EVS32 A world of E MOTION 2019 MAY 19 22
INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
EVS 50th anniversary 1969-2019

Hybrid Powertrain Technology Roadmap

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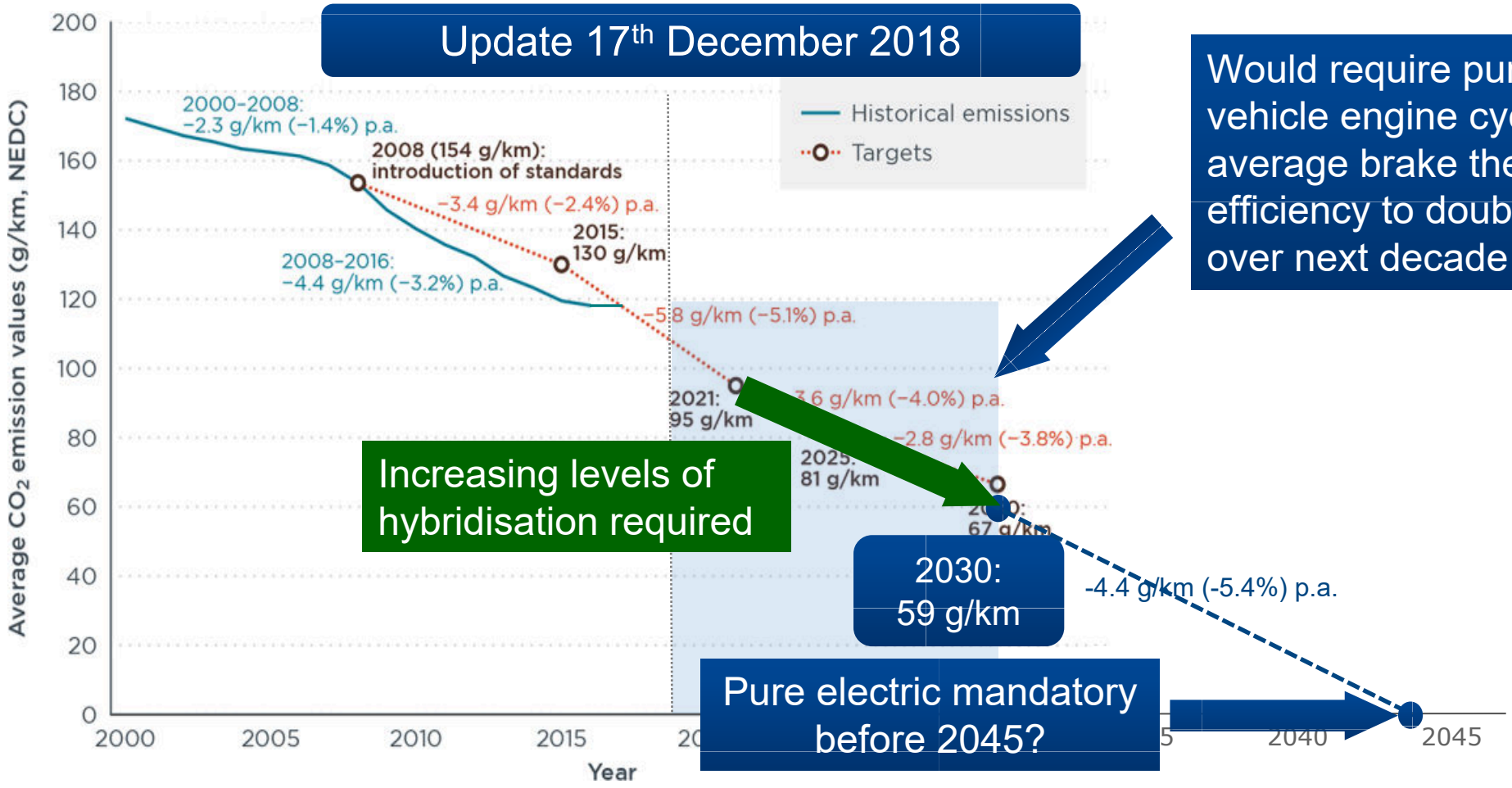
MAHLE Powertrain

MAHLE Powertrain

Overview

- Introduction
- MAHLE demonstrator engines
  - Downsizing engine
  - Range extender
- Powertrain technologies considered
- Fleet of vehicles analysed
  - Conventional powertrain family
  - Advanced powertrain family
  - MAHLE Hybrid Concept
    - Engine technology
    - Driveline layout
- Summary

Fleet CO_2 Limits



CO_2 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?

Downsizing and Range Extender Engine Timelines

MAHLE Di3

DS Concept Design

Single Turbo DS Engine & Vehicle

1.2L & 1.5L Industrialisation

MAHLE e-SC Engine & Vehicle

2006 2008 2010 2013 2016 2019

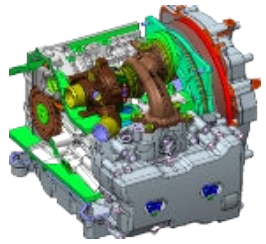
MAHLE REx

Concept Design

Demo car

GPS Based Controller

High Power REx



MAHLE Downsizing Engine

- 1.2 litre, 3-cylinder highly boosted engine
- 30 bar BMEP, 100 kW/litre
- Minimum BSFC of 235 g/kWh
- Demonstrator vehicle developed in 2010
  - 25% fuel consumption reduction compared to 2.4litre V6 baseline

Industrialised Downsizing Engine

- 1.2L & 1.5L variants with max commonality
- Design for manufacture & local suppliers
- 80 kW/litre Lambda 1 whole area map and 24bar BMEP with 970°C pre-turbine limit

227 g/kWh

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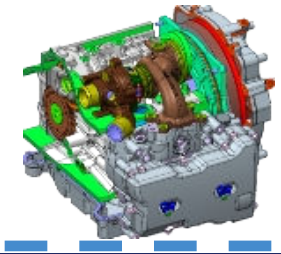
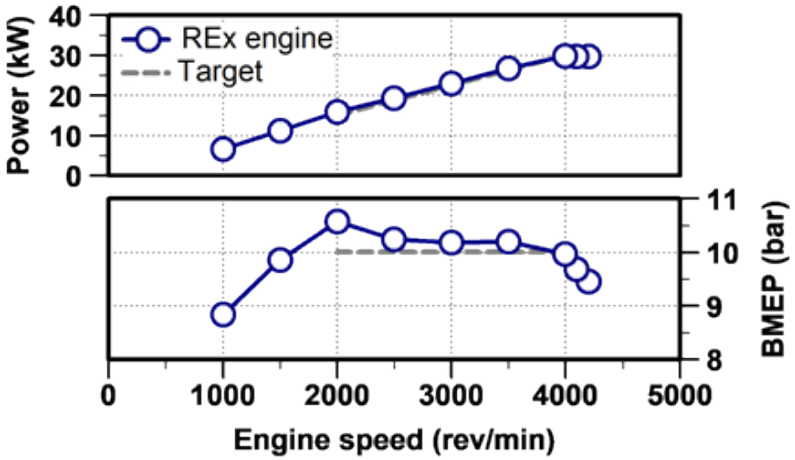


MAHLE Range Extender Unit

- 900 cc, in-line 2-cylinder, 4-stroke gasoline
- 30 kW peak power at 4000 rev/min
- Port-fuel injection (λ = 1)
- Fully integrated axial flux generator
- Compact package (65 litres total volume)



B-Segment Demonstrator Vehicle

- Total range 500 km
  (70 km pure electric range)
- 42 g/km CO_2 Tail-pipe emissions for NEDC
- Charge sustaining speed of 120 km/h
- Dynamic performance comparable to baseline vehicle

Technologies Assessed to Meet Future Fuel Consumption Targets

Engine measures:

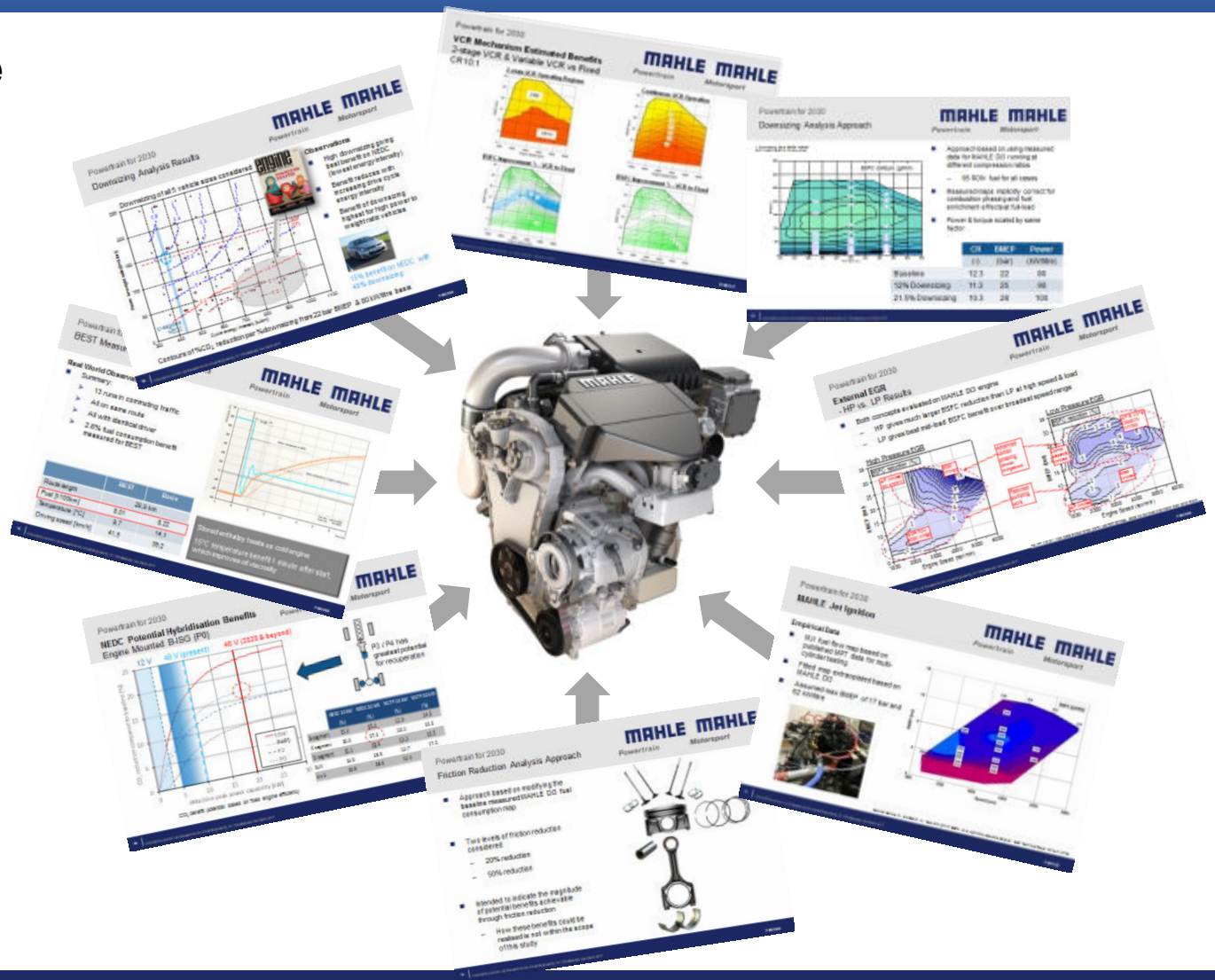
- Whole area λ=1 operation
- Higher fuel injection pressures
- Advanced boosting systems
- Additional after treatment solutions
- Enablers for higher CR:
  - High & Low pressure EGR
  - Water Injection
  - Advanced combustion systems

Alternative fuels:

- Biofuels / CNG

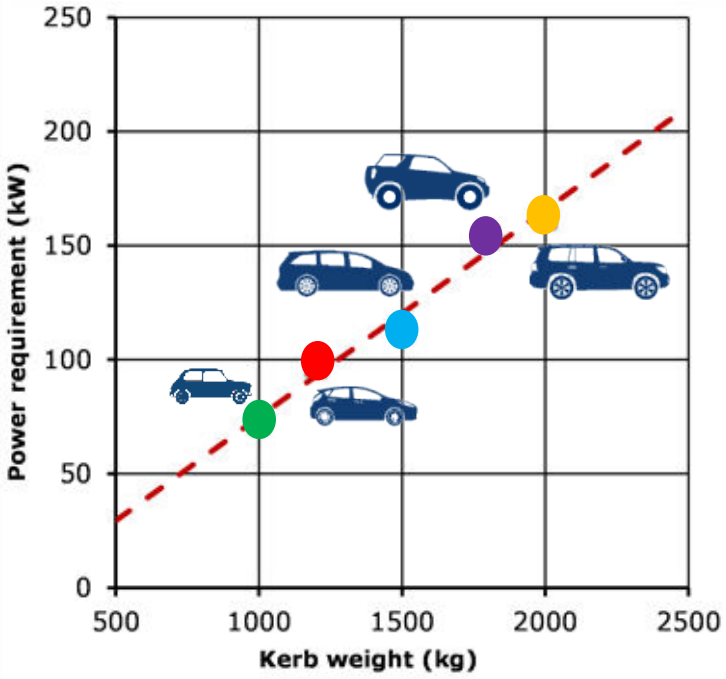
Increased electrification:

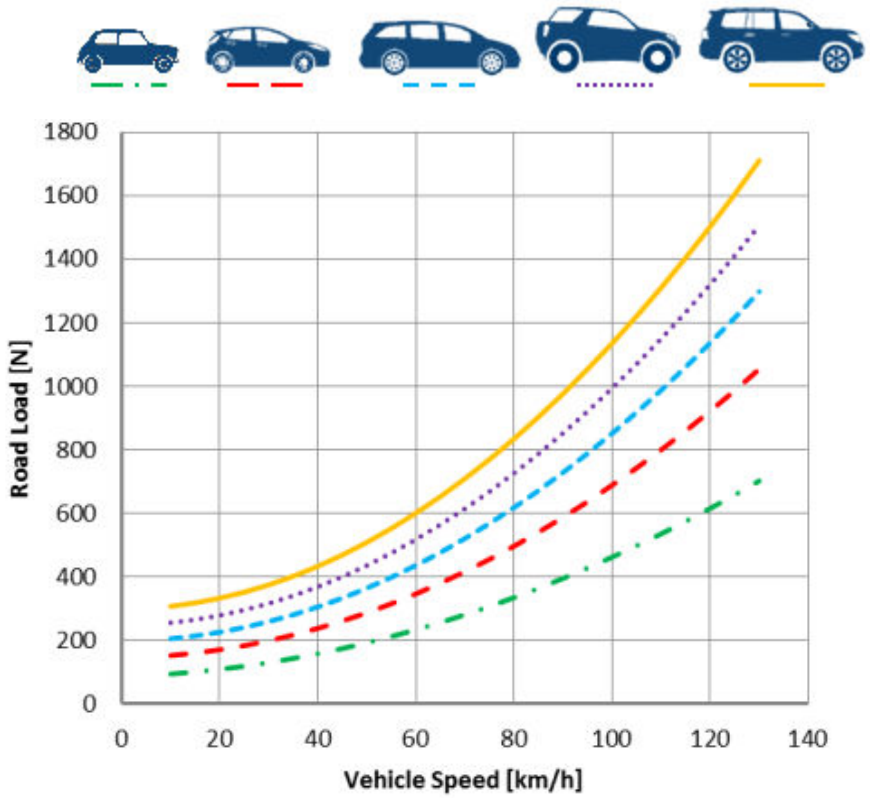
- PHEV & MHEV applications
- Different operating strategies
- Low cost / high efficiency engine



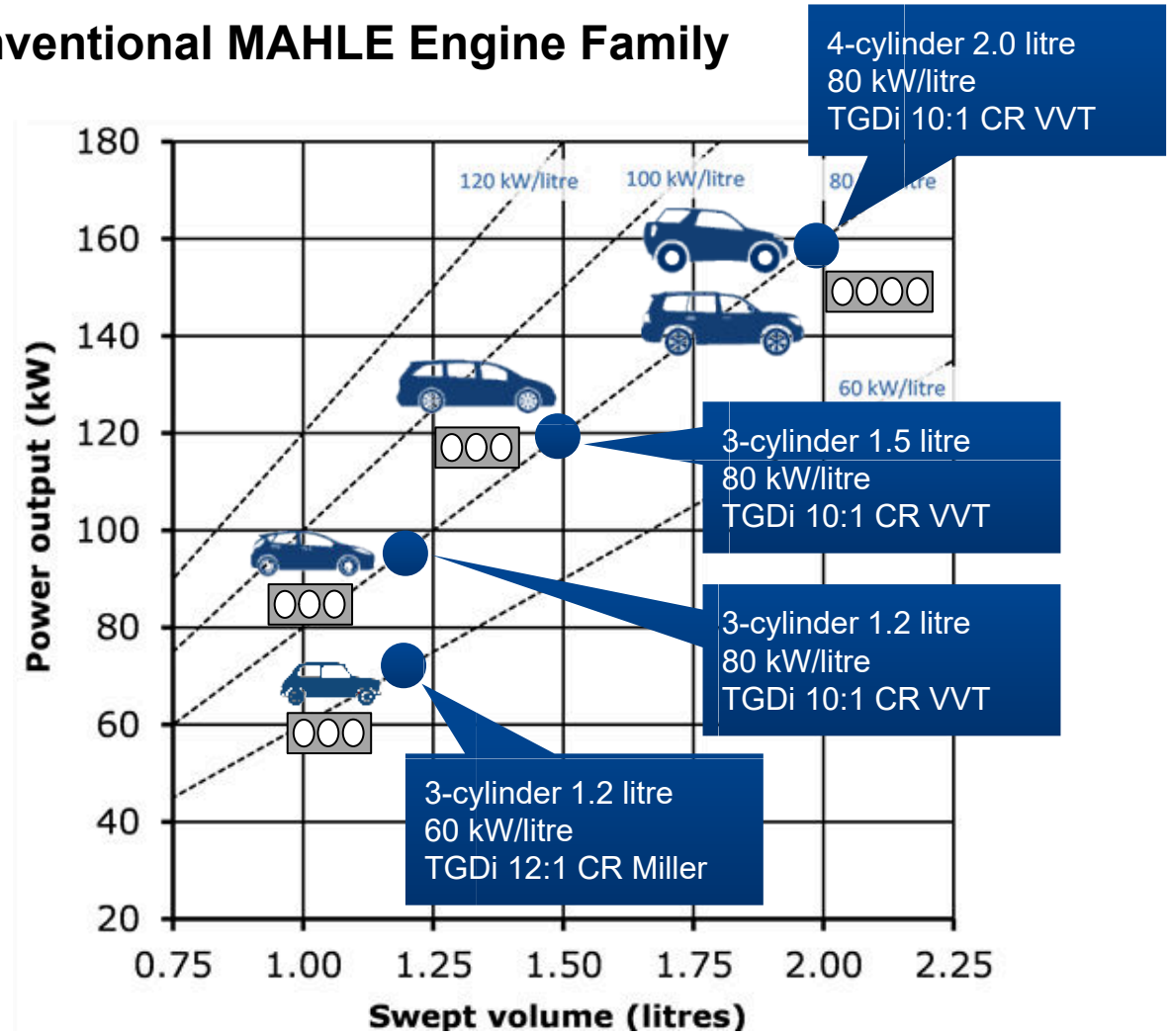
Fleet of Vehicles Analysed: Road Load Vehicle Power Requirement

- Power requirement from analysis of Vmax target & 0-100 km/h acceleration target
- Differing targets would give different power requirement
  - i.e. for differing model variants on same platform

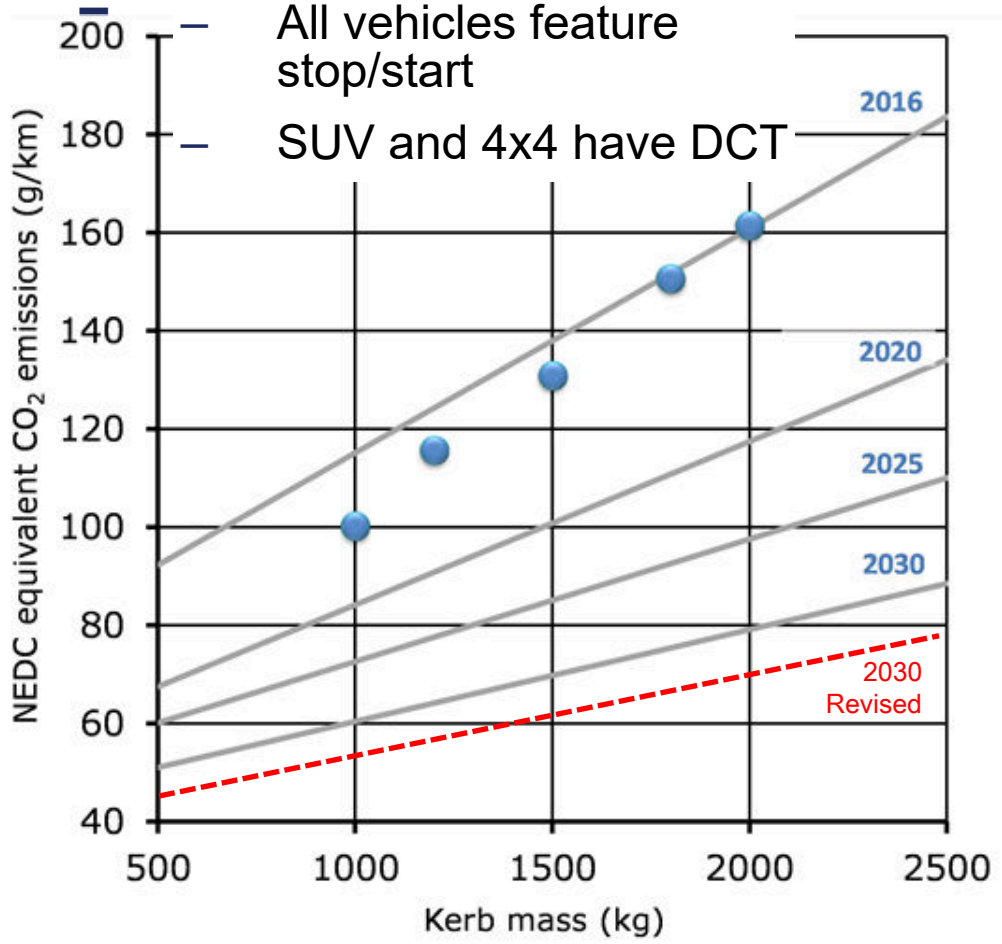




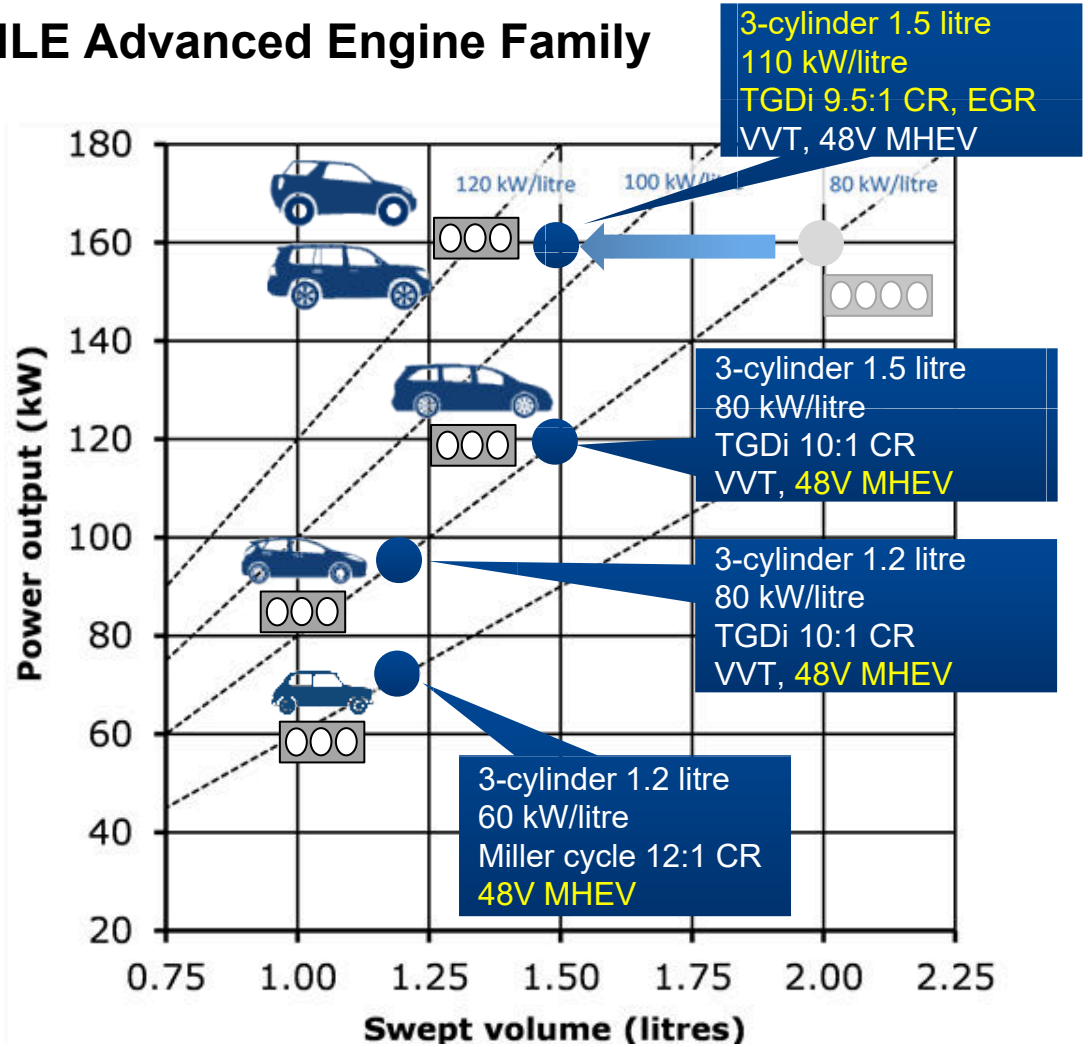
Conventional MAHLE Engine Family

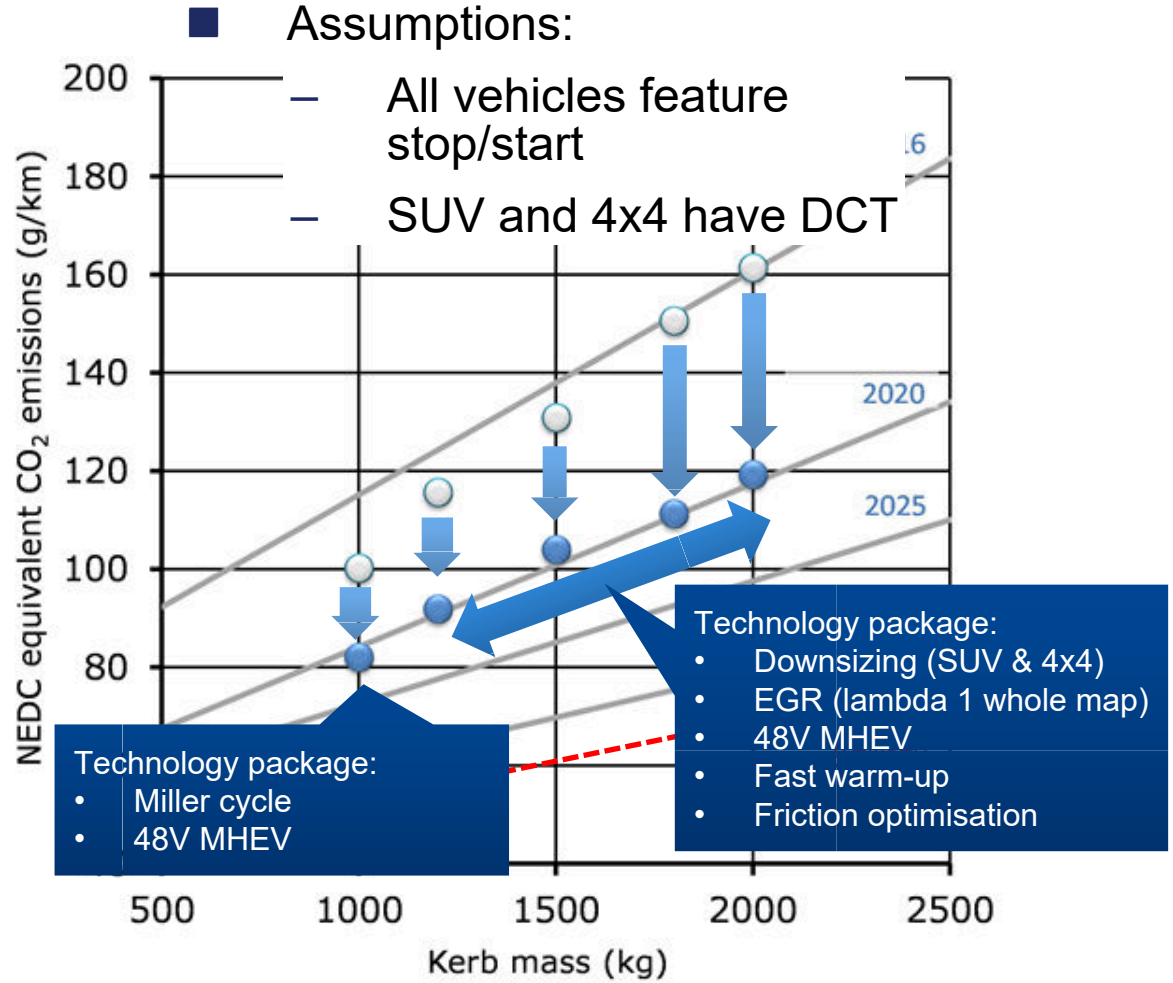


- Assumptions:
  - All vehicles feature stop/start
  - SUV and 4x4 have DCT



MAHLE Advanced Engine Family





What Next?

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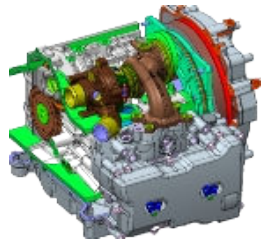
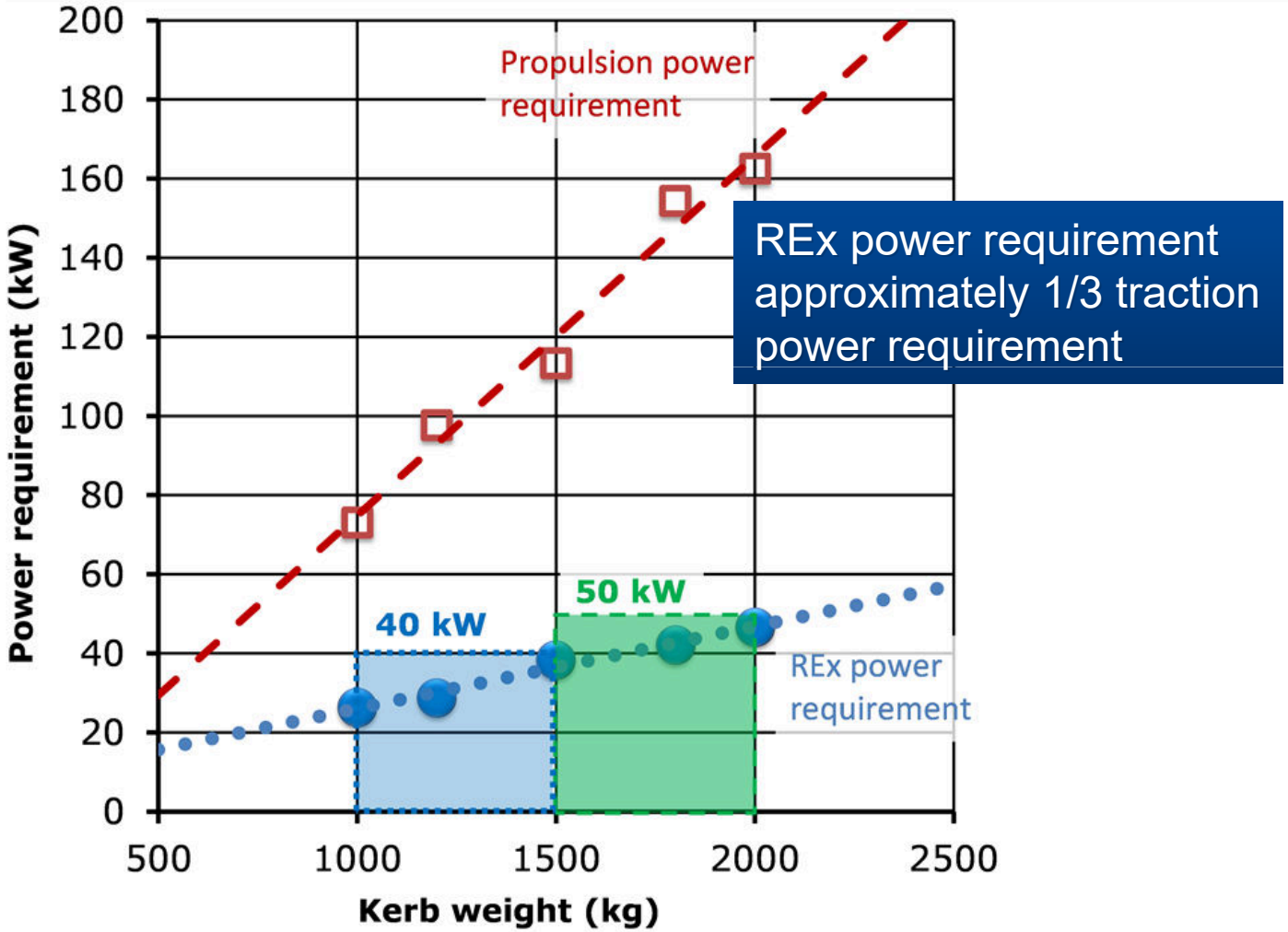


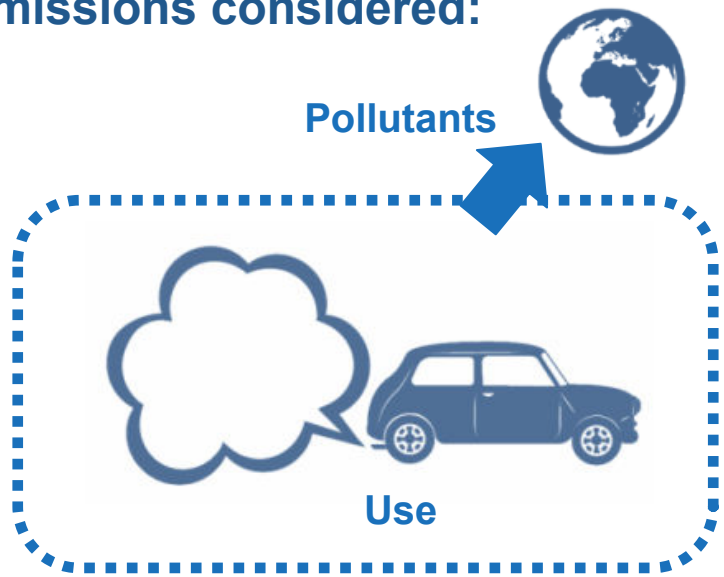
Range Extender Power Requirement

- REx power requirement lower than conventional ICE
  - ICE sized for Vmax and vehicle dynamic performance
- REx charge sustaining power requirement determined by
  - Charge sustaining cruse speed
  - Hill climbing capability during charge sustained operation
  - Charge sustained towing capability



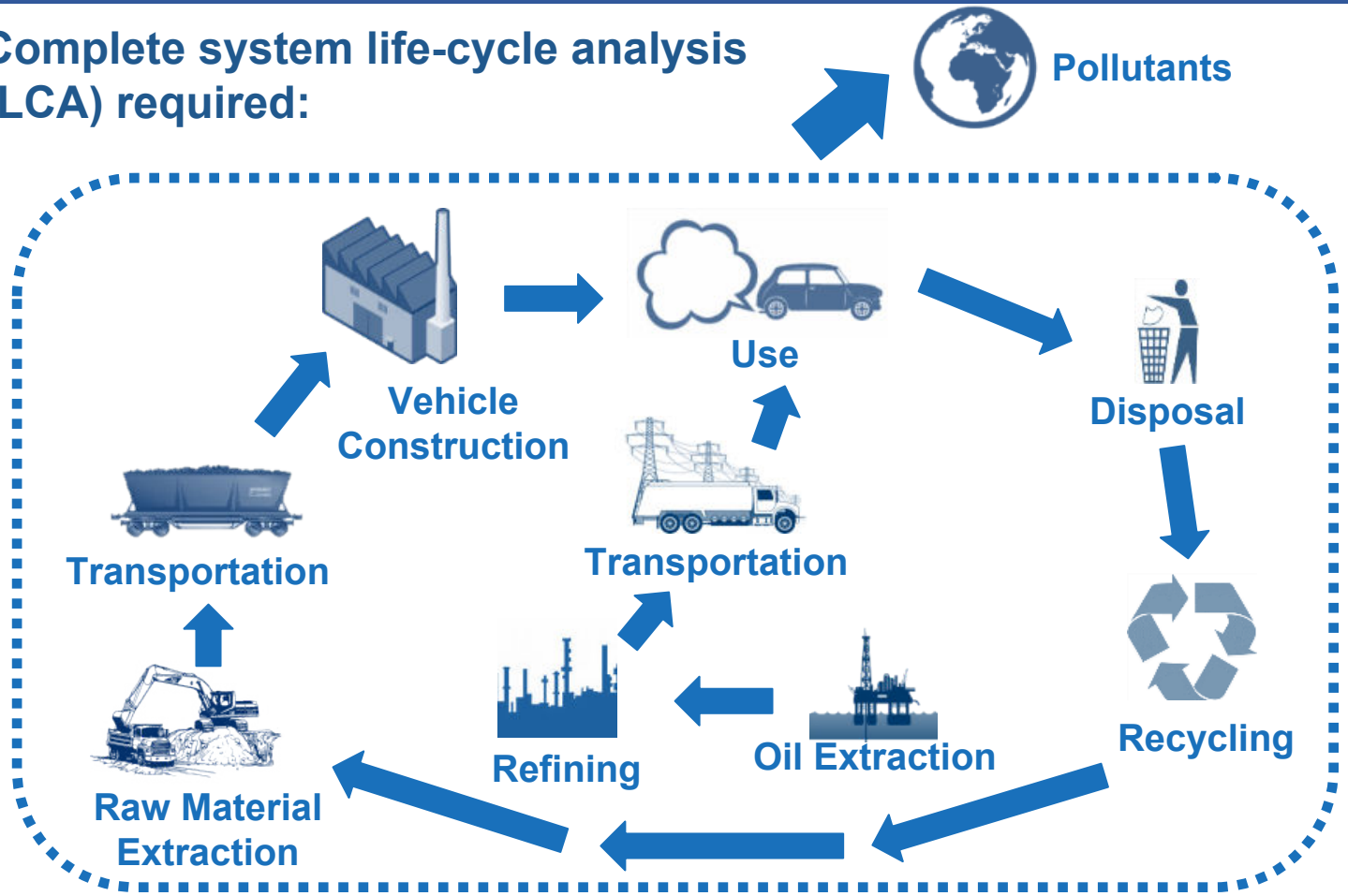
Life Cycle Analysis

Typically only in use tailpipe emissions considered:



System Boundary Under Consideration

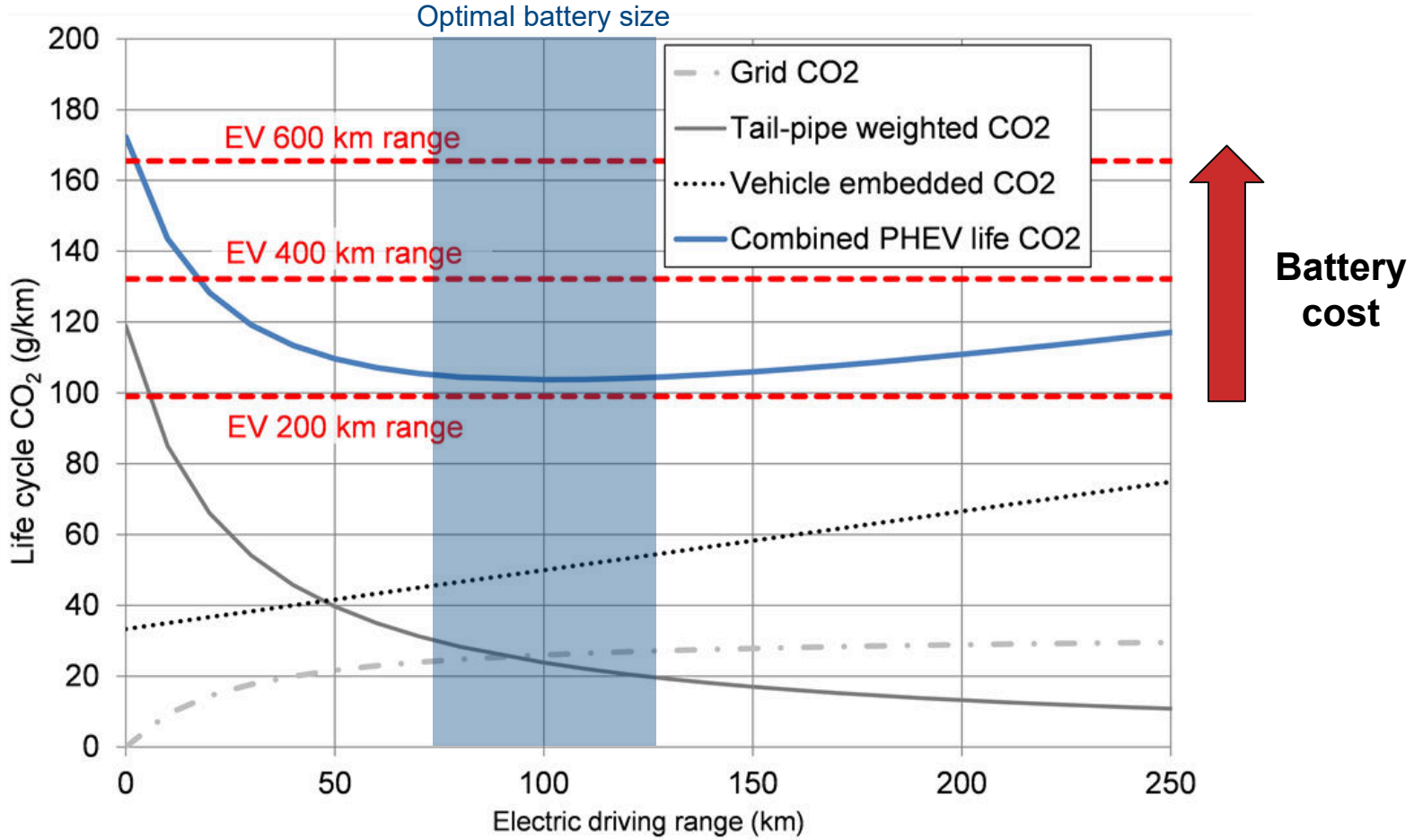
Complete system life-cycle analysis (LCA) required:



Need to consider the whole system lifecycle

PHEV – Optimal Battery Size

- Analysis based on 1400kg vehicle over NEDC
- 150,000 km life
- Battery embedded CO_2 175 kg/kWh[1]
- Utility factor based on R101 tail-pipe weighting factor
- Grid CO_2 intensity for UK
  - 292 g/kWh
- Well to tank contribution also considered

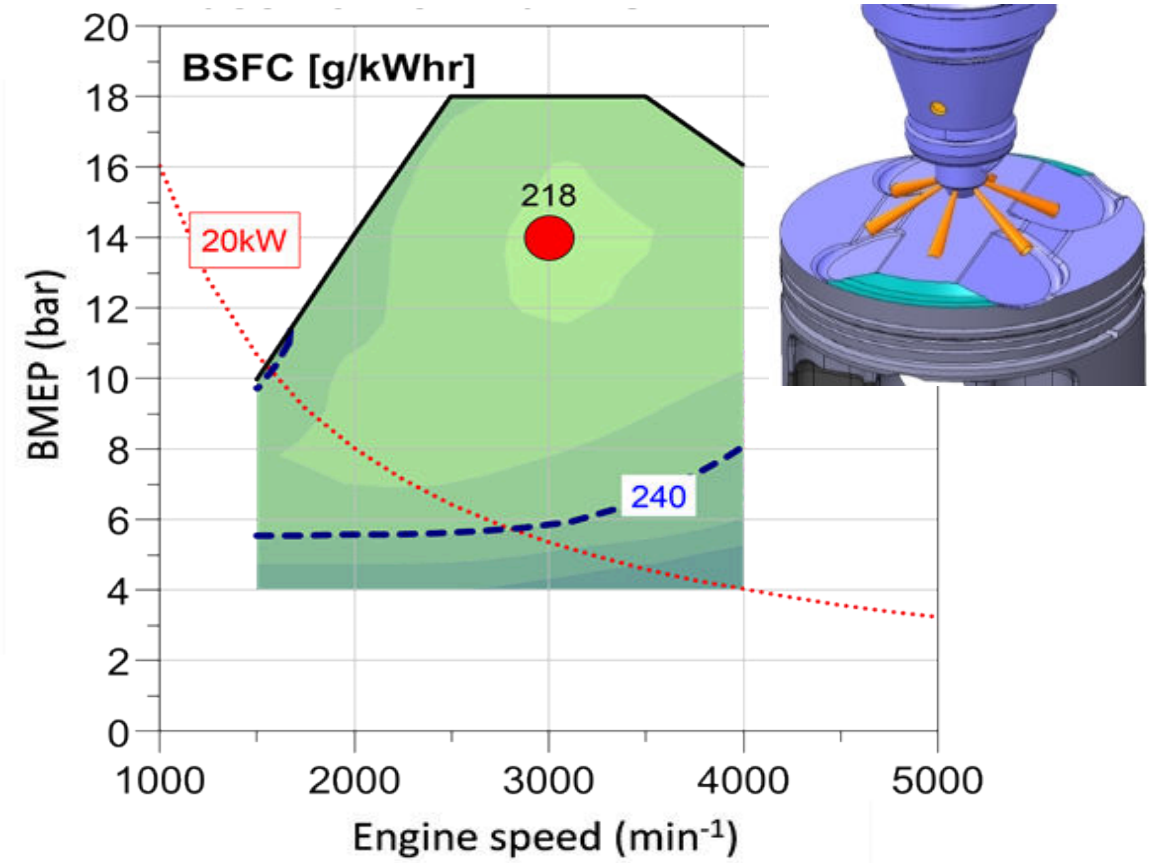


Are we overspecifying the battery to get equivalance to ICE vehicles?

1) Dale & Hall, ICCT, January 2018

Advanced Combustion Technologies

- MAHLE Jet Ignition® with passive pre-chamber
  - No additional fuel injector
- Rapid combustion
  - Increased CR capability
- Excellent efficiency across operating map
- Low cost technology content

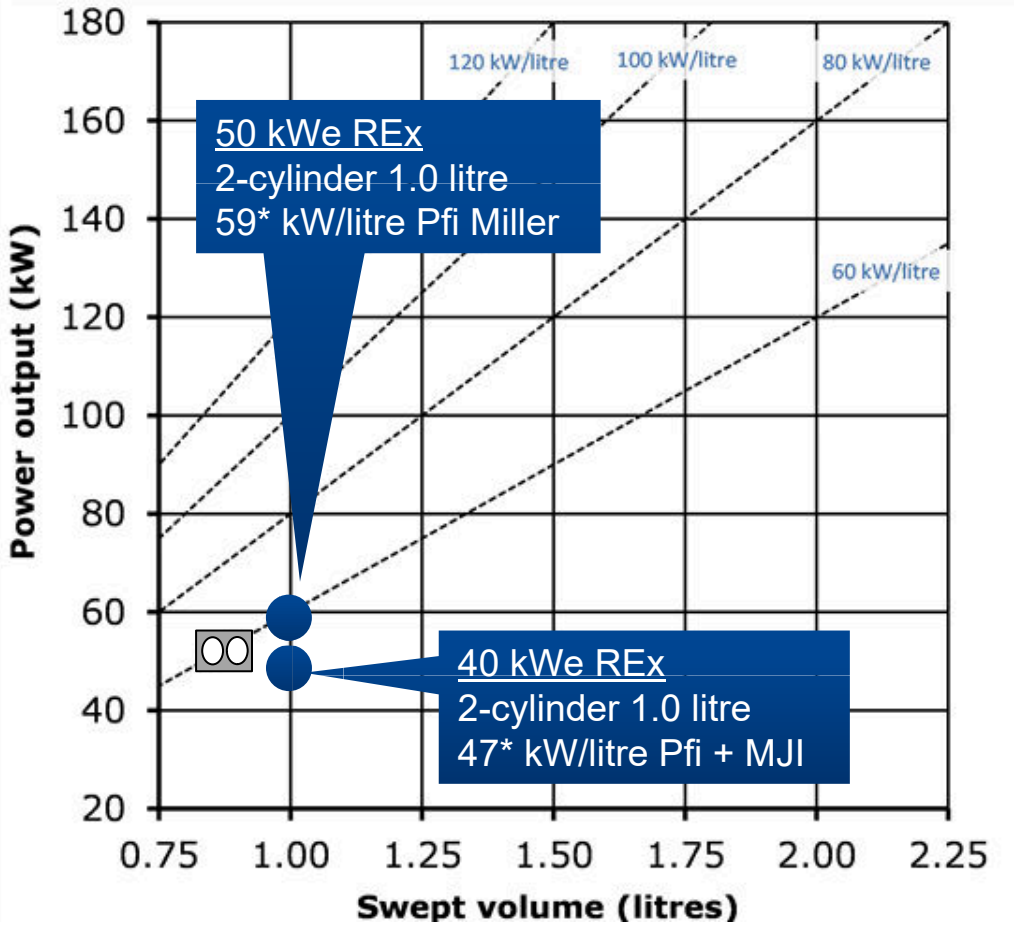


Initial fuel consumption measurements for the low cost dedicated hybrid engine with MJI®

MAHLE Hybrid Concept

- Hybrid operation and cost optimised engine
  - 2-cylinder, 1.0 litre, turbocharged
  - Port fuel injection
  - 2-valves per cylinder, fixed timing
  - MJI® combustion system for high efficiency

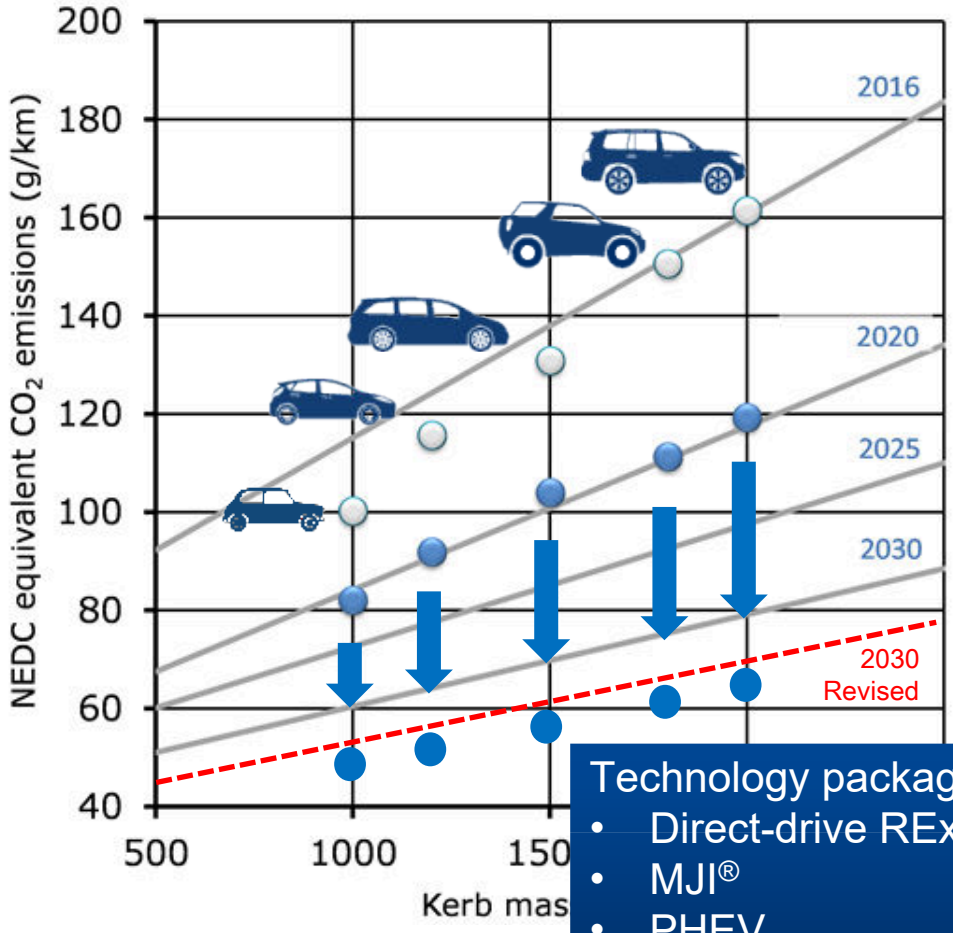
- **Engine concept verified by initial testing**



*Assumed 85% generator + inverter efficiency

MAHLE Hybrid Concept

- Traction motor with direct drive provides vehicle dynamic performance
- High SOC - pure EV mode:
  - Engine off and disconnected from wheels
- Low SOC – hybrid mode:
  - Low vehicle speeds
    - Series hybrid mode
  - High vehicle speeds
    - Parallel hybrid mode
    - Dynamic performance supported by motor
- Assumptions:
  - Battery pack sized to give required EV range to achieve target CO_2



Technology package:
- Direct-drive REx unit
- MJI®
- PHEV

Summary

- Vehicle manufacturers facing increasingly demanding legislative requirements
- Large reductions in fuel consumption needed to meet fleet targets
- PHEV's currently offer a compelling interim proposition for many markets
- Electrification opens up new engine development opportunities
  - Lots of potential left to develop engines for new applications
  - Hybrid powertrains offer potential for low total life-cycle CO_2 emissions
- **MJI® is a promising low cost and high efficiency solution**

Powertrain technology diversification is challenging and will remain so for the next decade

Thank you for your kind attention!

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