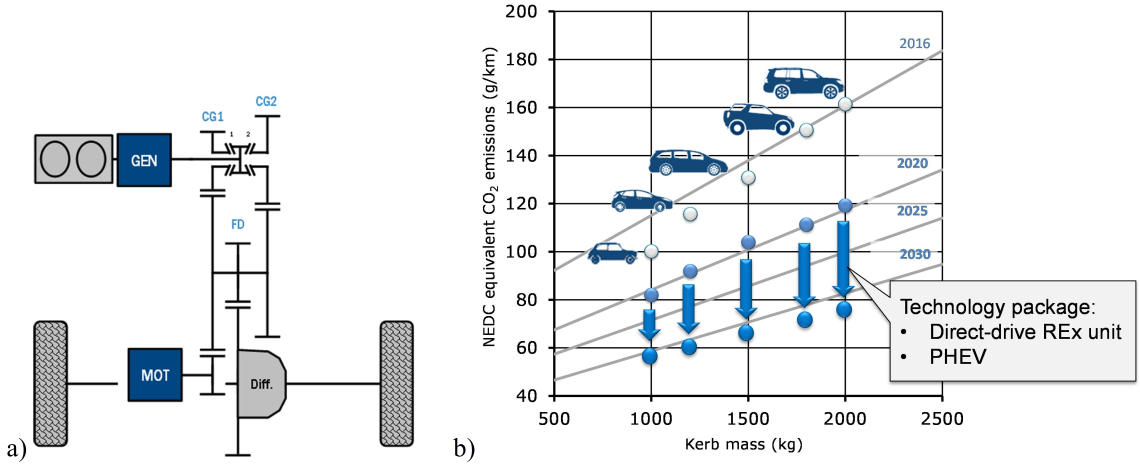


Figure 12: Hybrid vehicle; a) Driveline arrangement; b) Fleet CO_2 of the REx / PHEV powertrain family for the fleet of vehicles considered.

6. Summary

Vehicle manufacturers are facing increasing pressure by legislation and economics to reduce vehicle emissions and deliver improved fuel economy. Over the coming years, significant reductions in CO_2 emissions need to be achieved to meet fleet targets, whilst at the same time satisfying the more stringent forthcoming Euro7 emissions regulations. This focus on techniques to reduce the tailpipe CO_2 is increasing the interest in hybrid and electric vehicle technologies. Pure electric vehicles require bulky and expensive battery packs, with a high embedded CO_2 content, to enable an acceptable driving range. PHEVs partly overcome the limitations of current battery technology by retaining an ICE, thus allowing a reduction of the traction battery storage capacity, whilst still maintaining an acceptable vehicle driving range. It has also been shown that a PHEV with a 100 km electric range has a similar life-cycle impact to a BEV with a 200 km driving range.

Building on previous research projects, focused on REx and heavily downsized internal combustion engines, MAHLE have proposed a plug-in hybrid driveline in which the systems have been fully integrated and optimised. The hybrid drive-line features a cost effective and high-efficiency, turbocharged, two-cylinder gasoline engine, with a pre-chamber combustion system. Initial testing of this dedicated hybrid engine has demonstrated very low fuel consumption. This compact engine will be combined with an electric traction system which can satisfy the full-dynamic requirements of the vehicle, even during pure-electric operation. The internal combustion engine can be operated in either series hybrid or direct drive modes, via a compact multi-speed transmission.

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