SuperGen – Novel low cost electro-mechanical mild hybrid and boosting system

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• Quick overview of Integral Powertrain
• Supergen Concept
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• Test results from UltraBoost engine
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• Summary
Integral Powertrain

**Overview**
- UK-based powertrain engineering consultancy
- Founded in 1998 by the former Cosworth engineering management team
- ~170 engineering staff

**Core Business**
- Powertrain and controls engineering
- E-Drive Systems engineering & manufacture
- JV business with Magna (high volume industrialisation of SuperGen)

**Innovation**
- Electric machines and hybrid drives
- Boosting and turbo-compounding

**Facilities**
- Engineering Centre and low volume E-Motor manufacturing, Bletchley, Milton Keynes
- Emissions and Climatic Test Centre, Kiln Farm, Milton Keynes
- JV company location in Tanners Drive, Milton Keynes
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• **E1** is connected to the input and drives the **annulus** of the traction drive
• **E2** is connected to the **planet carrier** of the traction drive
• **Compressor input** shaft is connected to the **sun wheel**
• Therefore the **speed of E2 modifies the speed of the compressor**
• **E1 and E2 can be clutched together** for stop-start, mild hybridization
• **System replaces the alternator** and is **voltage agnostic**
SuperGen operating functions

- **Mild hybridization**
  - Stop/start, torque assist, anti-stall and other mild hybrid functions
  - Maximum brake energy recuperation between 4 and 17 kW depending on version

- **Boosting system**
  - Independent of the vehicle battery (self-sustaining) - capable of continuous operation
  - Traction drive planetary transmission – roller bearing technology without gear teeth
    - Planetary ratio, Annulus/Sun, R 10:1, belt ratio typically R2 ~ 3.5
    - Input power can split between the mechanical and electrical paths
    - Transmission is more electrical at low speeds, tending to 100% mechanical at higher speeds
  - Steady-state boost is unaffected by a depleted battery
  - Higher boost performance and self-sustaining for less system cost
    - System capable of up to 15 kW boost at 12 V
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SuperGen fuel economy analysis – baseline assumptions

**Base vehicle**
- SUV, ~1750kg Kerb Weight
- 2.0L DI VVT W/G T/C ~100kW/L gasoline engine
- 8/9-speed transmission, Stop-start as standard
- NEDC cycle, CO₂ = 163g/km

**SuperGen system added to 2.0L baseline in the high-pressure (HP) position after LP turbocharger. Analysis conducted to investigate SuperGen benefits from:**
- Stop-start as per baseline system (no change to CO₂ but more refined)
- Further down-speeding by 20%
- Hybrid functions (i.e., regenerative braking and torque assist) between 6kW and 10kW for 14V, 14kW and 17kW for 48V
- Supporting advanced combustion strategies i.e.. Miller cycle (early or late IVC), Dilute-Homogenous, Stratified-Lean Burn
- Extending down-sizing even further
Baseline Engine Results

- Results summary for baseline combustion system
- Down-speeding benefit 8.2g/km (5%) due to longer gearing
- Regenerative braking benefit at 6kW is an additional 7g/km (4.3%)
- Further reductions with increased power capability are limited by available energy after road-load, aerodynamic drag, engine friction and other driveline drag losses
- 8kW 8.1g/km (5.0%), 10kW 8.9g/km (5.5%), 14kW 9.6g/km (5.9%), 17kW 10.2g/km (6.2%)

Summary

- 14V SuperGen on ‘standard’ 2.0L engine can deliver up to -10.5% CO₂, +12% on mpg
Advanced Combustion Strategies Interactions & System Simulation Results

- Utilise the Miller-cycle and/or advanced charge motion and EGR to extend knock limit (CR increase), reduce pumping and heat-rejection losses and therefore achieve higher cycle efficiency
- Most strategies not suited to pure turbocharged system due to the conflict between available exhaust enthalpy, compressor and turbine match and combustion requirements
  - ‘Basic’ Miller-Cycle with increased compression ratio and three-way catalyst – 5%
  - Dilute homogenous mode with high EGR but Lambda=1 overall – 8%
  - Lean homogenous mode with EGR and true lean operation - LNT required for highest gains - 12%
  - Overall results with SuperGen, down-speeding and regen ranged from 15-22%

Future Stretch Opportunity to Down-size to >130kW/L

- Results have indicated potential to down-sizing to over 130kW/L
- Down-sizing to 1.6L vs. 2.0L reduces CO₂ by further 9g/km (5%)
- 14V SuperGen with conventional engine can deliver up to -16% CO₂, +19% on mpg
- With adv. combustion system this extends to -26% CO₂ or +35% on mpg
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2500rpm Torque Response on UltraBoost engine

At 2500 rpm, the target full-load performance is 478 Nm.
With SuperGen, 10-90TTT is <1.2 s.

2500 rpm runs with and without SuperGen

- 2500 rpm Turbo Only
- 2500 rpm Turbo plus SuperGen
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## Automotive Council technology APS roadmap alignment

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• **Summary**
• SuperGen can provide class leading mild hybrid capability with peak recuperation power potentially approaching 20 kW
• However, due to the cost versus capability / life of the energy storage mediums required for optimum mild hybrid performance, the best £/CO₂ trade-off is achieved at 12V
• SuperGen was designed as a boosting system with class leading response and sustainable, continuous operation compressor powers beyond any pure e-Booster system
• The boosting capability enables extreme downsizing and down speeding of both gasoline and Diesel engines
  • The UltraBoost project has shown that SuperGen’s ability to improve low-speed torque and transient response may enable downsizing to be taken beyond 60%, with further significant fuel economy potential
• The ability to generated sustained mass flow and pressure ratio largely independent of engine speed and load also enables advanced combustion strategies in gasoline engines for significant thermal efficiency improvements and thus further reductions in fuel consumption
  • Similarly, more capability can be added to Diesel engines at part load for emissions optimisation using SuperGen as an EGR pump for example
• Finally, the roadmap for SuperGen based technology developments, e.g. turbo compounding, shows that even further reductions in CO₂ could be possible from ICE