Development of a Low Cost Auxiliary Power Unit for Range Extended Electric Vehicles

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Project Background

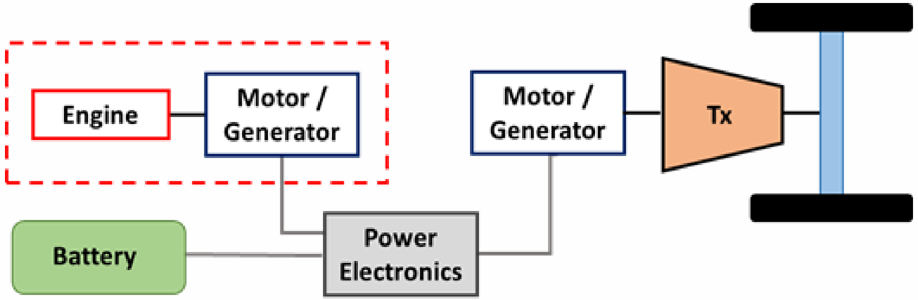
- Objective – Concept demonstration (TRL 4) of a low cost auxiliary power unit suitable for range extended electric vehicles
- Project commenced October 2013, funding support by Innovate UK
- Partners;
  - Ashwoods Automotive Ltd
  - University of Bath
  - Tata Motors European Technical Centre (TMETC)
- Due for completion June 2016

Range Extended Electric Vehicles (REEV)

- Ultimately an ‘electric engine’ (or E-drive) will provide tractive drive for passenger vehicles
  - Driving characteristics are suited to Indian market requirements
  - Indian government encouraging development of electrified vehicles
  - CAFE and BS-VI emission from 2020

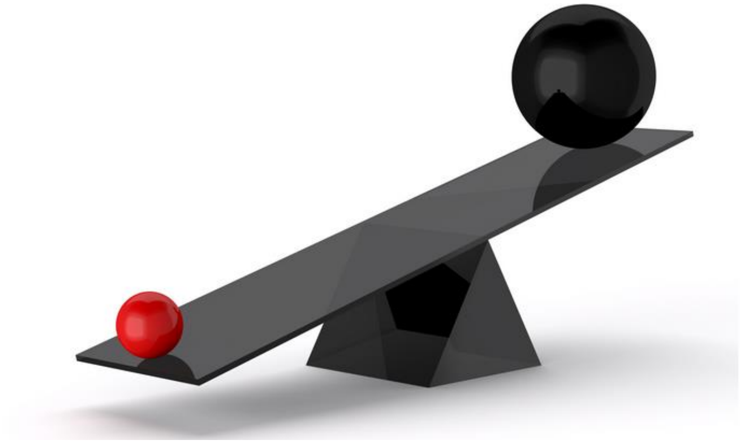
- Battery cost, weight, package and charging time / infrastructure are major challenges still to be overcome

- Range extension via use of an on-board Auxiliary Power Unit (APU) is an attractive solution
  - Series hybrid efficiency suited to low speed transient cycles
  - Single vehicle solution possible
  - Reduced dependency on charging infrastructure



APU Requirements

- For a REEV, the APU is expected to be used << 20% of vehicle life
  - Balance of ‘Cost vs. Efficiency’ is shifted towards low cost, rather than highest efficiency
  - Use of a current production engine becomes favourable over a new (low volume) development



- Charge sustaining performance
  - The APU should deliver sufficient electrical power to enable continuous vehicle operation on the highway (a full capability REEV)
  - Target B-segment vehicle showed this to be in the range of 15 - 30 kW (100 – 120 kph, with / without A/C)

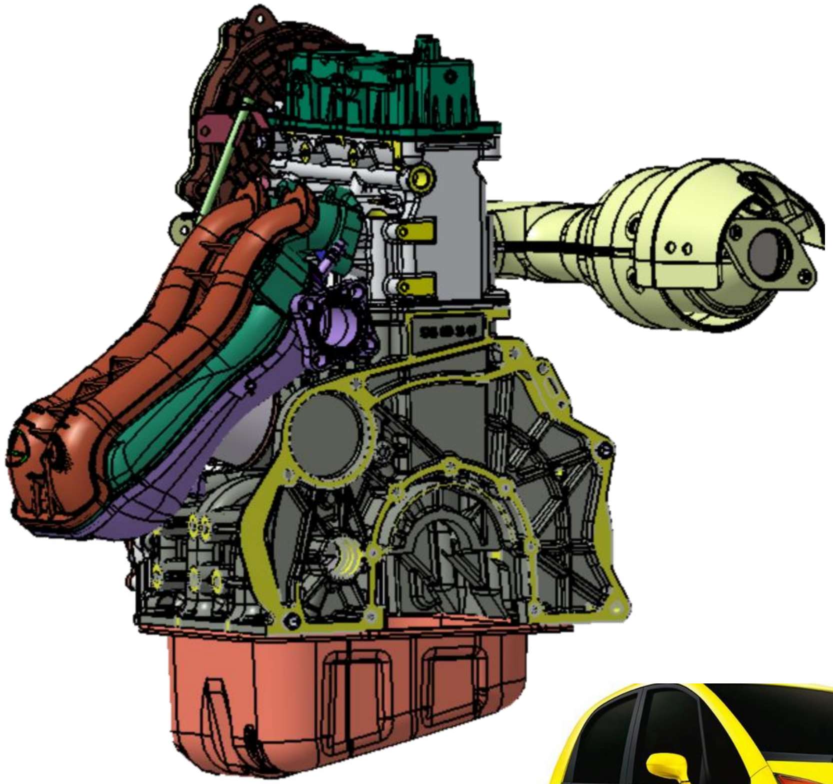
  - Target APU performance: 20 – 25 kW (electrical power)

Contents

Engine

- 2-cylinder 624cc PFI Gasoline engine (Nano, rear engine)
- Inherently low cost (small, simple, made in India)
- Maximum power output compatible with APU performance requirement

Displaced volume	624 cc
Bore / Stroke	73.5 mm * 73.5 mm
Compression ratio	10.3:1
Maximum power	37 bhp [28 kW] @ 5500 RPM
Maximum torque	51 Nm @ 4000 RPM
Firing order	1 - 2 (360° firing)
Valvetrain	2 v/cyl. SOHC
Fuel System	Sequential PFI



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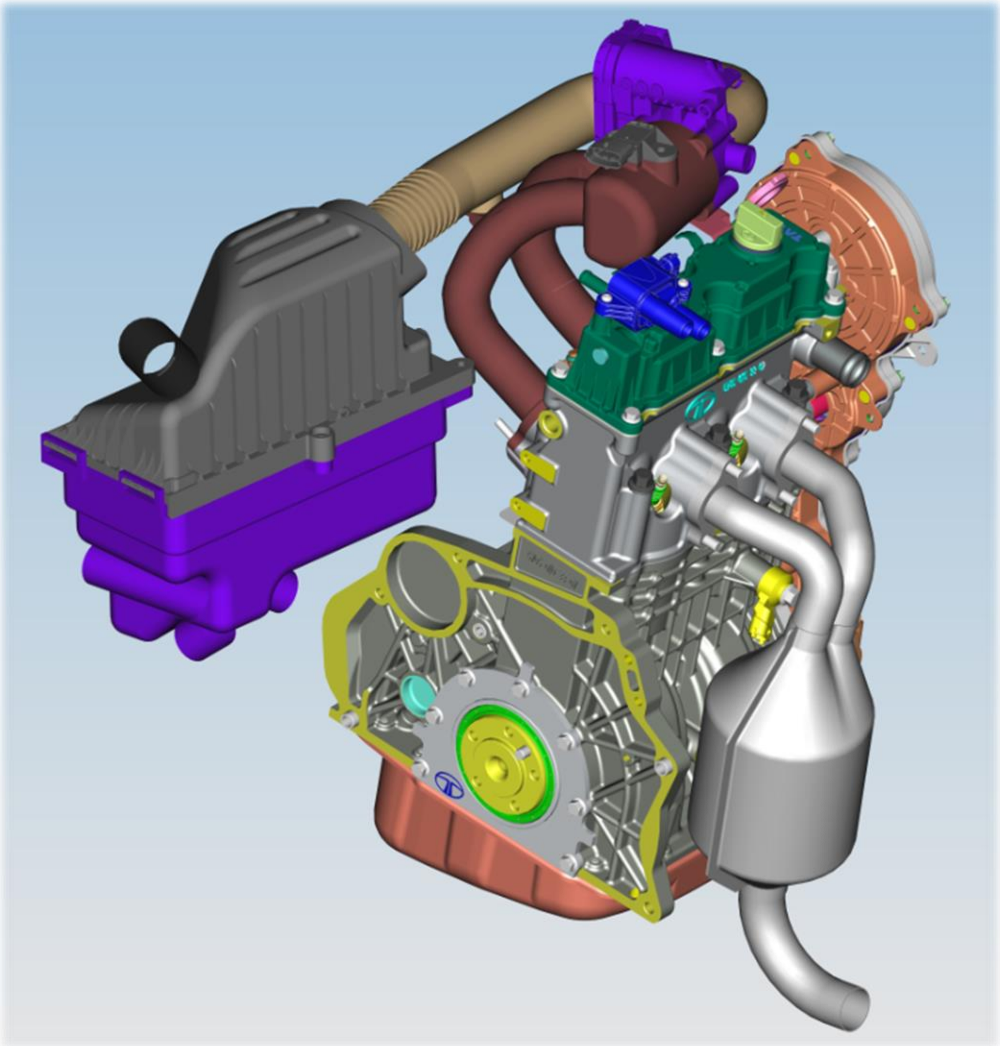
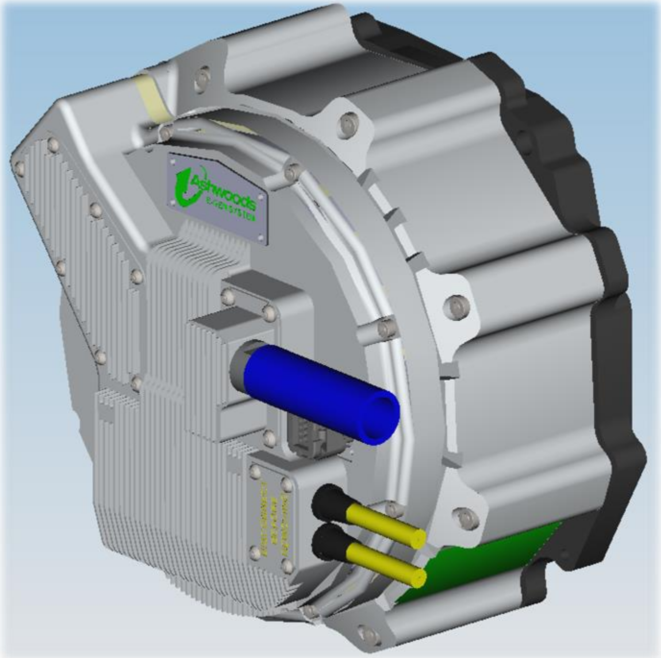
- Intake and exhaust manifolds re-designed to improve vehicle package and performance within APU operating range (2000 - 5000 rpm)



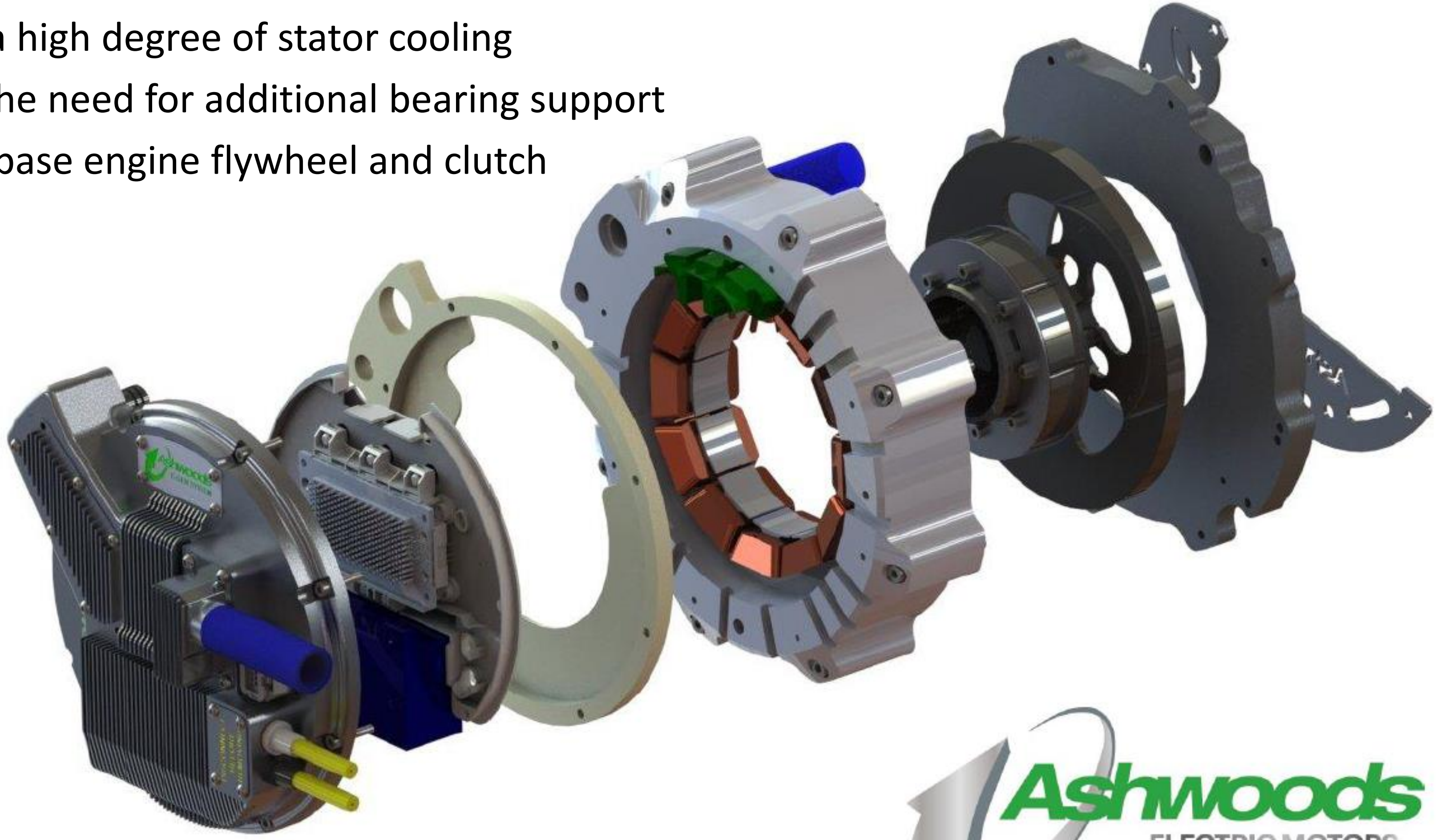
Generator

- Integrated generator & inverter designed by Ashwoods Automotive
- 350V – 450V operating range
- High temperature operation (facilitating shared cooling circuit with engine)
- Maximum continuous performance & peak efficiency location matched to APU performance requirement
- Peak performance to deliver engine cranking during cold start (-25 ^{o}C)

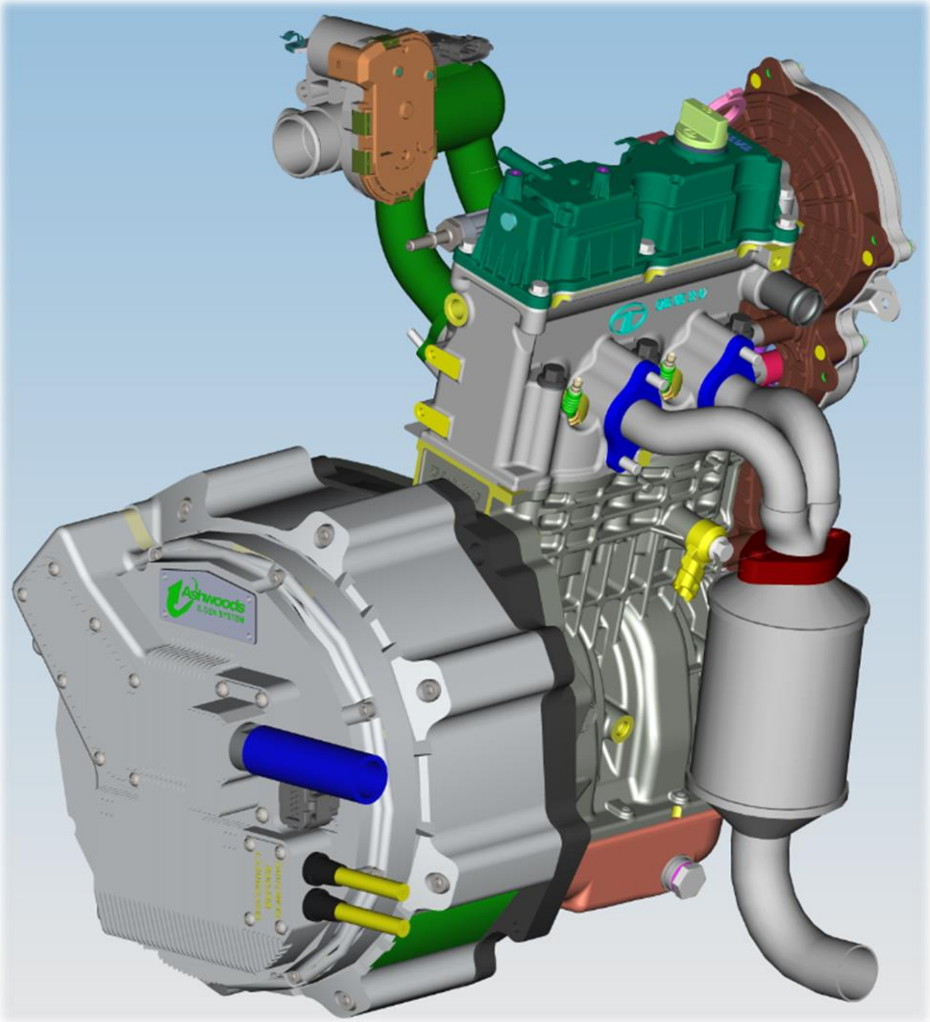


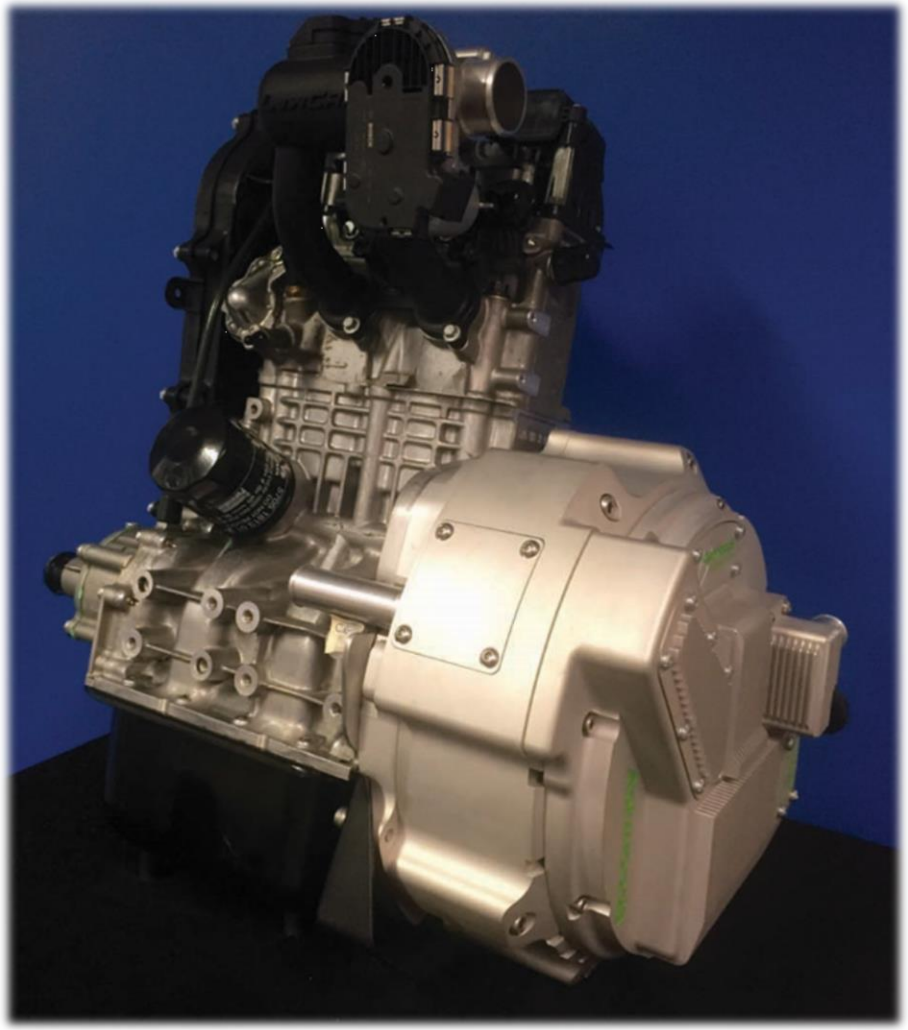
Generator

- Inner rotor topology, facilitating a high degree of stator cooling
- Direct rotor coupling, removing the need for additional bearing support
- Rotor system inertia matched to base engine flywheel and clutch



Auxiliary Power Unit





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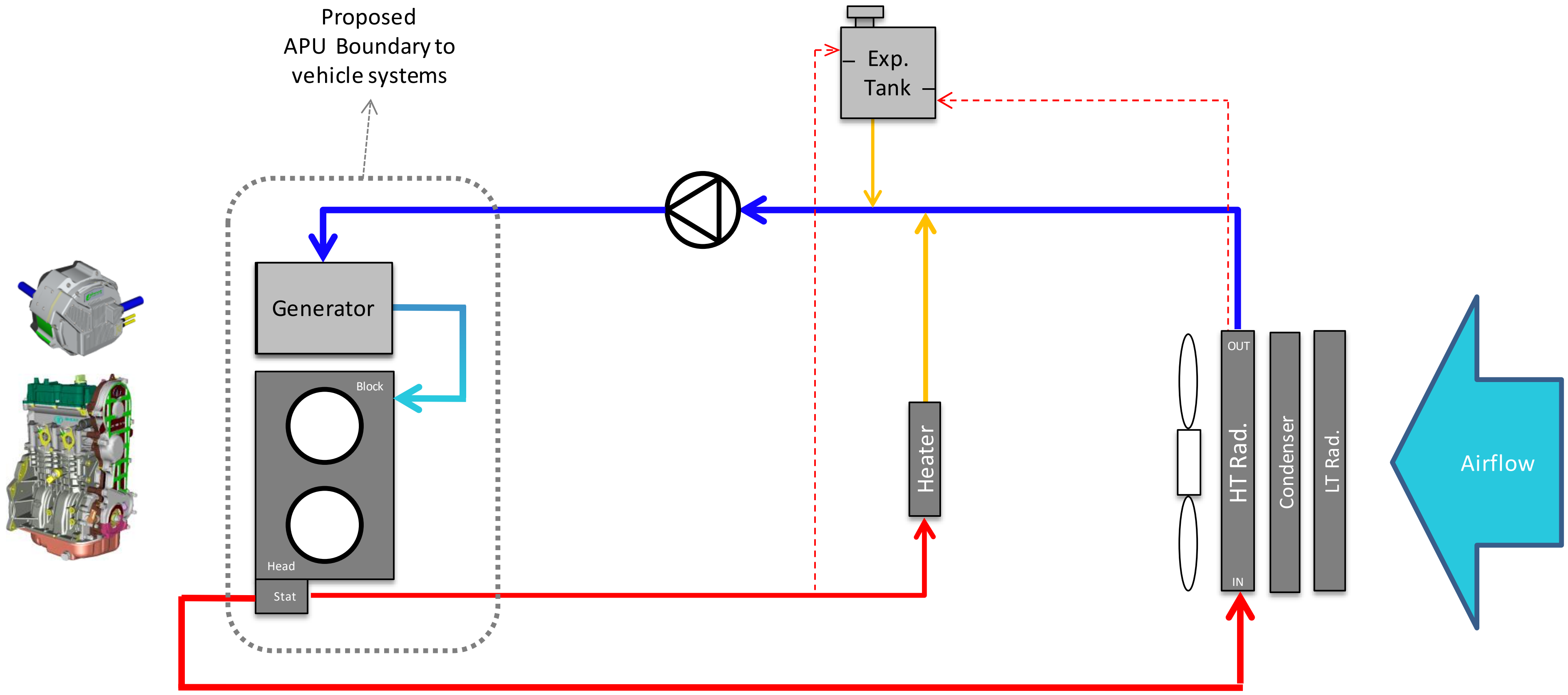
- Project Background and APU Requirements
- Engine, Generator and APU Details
- Results from Testing
- Summary

Results: High Temperature Performance

- A combined, high temperature, cooling circuit was proposed for the APU in order to simplify vehicle integration



Results: High Temperature Performance

- Cooling circuit operating temperature was determined by considering generator performance, radiator heat rejection and engine efficiency

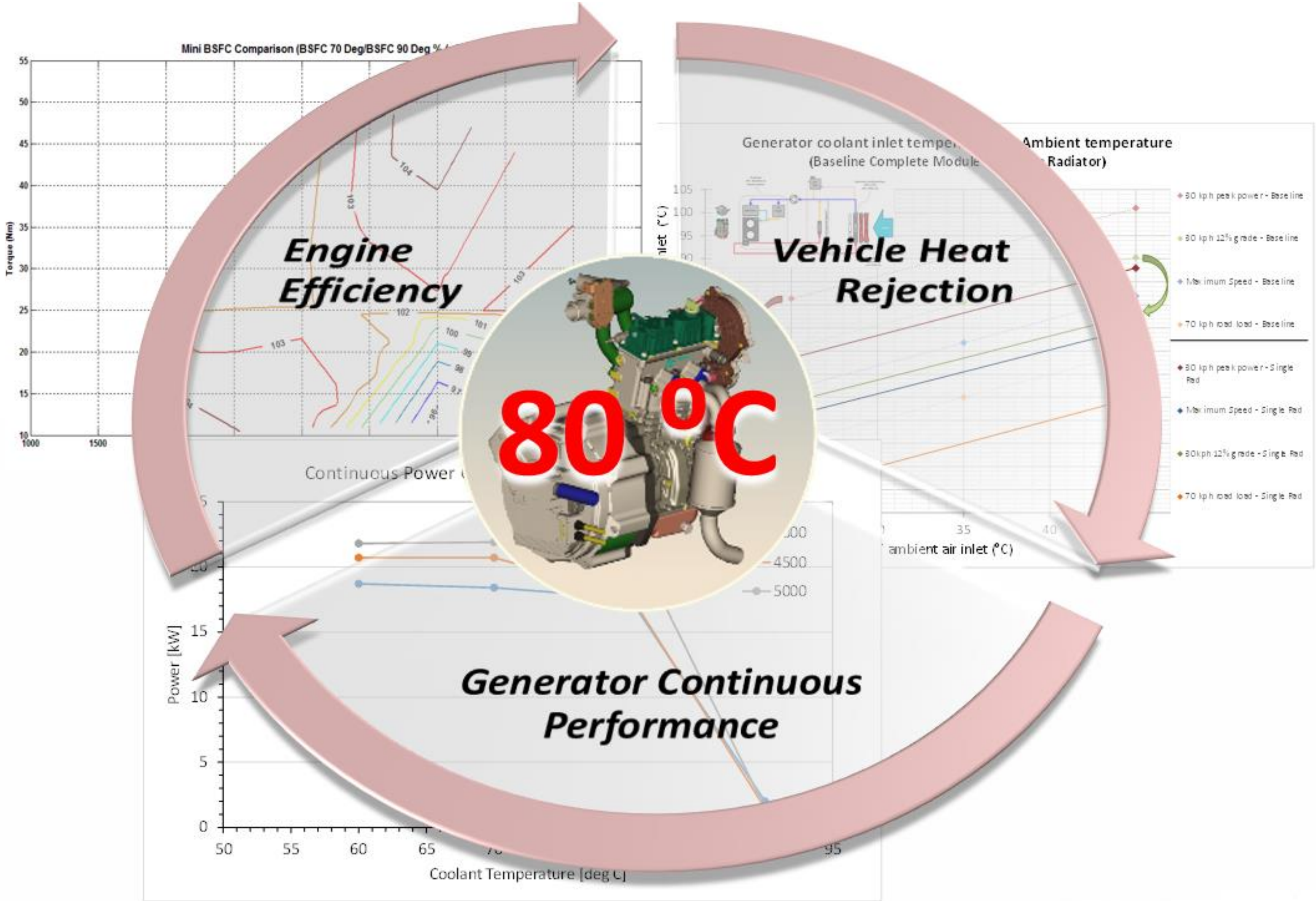
Radiator Heat Rejection

Engine Efficiency

90 ºC

Generator Continuous Performance

50 ºC

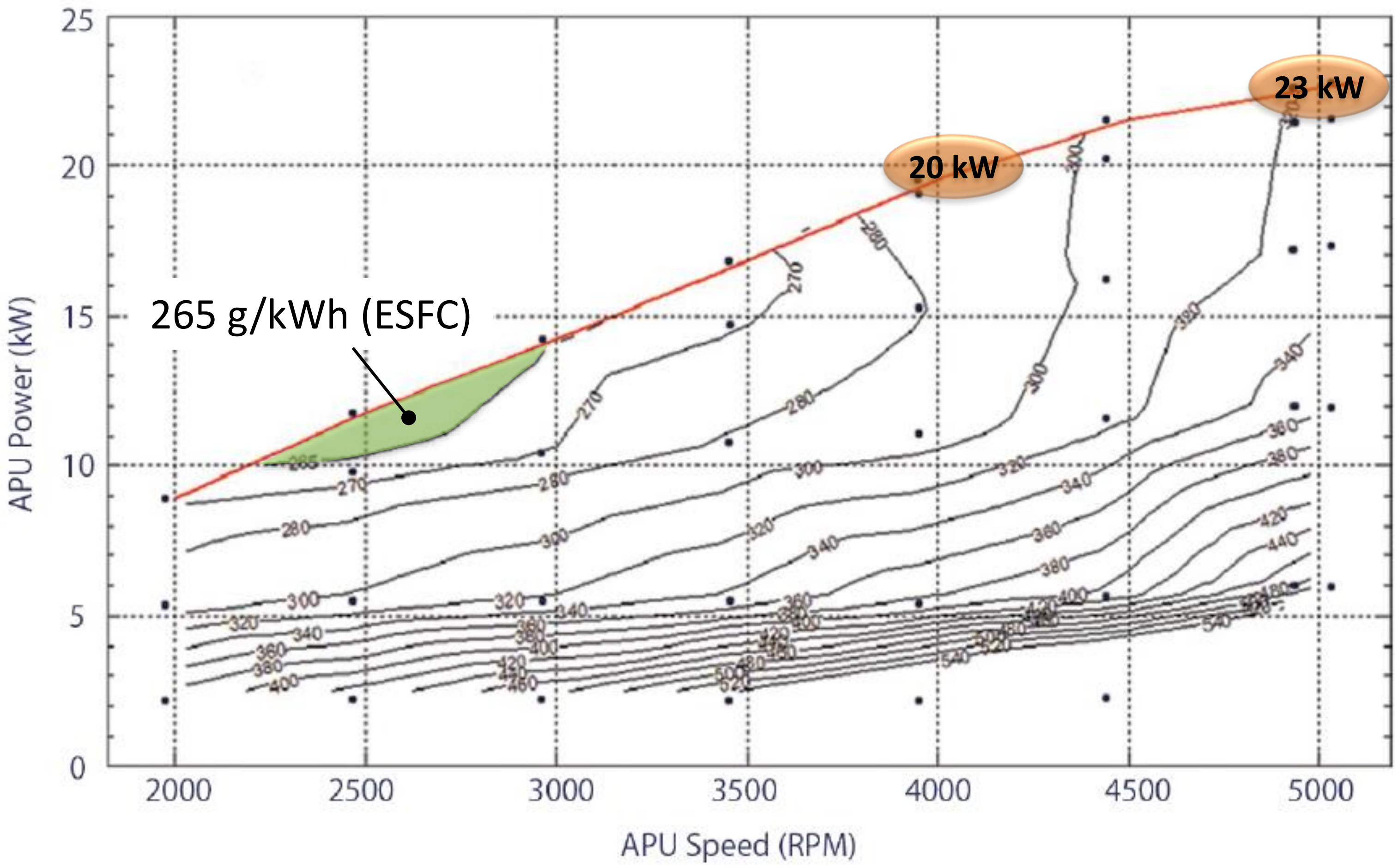


Results: Performance and Efficiency

- Electrical power output (80 °C continuous)
  - 20 kW @ 4,000rpm
  - 23 kW @ 5,000rpm

- Minimum Electrical Specific Fuel Consumption (ESFC) 265 g/kWh @ 2,500rpm (10 kW)
  - c.240 g/kWh BSFC
  - c.90% Electrical Efficiency

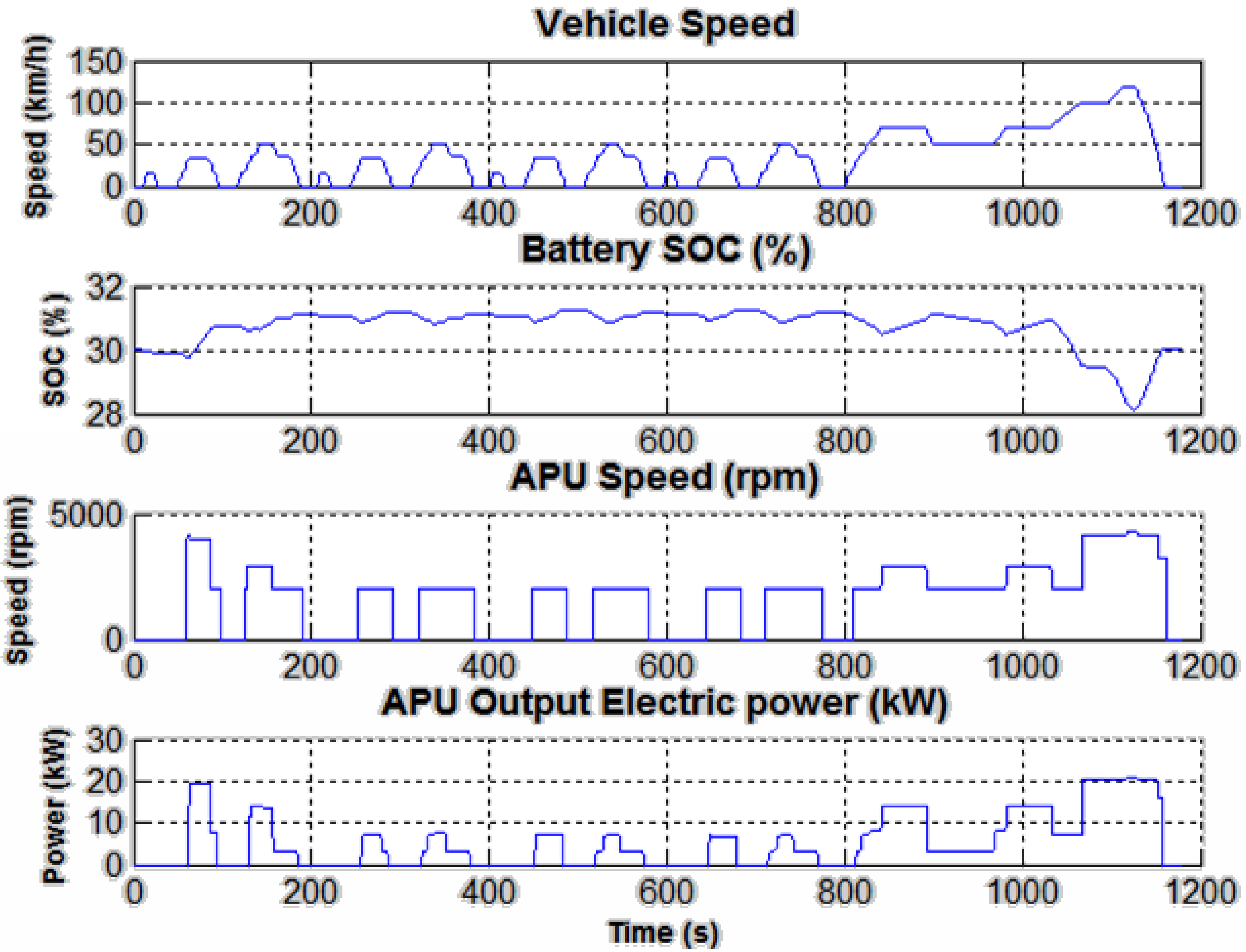
LowCAP ESFC Map



Results: Fuel Economy / Duty Cycle

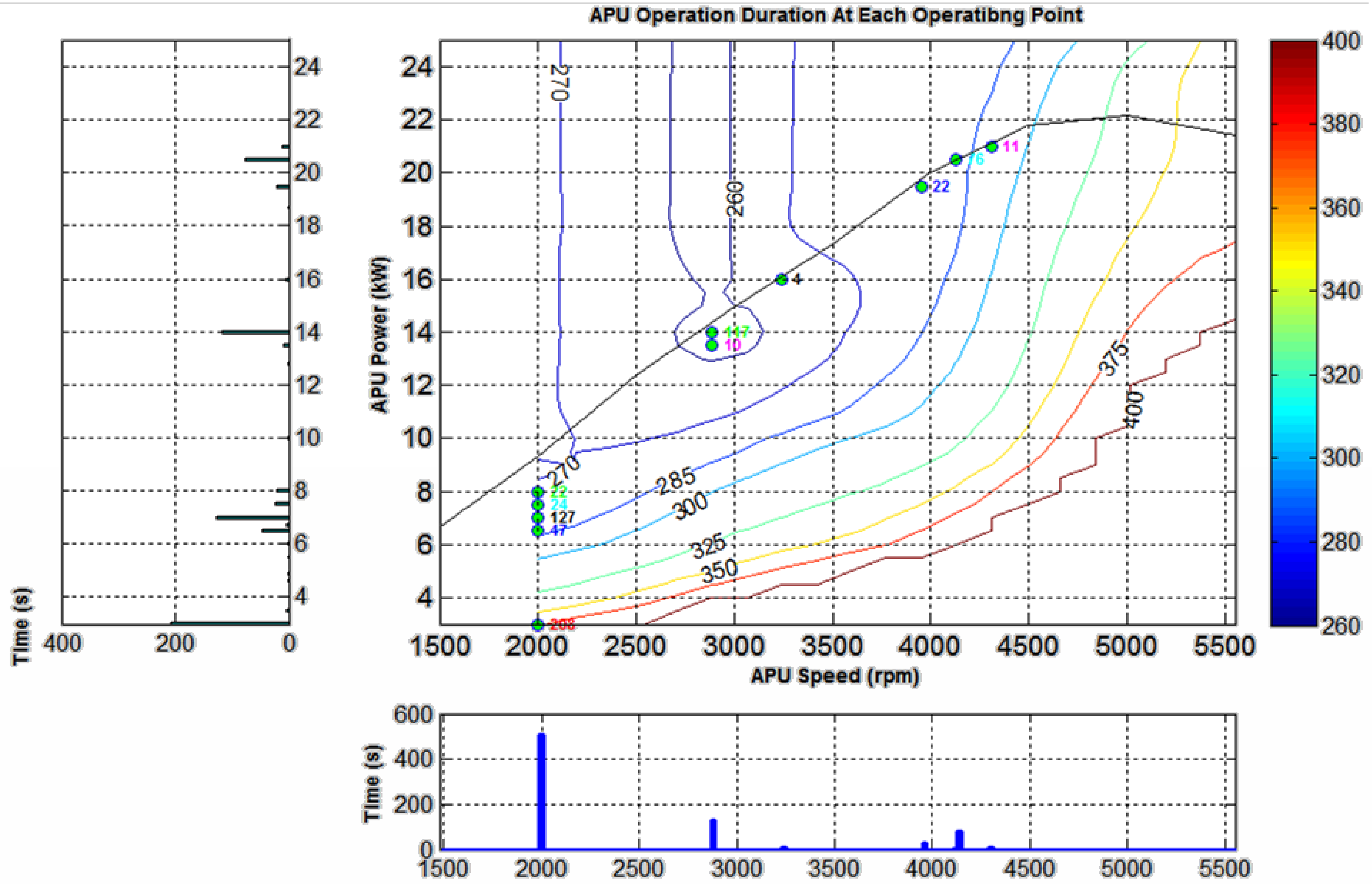
- Drive cycle analysis completed for representative B-segment vehicle to determine
  - Fuel consumption performance
  - APU duty cycle

- APU ran in charge sustaining mode using real time ‘Adaptive Equivalence Consumption Minimization Strategy’ (A-ECMS)
  - Real-time optimisation strategy
  - Considering (for example) noise, fuel economy, emissions



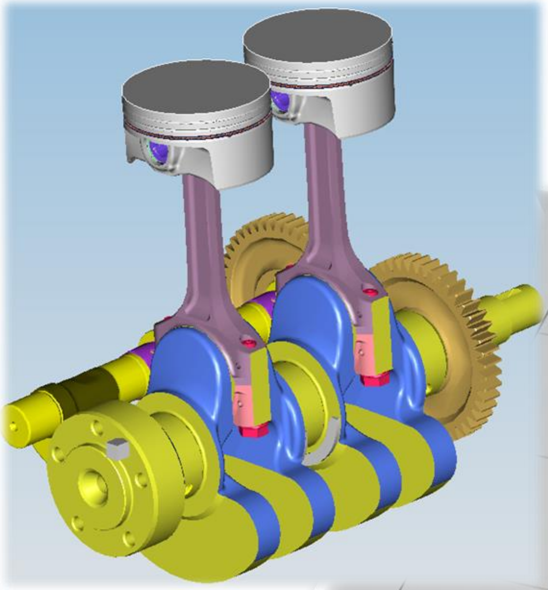
Results: Fuel Economy / Duty Cycle

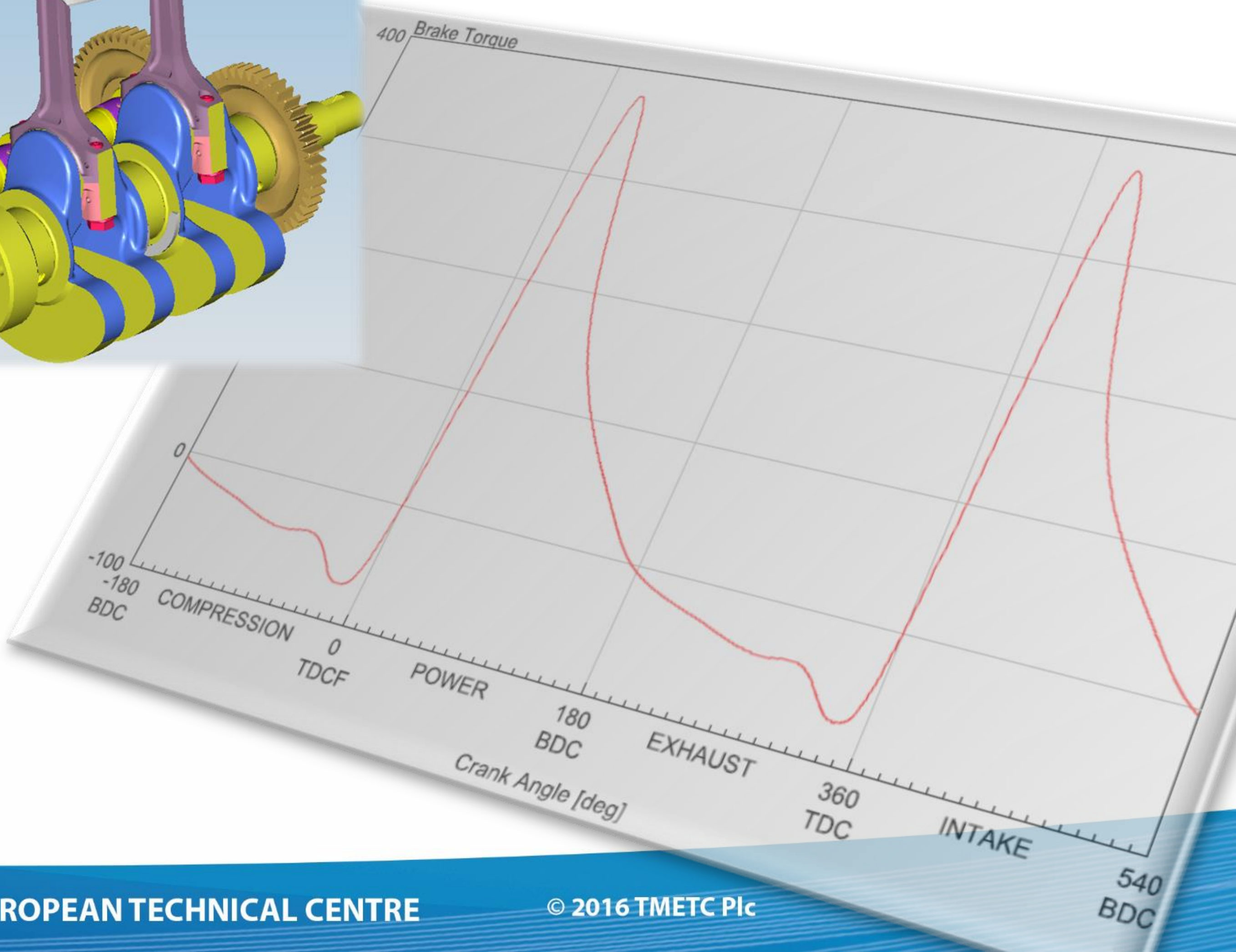
- Drive cycle fuel consumption in charge sustaining mode ~ 17 km/l (~ 140 g/km)
- R101 calculation < 40 g/km with 65 km EV range (~ 15 kWh battery)
- Fuel economy optimised duty cycle shows significant operation at
  - 7 kW @ 2000rpm (min. operating speed)
  - 14 kW @ 2900rpm (point of best ESFC)
  - 21 kW @ 4200rpm (higher power)



Results: In-cycle Speed Fluctuation

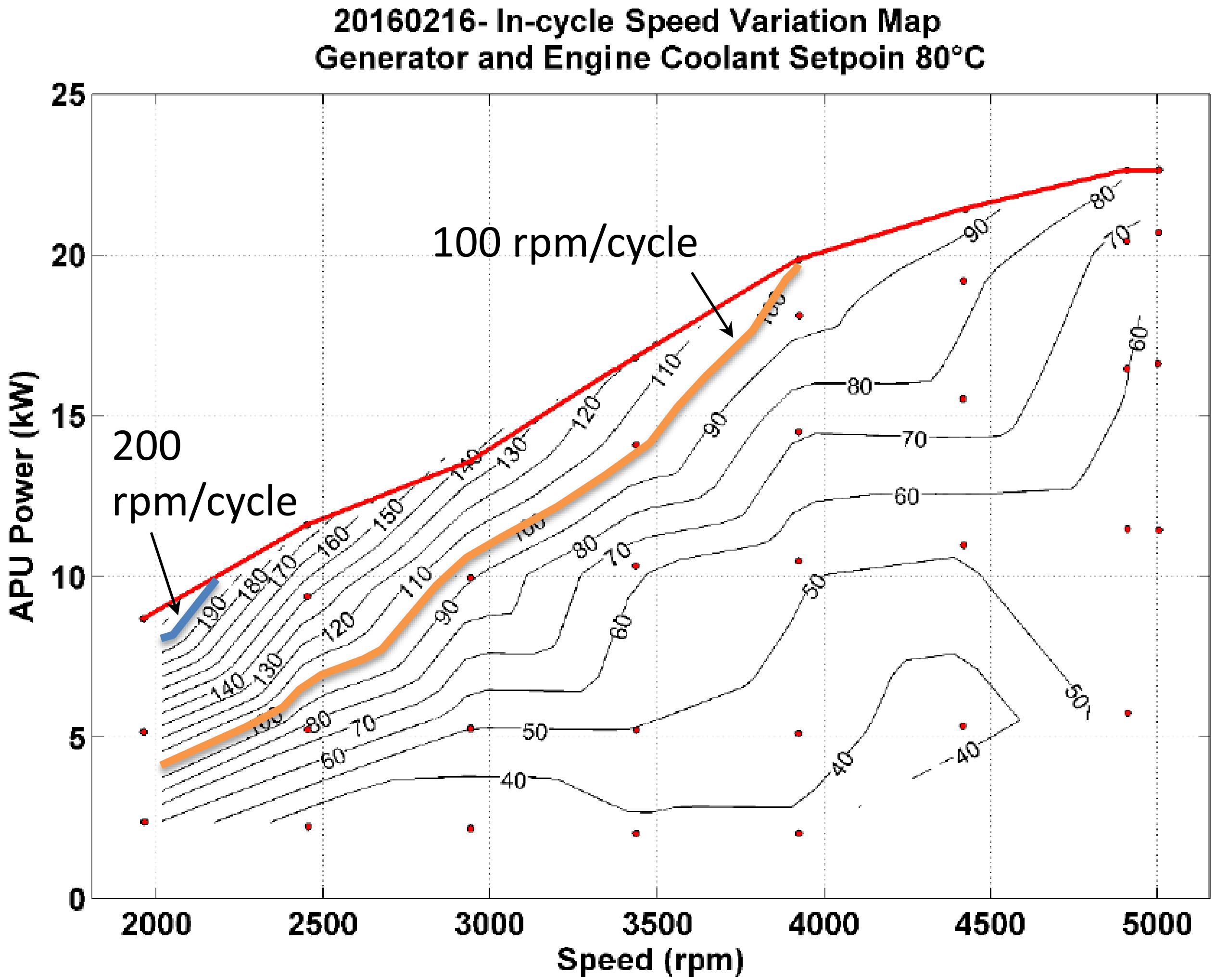
- Reducing in-cycle speed fluctuation is desirable from NVH perspective
- Minimised through a relatively high-inertia rotor system
- In-cycle generator torque control (Dynamic Torque Control) provides an opportunity to reduce further





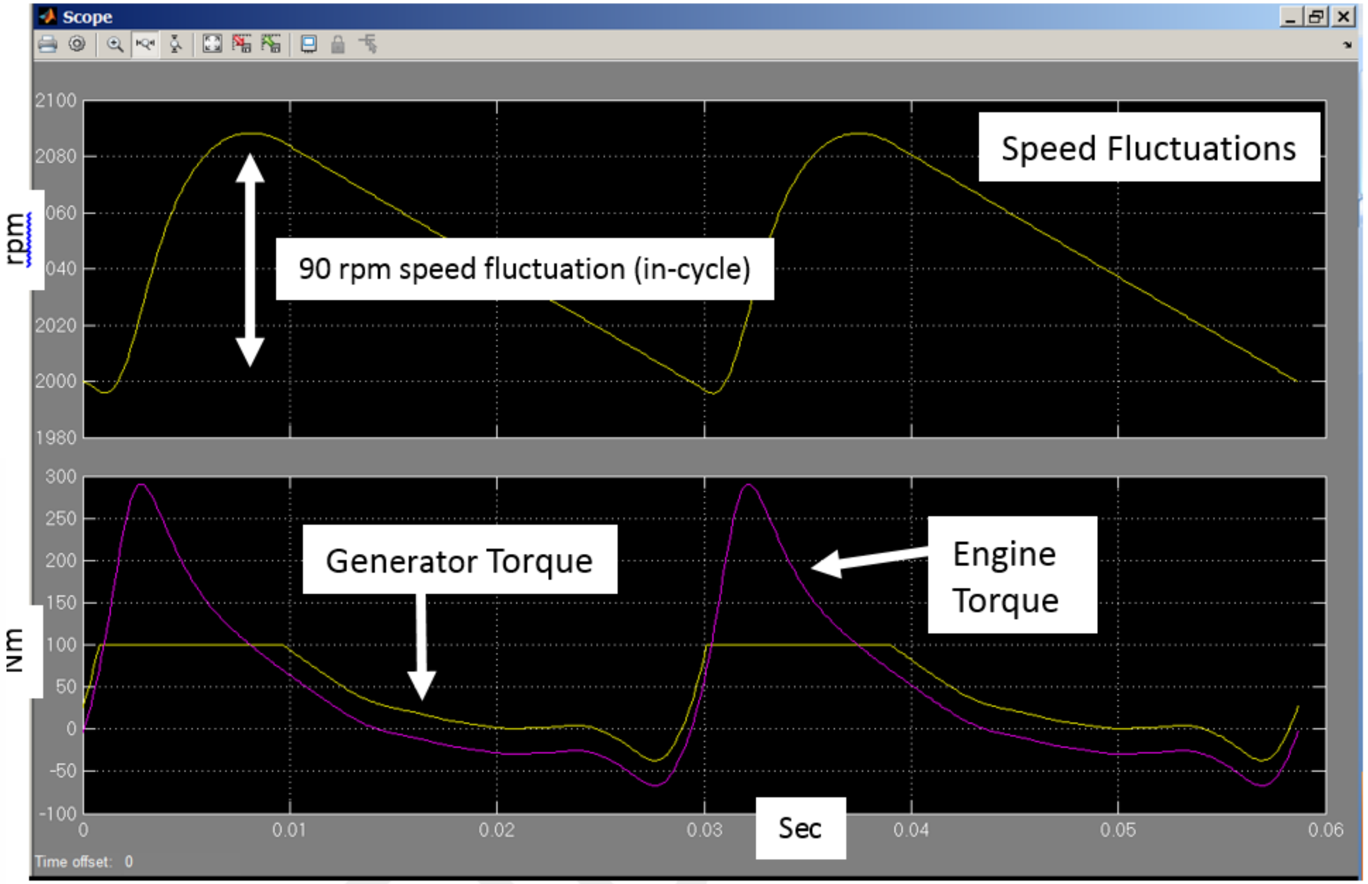
Results: In-cycle Speed Fluctuation

- Measured data (without Dynamic Torque Control)
  - Up to 200 rpm (within cycle) at 2000 rpm
  - Up to 100 rpm (within cycle) at 4000 rpm



Results: In-cycle Speed Fluctuation

- Measured data (without Dynamic Torque Control)
  - Up to 200 rpm (within cycle) at 2000 rpm
  - Up to 100 rpm (within cycle) at 4000 rpm
- Modelling used to demonstrate expected reduction via use of Dynamic Torque Control (within generator performance limits)
- Worse case speed fluctuation expected to be reduced to <100 rpm
- Test results are pending, including consideration for generator thermal performance and implications for current ripple on HV bus



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Summary

LowCAP – Low Cost Auxiliary Power Unit

- Tata Motors 2-Cylinder 624cc Gasoline Engine
- Integrated Ashwoods Generator & Power Electronics
- Maximum power:
  20 kW @ 4000rpm
  23 kW @ 5000rpm
- Minimum ESFC:
  265 g/kWh @ 2500rpm (10 kW)
- Mass (dry): 81.5kg (prototype)
- Operating voltage: 350-450V

Project co-funded by

Innovate UK

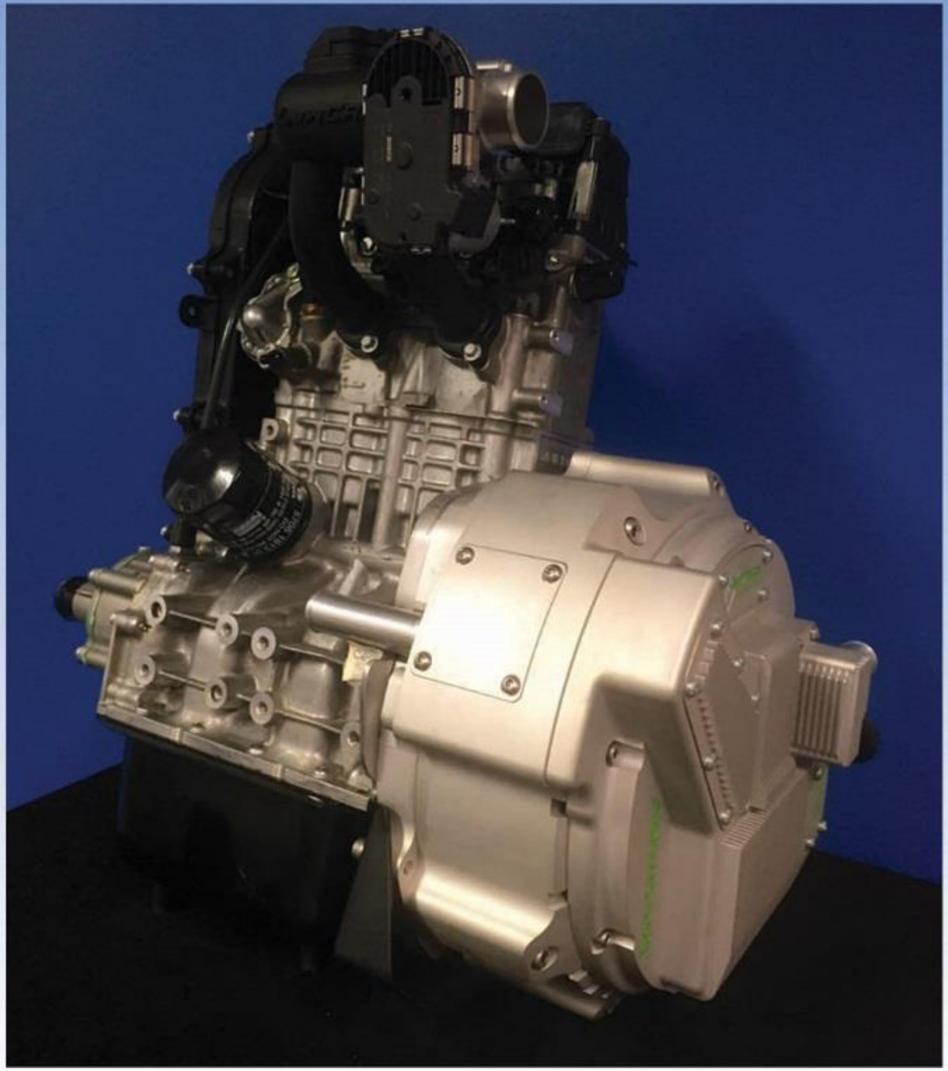
Project partners

Ashwoods ELECTRIC MOTORS

UNIVERSITY OF BATH

TATA

TATA MOTORS EUROPEAN TECHNICAL CENTRE



Thank You