



The 27th INTERNATIONAL
ELECTRIC VEHICLE
SYMPOSIUM & EXHIBITION.

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Development of a Dedicated Range Extender Unit and Demo Vehicle

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- Introduction
- Range Extender Unit
 - Specifications
 - System Efficiency
- MAHLE Range Extender Demonstrator Vehicle
 - Targets
 - Component Selection and Packaging
 - Control Architecture
 - REx Operating Strategy
 - Initial Test Results
- Summary

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Electric Vehicle (EV)

- Vehicle propelled by electric motors
- On-board battery pack sole energy source
 - Range currently typically **80 to 250 km**
- Charged from residential electrical outlet



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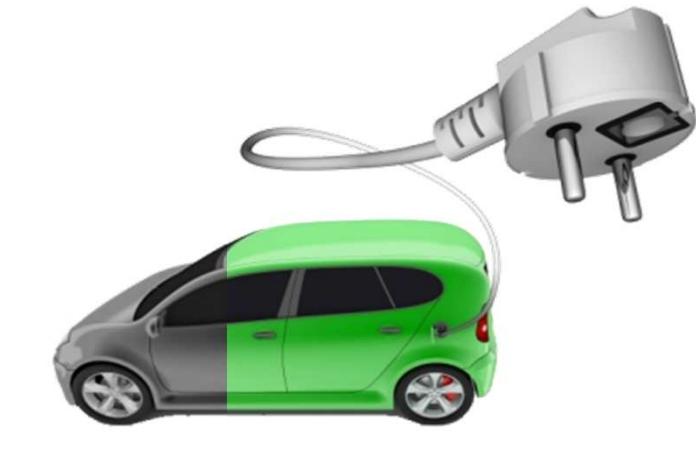


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Range Extended Electric Vehicle (REEV)

- Vehicle propelled by electric motors
- Battery pack downsized
 - Typical battery only range of 20 to 100 km
- Charged from residential electrical outlet
- On-board generator re-charges battery
 - Typically IC engine coupled to generator
 - Used whilst vehicle moving



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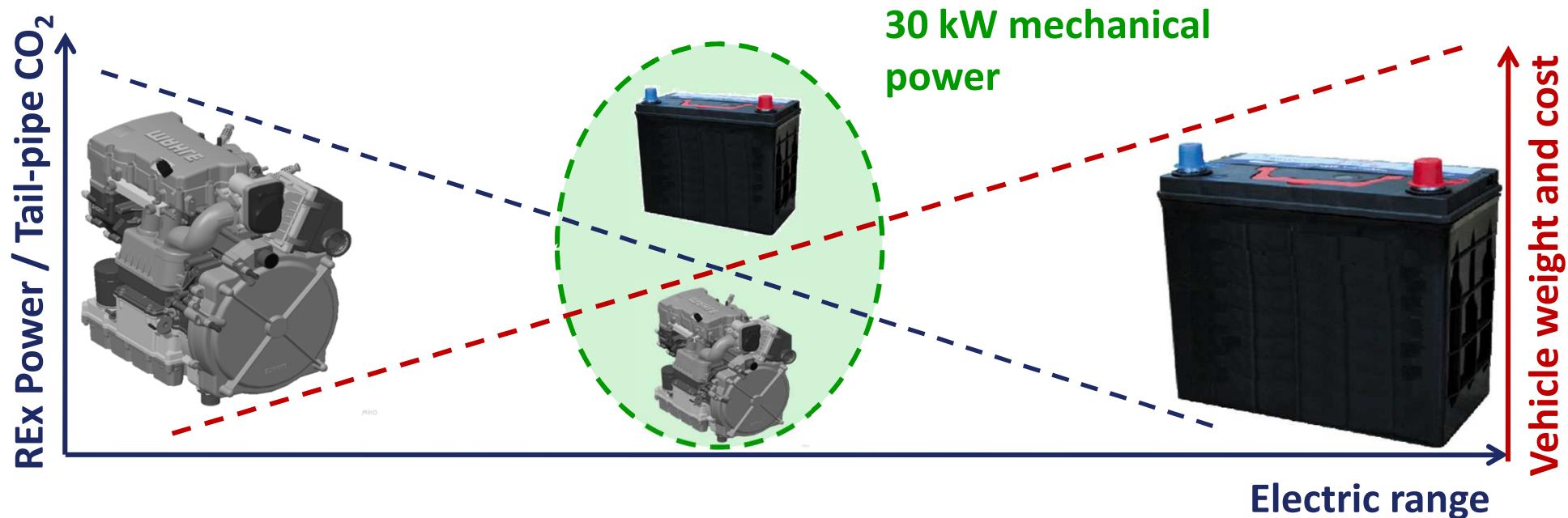
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- Battery provides load-levelling of driver demand
- REx power requirement depends on battery size
 - No battery – REx must provide instantaneous power
 - Limitless battery – REx not required



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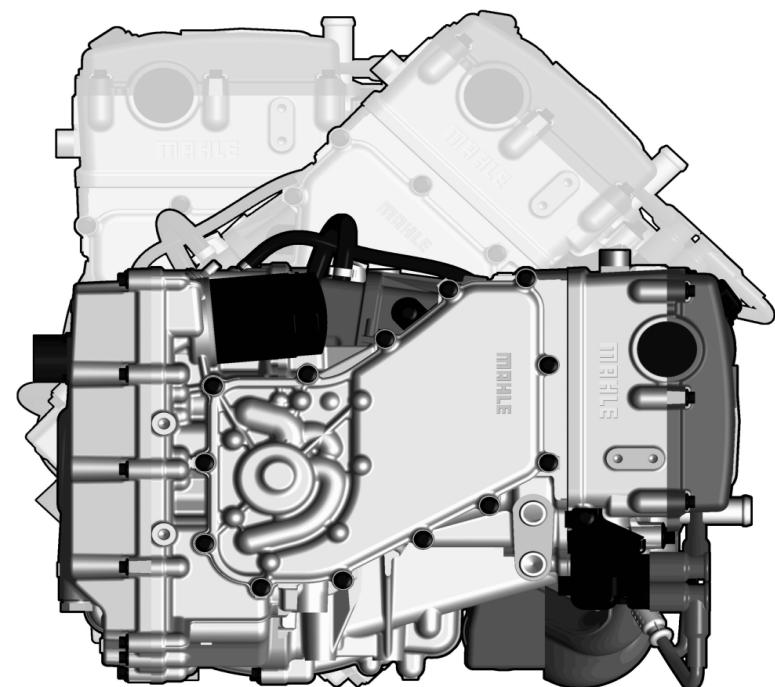
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- 0.9 litre, In-line 2-cylinder, Four-stroke, Gasoline
- 30 kW peak power at 4000 rev/min
- Port-fuel injection ($\lambda = 1$)
- $0^\circ / 180^\circ$ TDC firing angles
- Flexible installation angle
- Fully integrated generator
- Euro 6 Emissions compliant



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Dimensions

- L x W x Height: 416 x 327 x 481 mm
- Volume (Box): 65 litres



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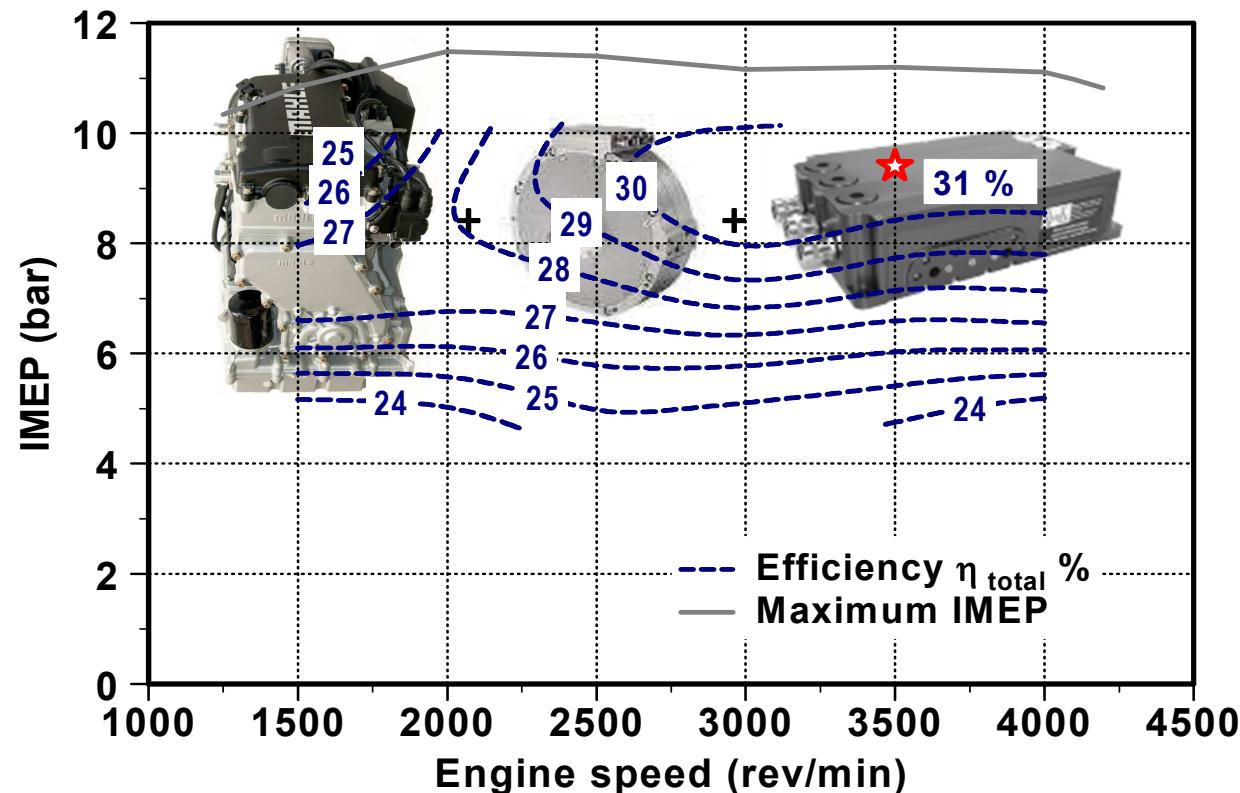
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- REx unit efficiency (engine + generator + invertor)



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Lightweight and Compact Package Concept

- No primary out of balance forces (0° /180° firing)
 - No balancer shaft required
- Two bearing crankshaft
 - Low cost and low friction
- Flywheel located between cylinders
 - Small package volume
 - Low rotational inertia
- Challenge: Cyclic speed fluctuations



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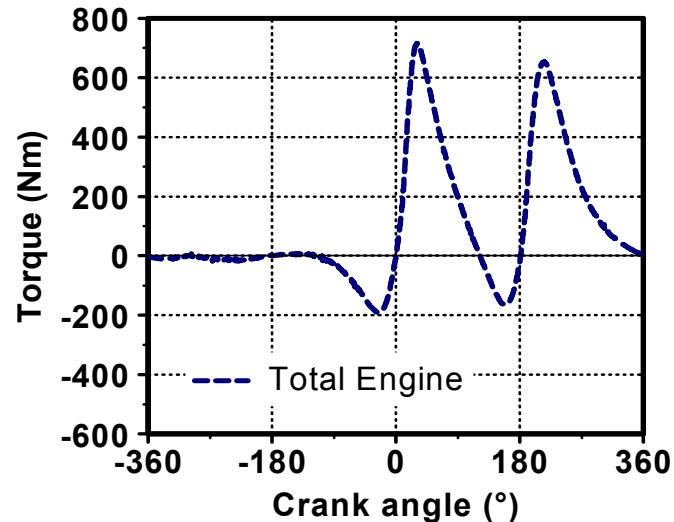


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Uneven Torque Profile

- 0° /180° firing
 - All torque from single crank revolution
 - No torque from other revolution



Cyclic Torque Variation
(2000 rev/min, 8 bar BMEP)

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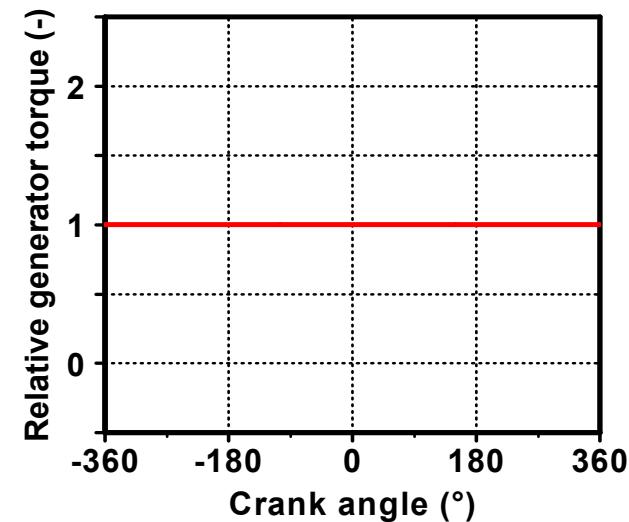
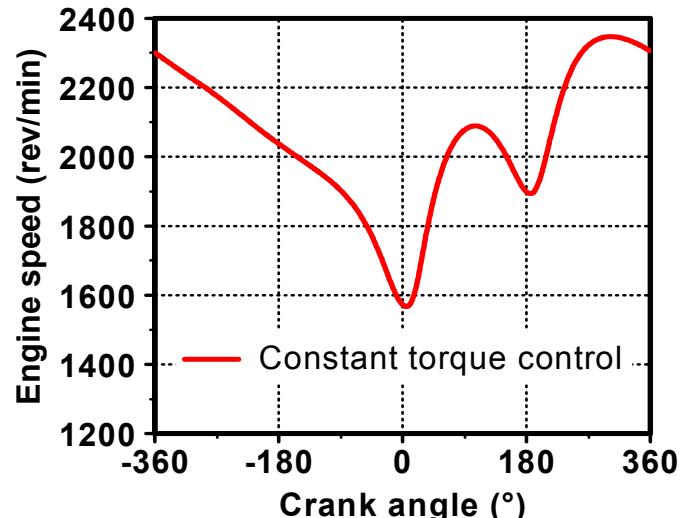
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Speed Fluctuation

- Constant generator torque:
 - ± 400 rev/min speed fluctuation

Low cranktrain inertia \rightarrow high speed fluctuation

Dynamic Generator Control



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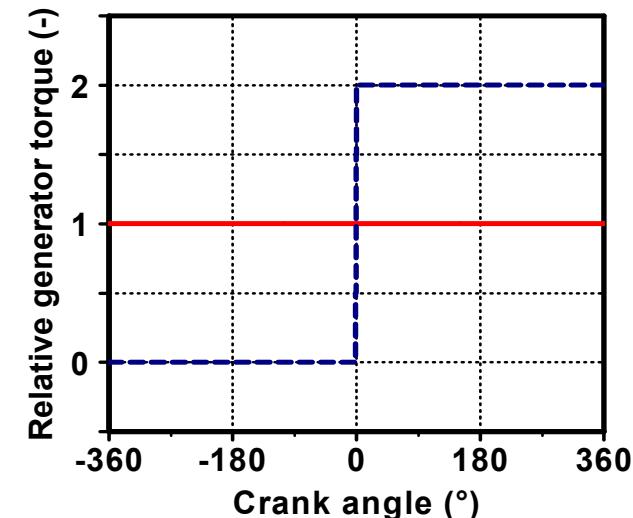
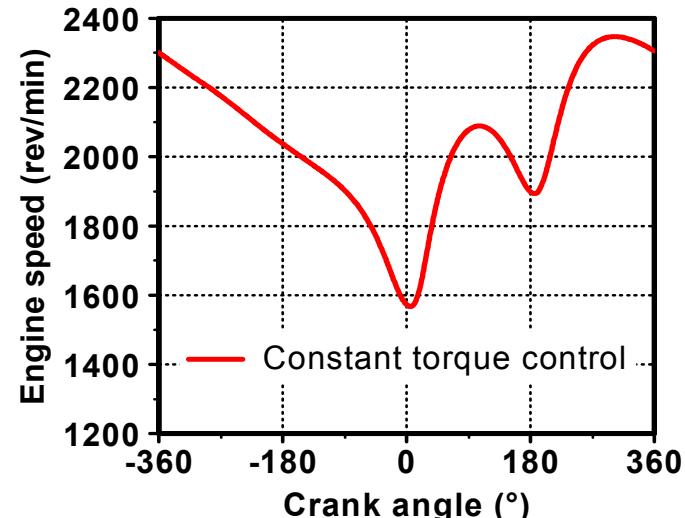


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Dynamic Control

- Constant generator torque:
 - ± 400 rev/min speed fluctuation

Dynamic Generator Control



Solution → Dynamic Generator Control

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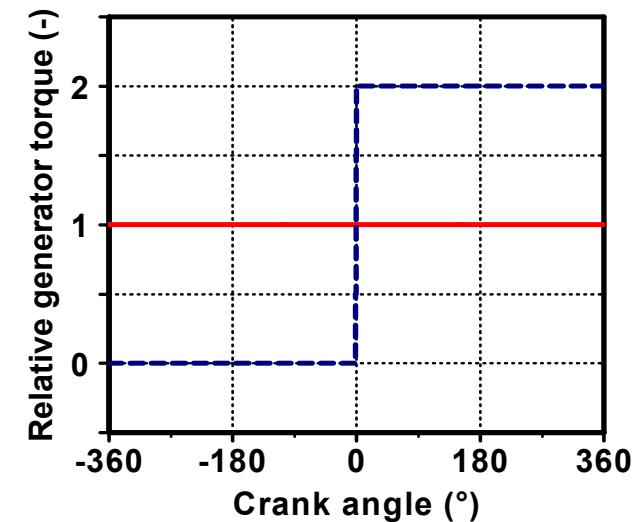
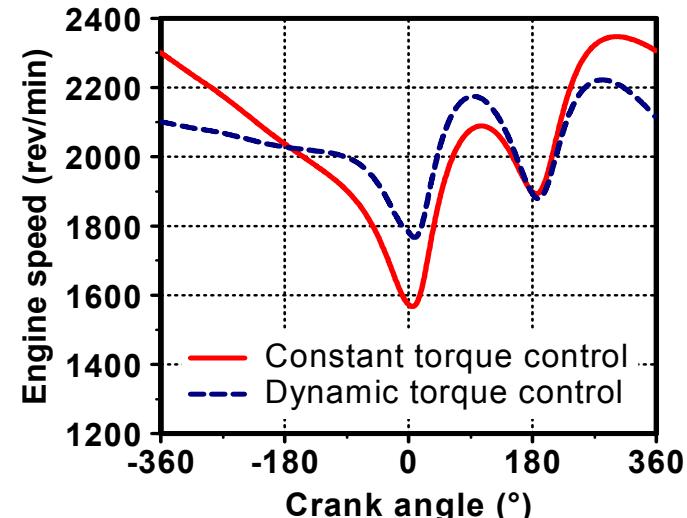
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Dynamic Control

- Constant generator torque:
 - ± 400 rev/min speed fluctuation
- Dynamic generator torque:
 - Reduced speed fluctuation down to ± 200 rev/min
 - Smoother engine operation
 - No large flywheel requirement



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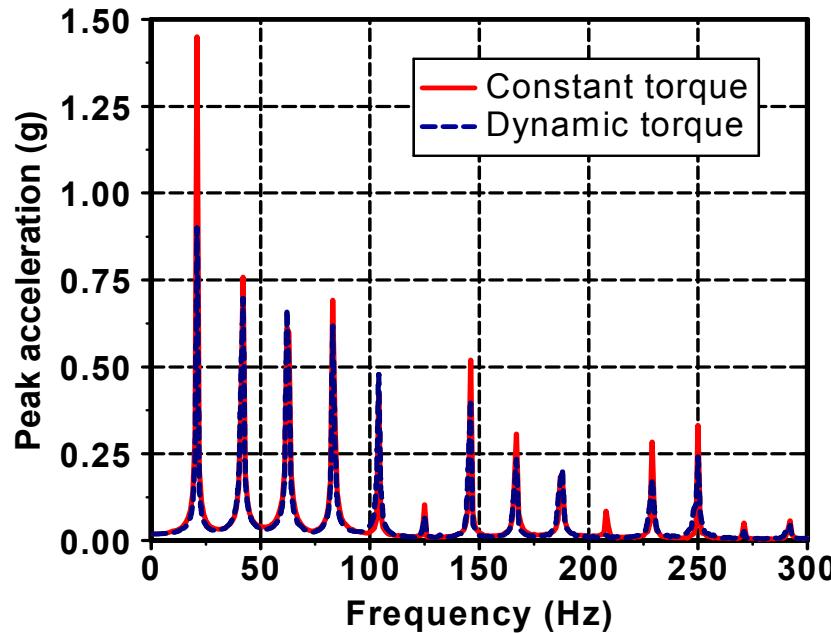


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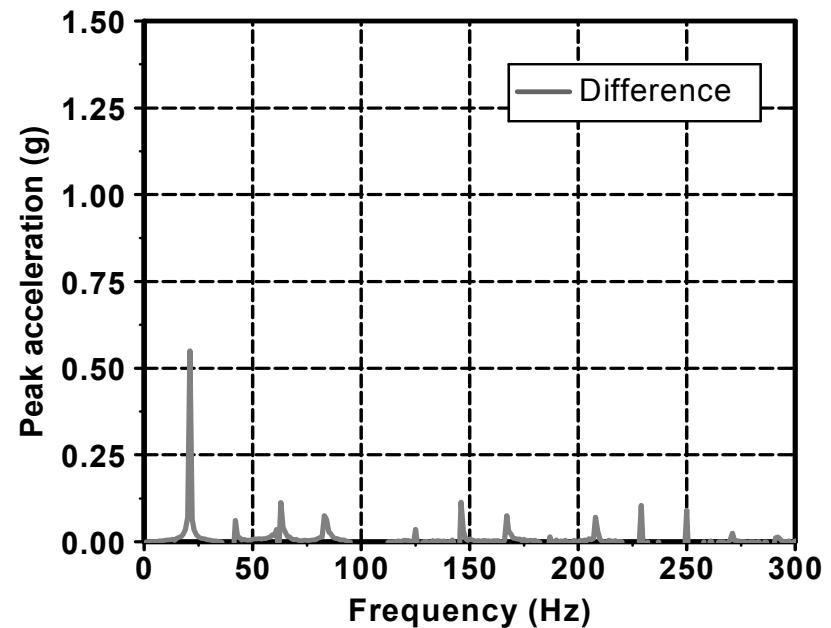


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Dynamic Generator Control



Measured peak accelerations in Dynamic and Constant generator control modes
(2000 min⁻¹, 50% load)



Difference between the measured peak accelerations in Dynamic and Constant generator control modes

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Vehicle Concept

- Range Extended Electric Vehicle (REEV)
 - Plug-in series hybrid
 - Compact class
- Packaging challenge!



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Demonstrator Vehicle

Vehicle Targets

Parameter	Units	Base Vehicle	REEV
0-100 km/h acceleration time	s	11.7	12.0
Maximum speed	km/h	180	145
Grade ability	%	—	20
Maximum speed on 6 % grade	km/h	—	90
Pure EV range	km	—	> 60
NEDC CO ₂	g/km	118	< 45

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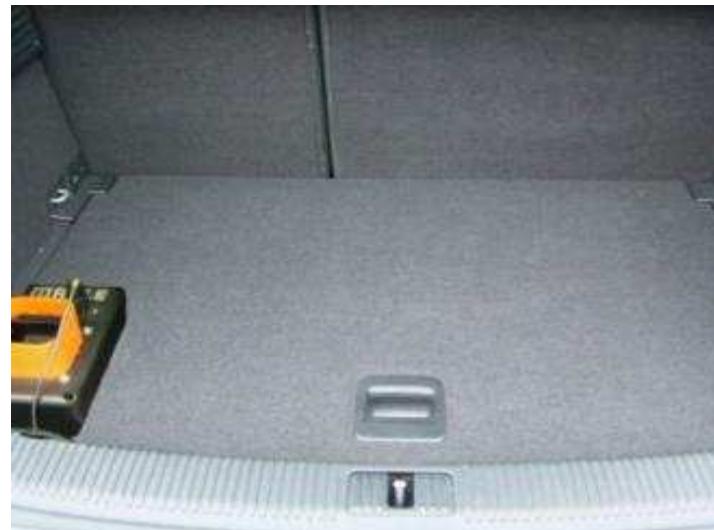


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- Water cooled Li-Ion battery pack
 - 14 kWh capacity
 - 350 V nominal
 - Integrated BMS
 - Under boot floor installation



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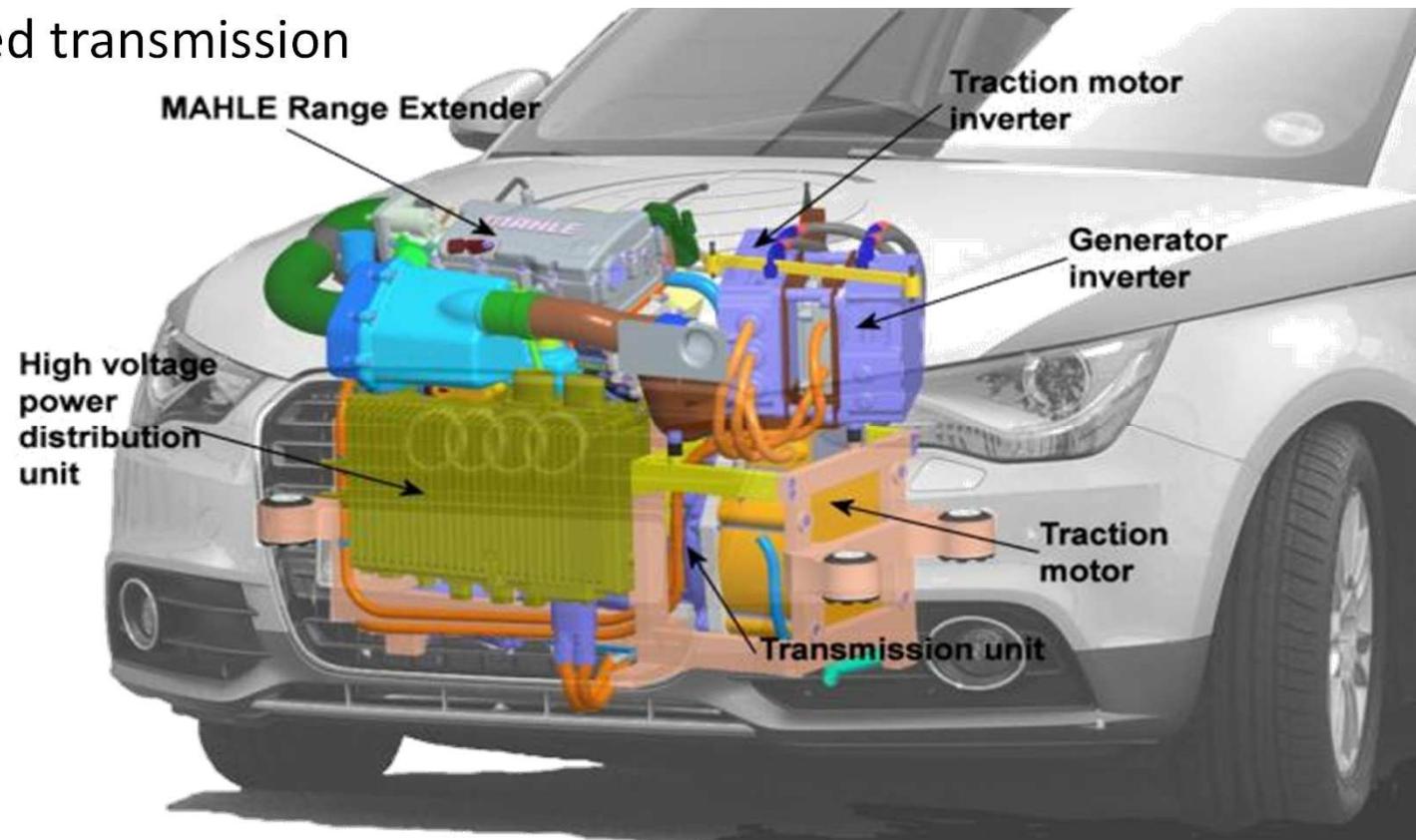
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- 55 kW (100 kW peak) traction motor
- 2-speed transmission



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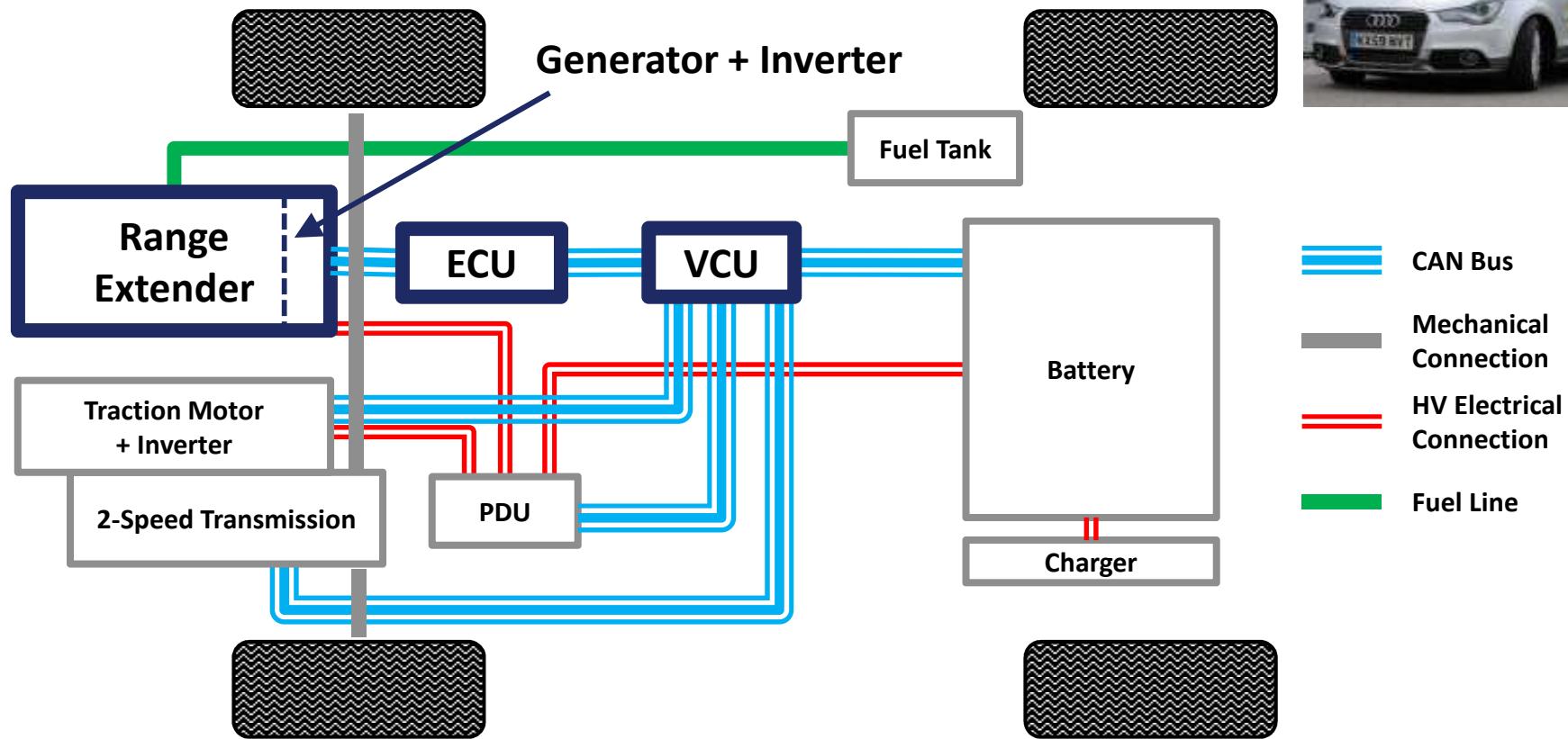


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ECU: Engine Control Unit, VCU: Vehicle Control Unit, PDU: Power Distribution Unit

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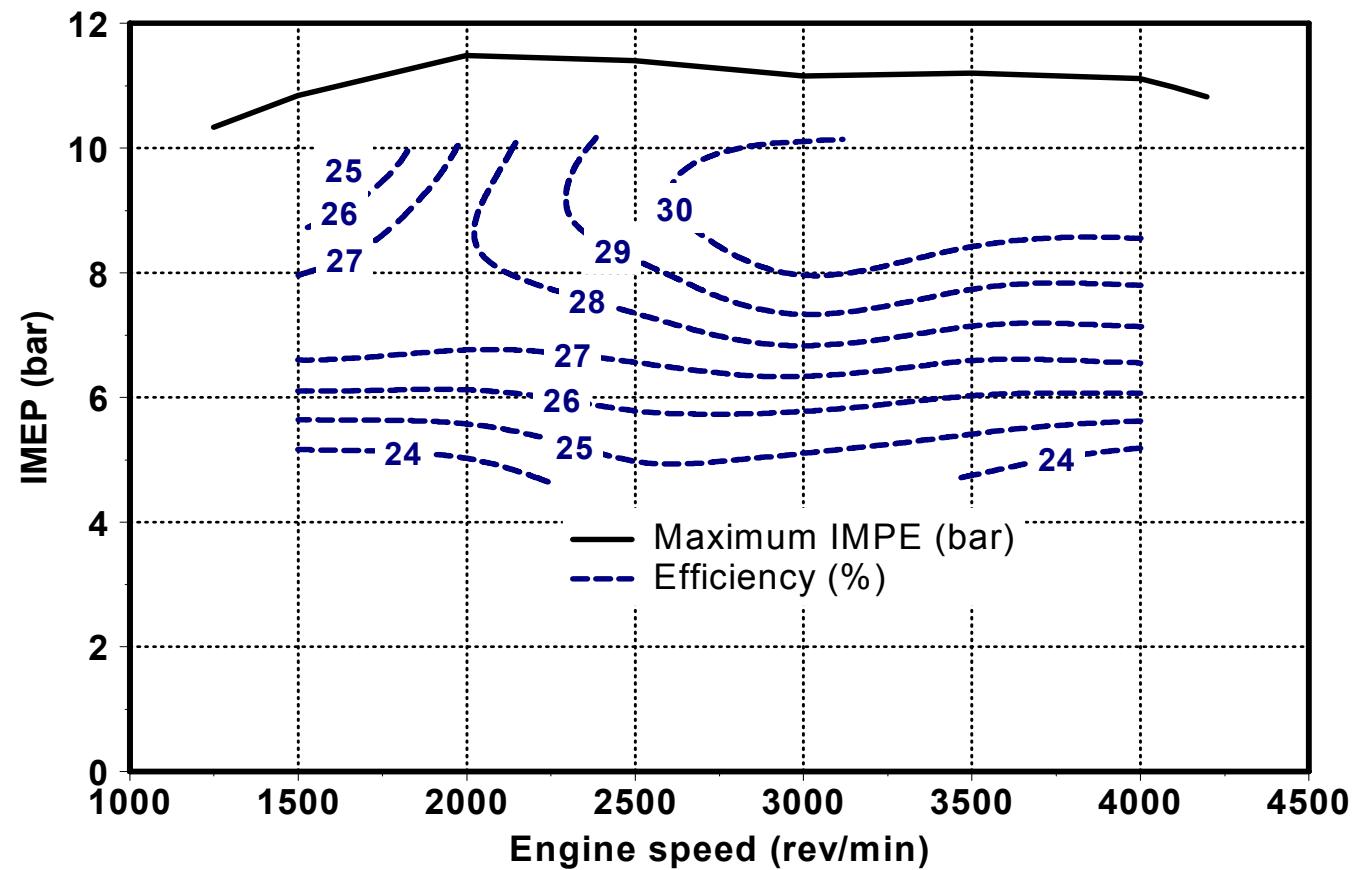
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- REx Efficiency



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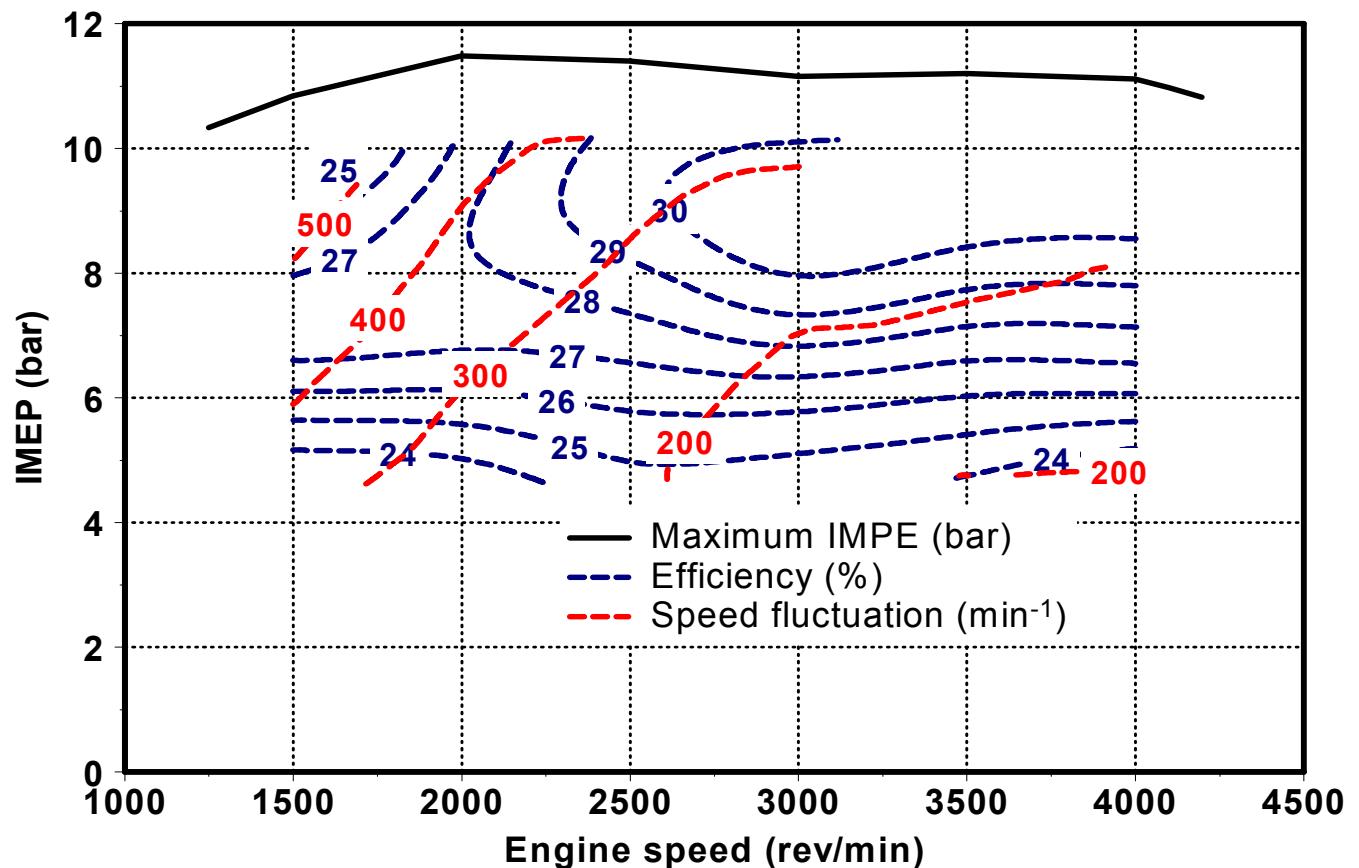
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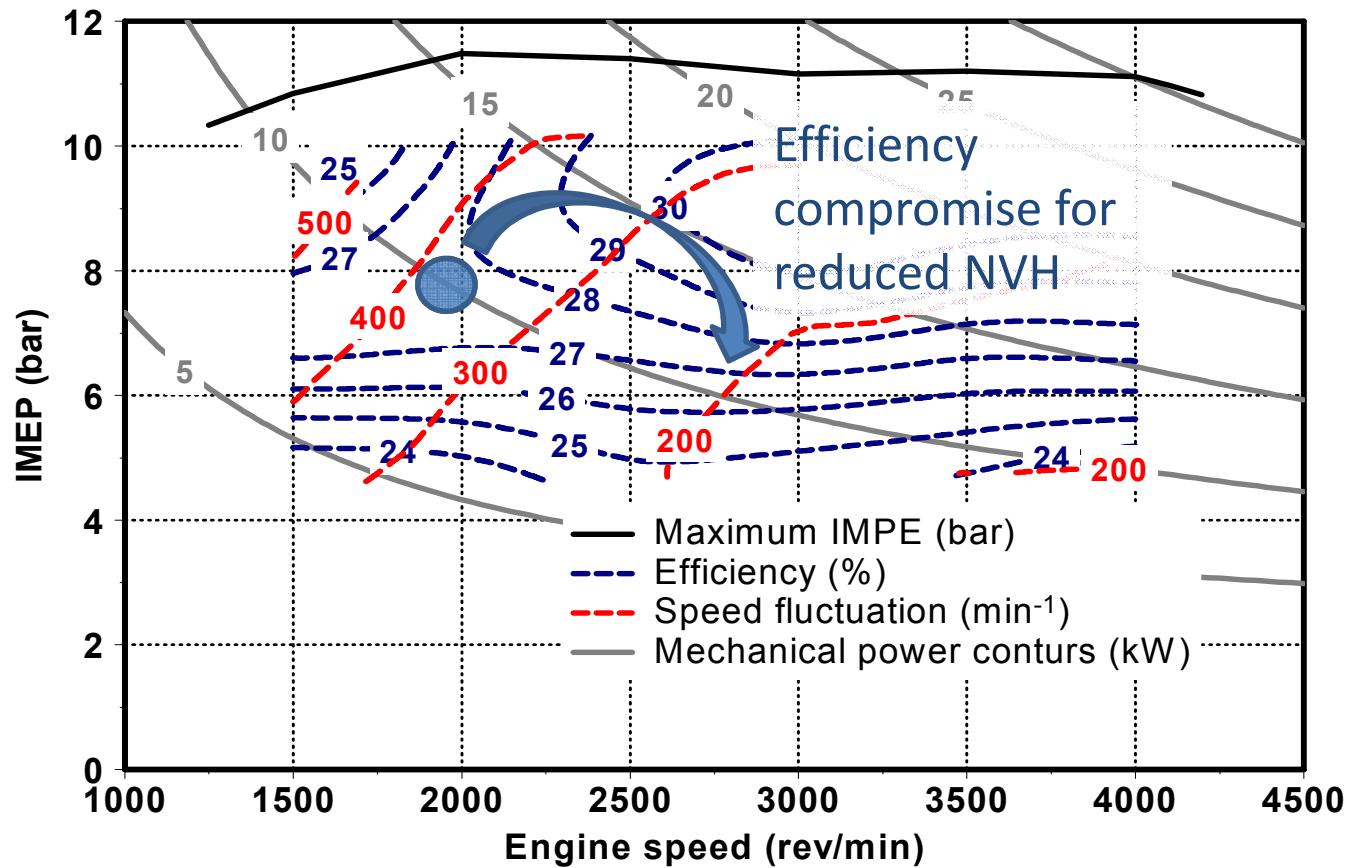
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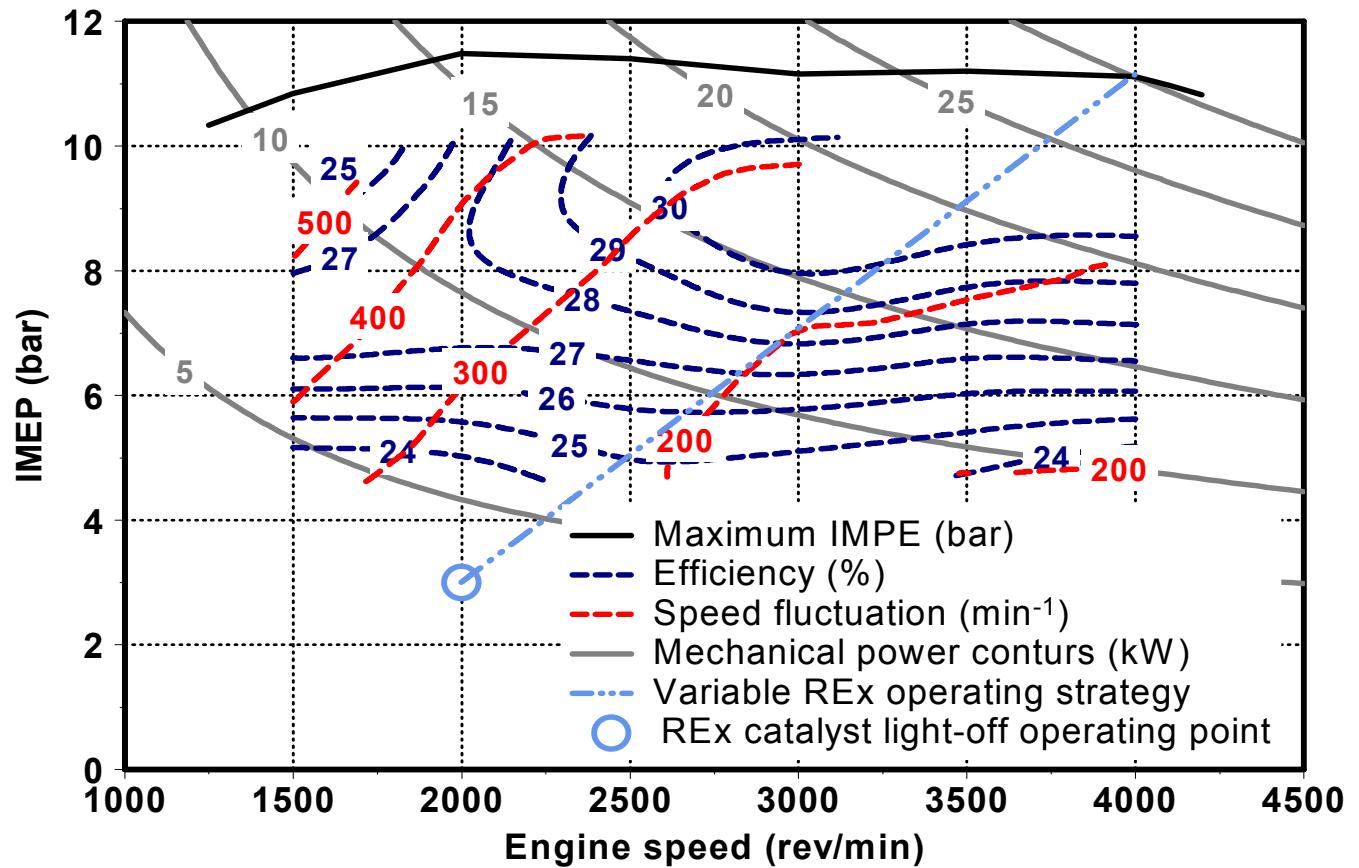
- REx Efficiency
- NVH
 - Speed fluctuations



- REx Efficiency
- NVH
 - Speed fluctuations



- REx Efficiency
- NVH
 - Speed fluctuations
- Operating line of best compromise



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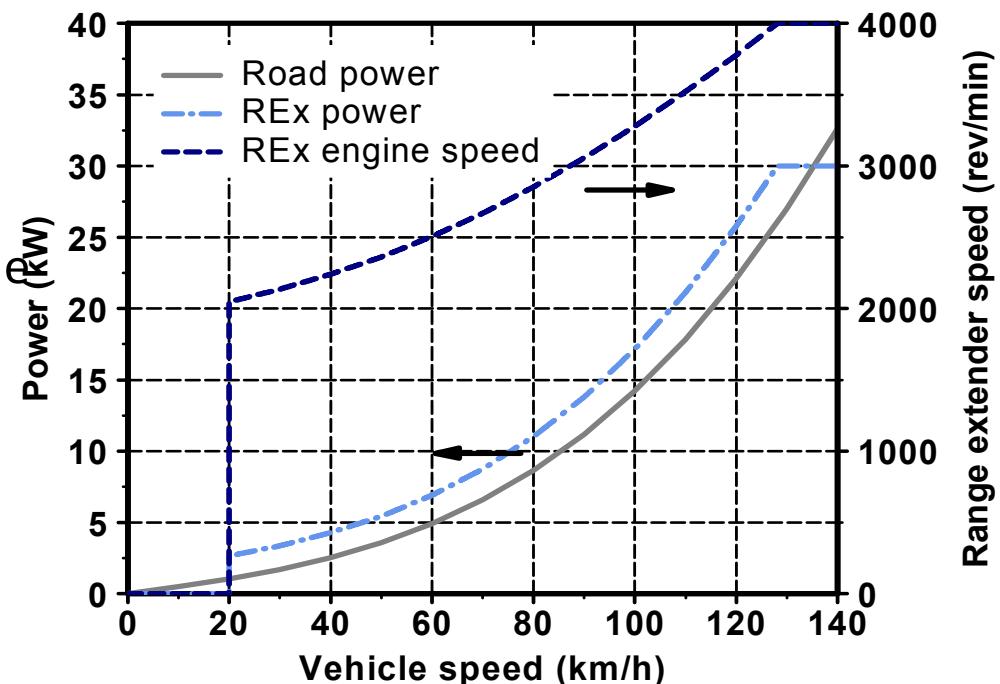
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- Deplete battery
 - Maximise EV range
- Load follow
 - SOC sustaining
 - Engine speed/load follows vehicle speed
 - Minimise noise and fuel consumption
 - Vehicle noise masks REx
- REx off at low vehicle speeds
 - Unless SOC critically low

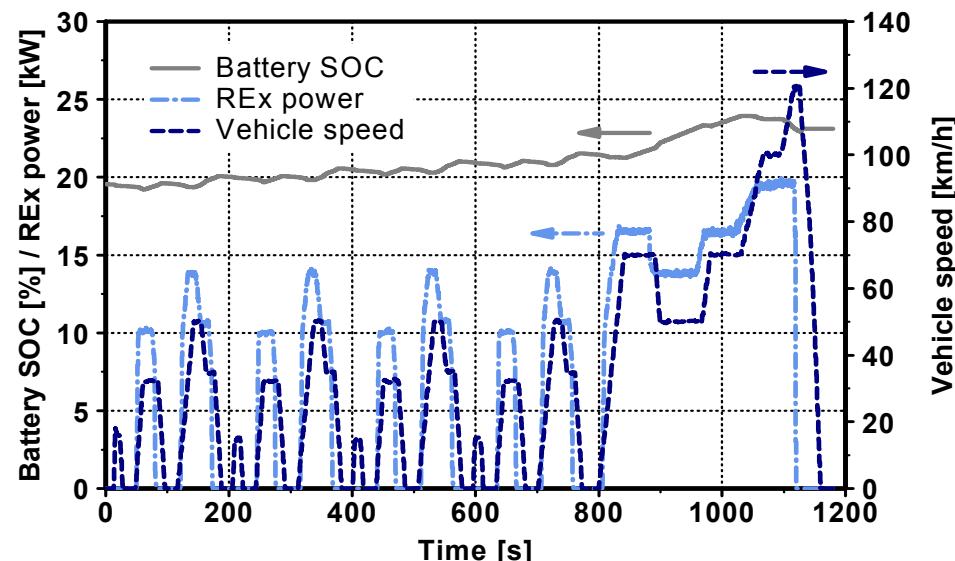


- Depleted battery test conducted
 - Some recharging of battery occurred
 - Strategy could be further refined
- R101 CO₂ 42 g/km

67 km EV range

430 km Extended range

~500 km Combined range



REx operation and battery SOC during NEDC test

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- Compact and light weight REx unit developed
- Plug-in series hybrid drive train system integration and vehicle conversion
- Fully-fledged B-segment REEV demonstrator vehicle with 500 km range and 42 g/km CO₂



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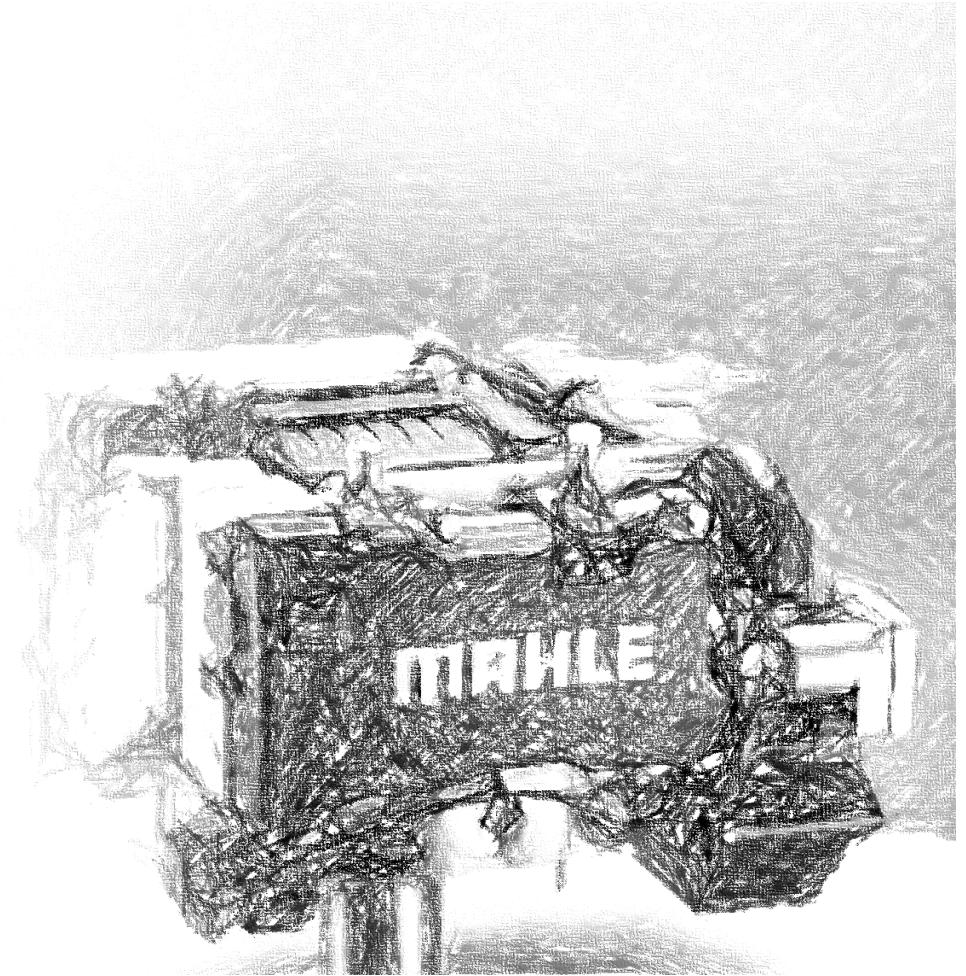


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