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ULTRA-HIGH EFFICIENCY

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Innovation & Technology

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How to achieve the next steps in engine efficiency for hybrid vehicles

Richard Osborne and Roscoe Sellers
Ricardo Automotive & Industrial

27 June 2019

www.ricardo.com

Agenda

- **Introduction**
- Future powertrain requirements
- Ricardo Magma xEV concept
- Maximising efficiency through simulation
- Does reality match the theory?
- Future outlook

Introductions

Roscoe Sellers
Chief Engineer
Product Leadership Team

~18 years at Ricardo in powertrain development

Dr. Richard Osborne
Global Technical Expert
Gasoline Combustion

~20 years at Ricardo in engine development

Brief overview of Ricardo – over 100 year history of delivering excellence – we work with our clients to define the future

We are a global, multi-industry, multi-discipline consultancy and niche manufacturer of high performance products

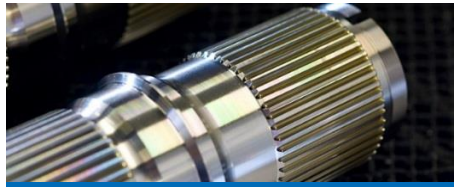
The objective throughout our history has been to maximise efficiency and eliminate waste in everything we do.

3,000+ staff
73 nationalities
48 sites in **20** countries


Hybrid and Electrical Vehicles


Engines


Niche Manufacturing


Drivelines


Vehicle Engineering

Strategic Consulting


Software


Testing


Knowledge & Training

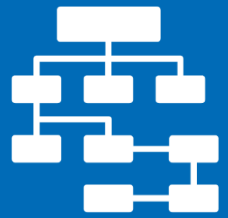

Environmental Consulting


Energy Consulting


Assurance & Cert

With huge pressure to reduce vehicle CO_2, we must achieve the most cost-effective benefits from electrification

R&D cost reductions



Growth in architecture solutions

Emissions reduction

Faster-to-market expectations

Ricardo have developed the Magma xEV engine concept to deliver a significant improvement in efficiency for hybridised powertrains

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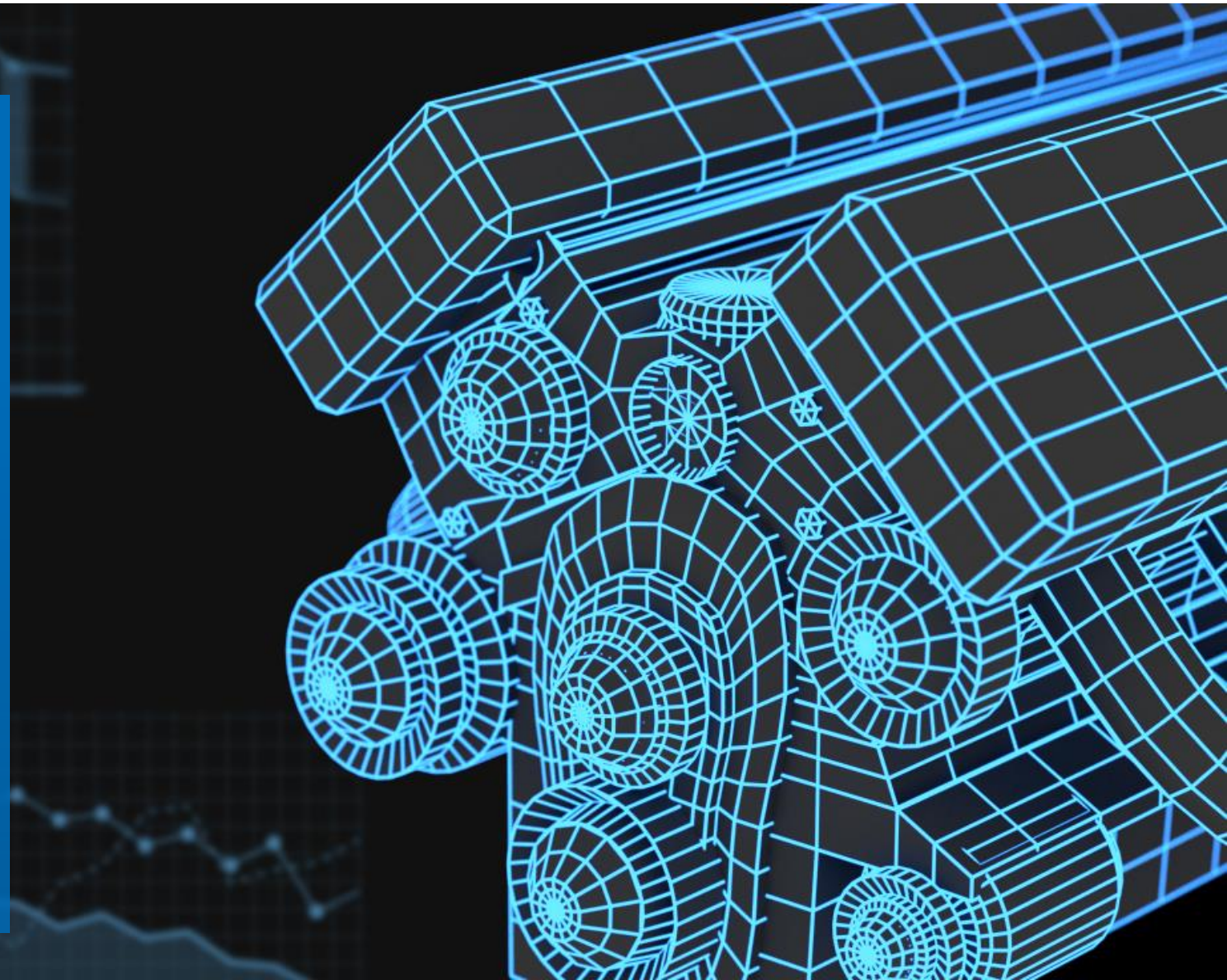
An engine architecture to maximise thermal efficiency for the next generation of hybrid powertrains

Designed to enhance the benefits from technology such as:

- Lean homogeneous combustion
- Corona-discharge ignition
- Water injection



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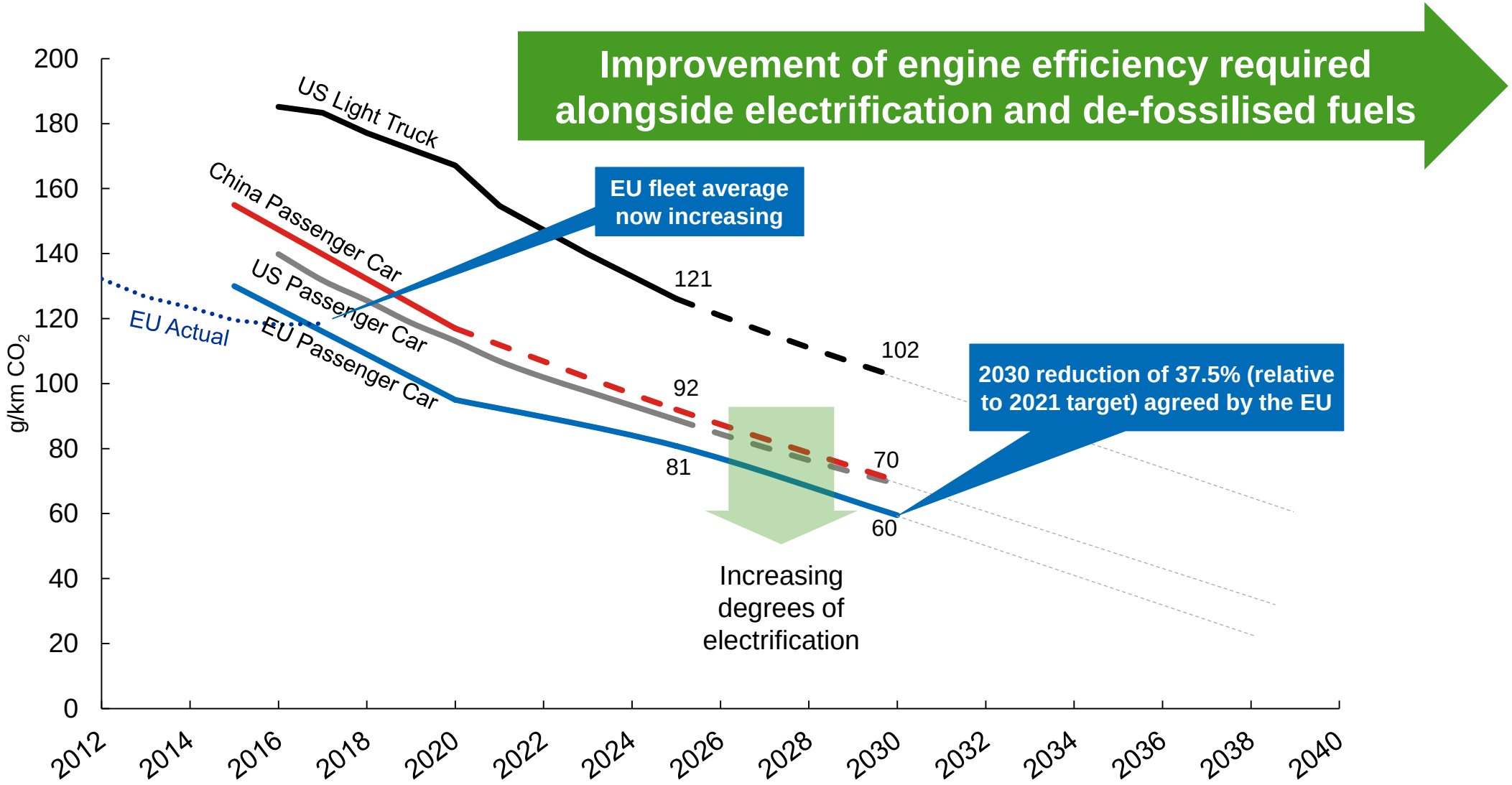
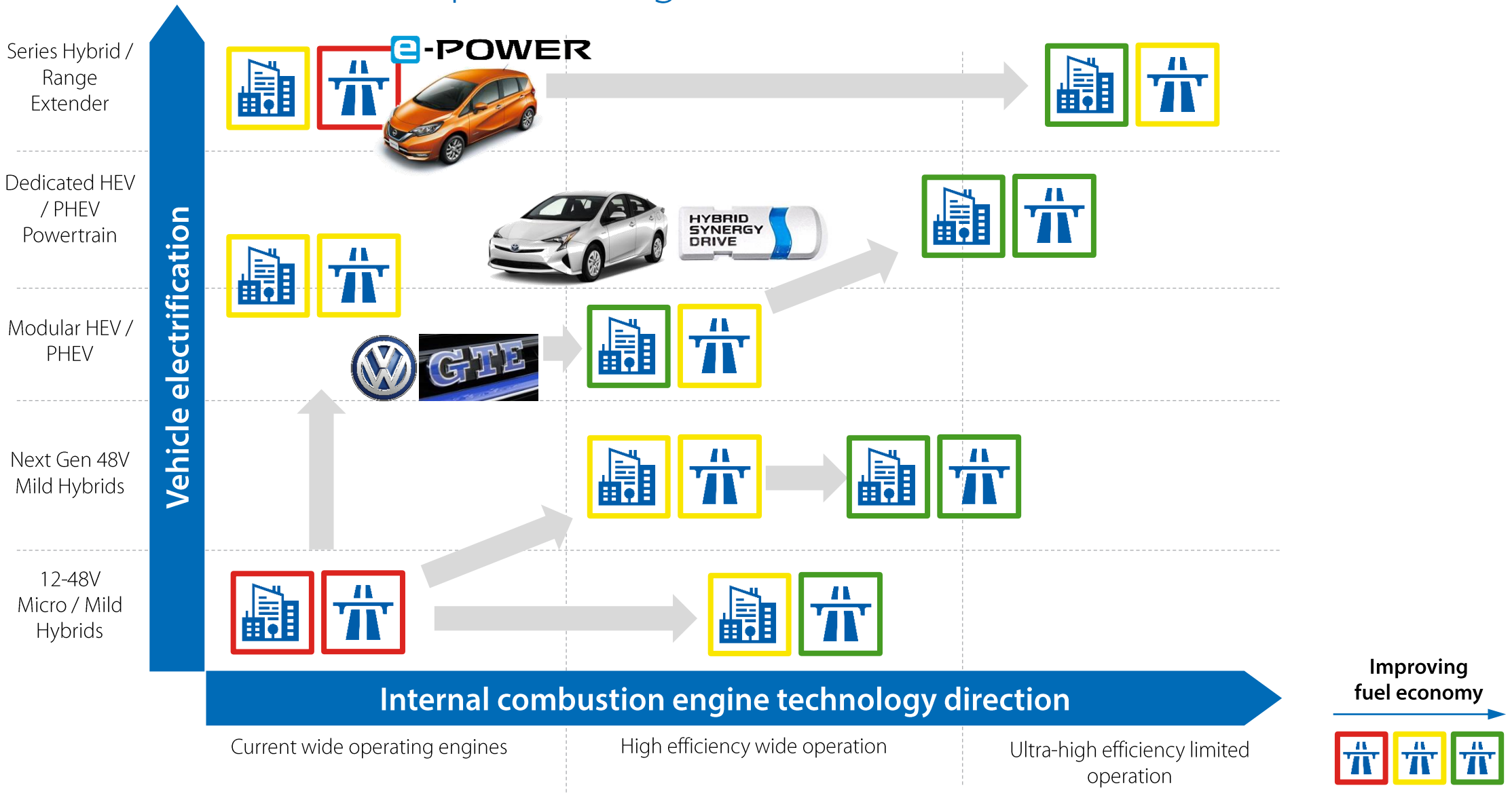
Reduction of vehicle CO_2 needs to continue at an aggressive pace, and downward trends are stalling, showing need for further innovation



Source: Ricardo Analysis

Optimising the complete propulsion system to improve efficiency and reduce cost is critical for competitive high-volume electrification



Increasing hybridisation brings the biggest opportunity for new ways of considering the powertrain optimisation

Series Hybrid / Range Extender

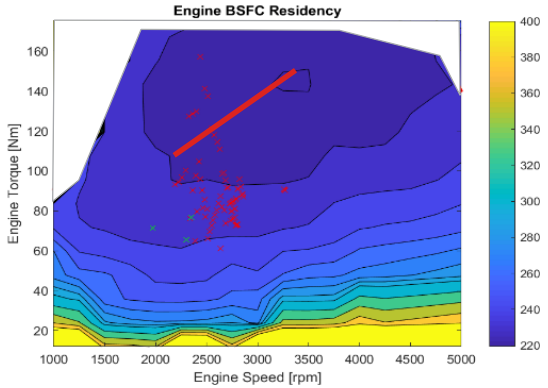
Dedicated HEV / PHEV Powertrain

Modular HEV / PHEV

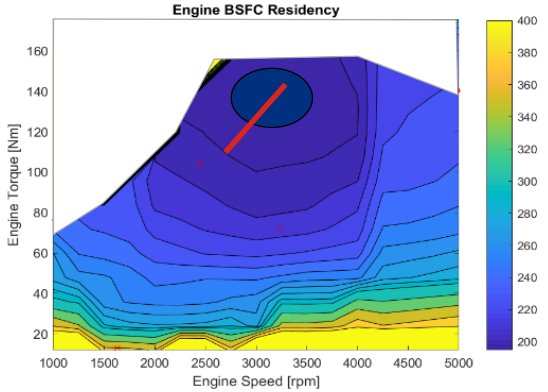
Next Gen 48V Mild Hybrids

12-48V Micro / Mild Hybrids

Vehicle electrification

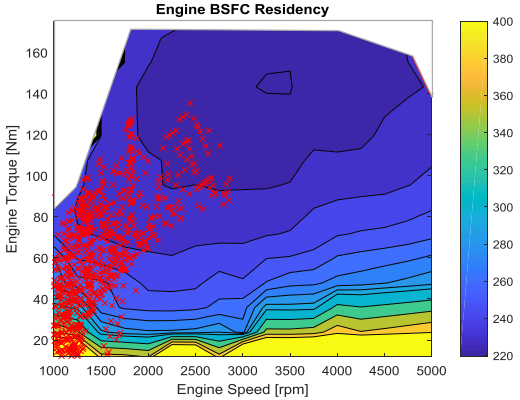


Increasing control over engine operation

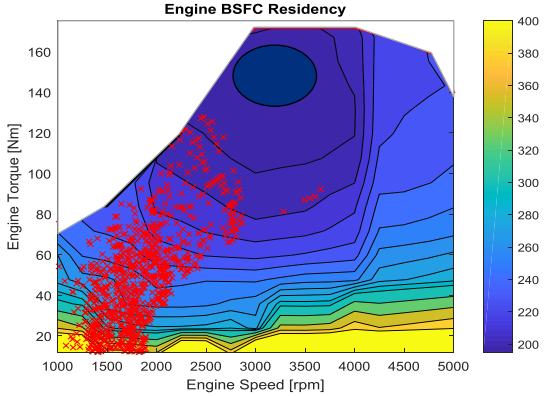


Wider engine range but lower efficiency

Reducing operating range at higher efficiency



Engine follows vehicle drive profile



Internal combustion engine technology direction

Current wide operating engines

High efficiency wide operation

Ultra-high efficiency limited operation

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Considering the drivers, what should the characteristics of new gasoline engines be to maximise the benefits from electrification?

- If battery costs remain relatively high and charging infrastructure is limited, the gasoline engine will remain a critical part of propulsion systems
  - However, there is more than one option for the engine characteristics

Vehicle types

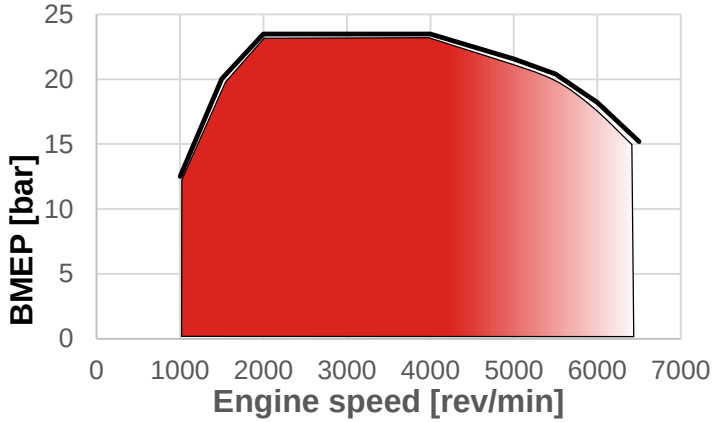
Micro Hybrid

Mild Hybrid

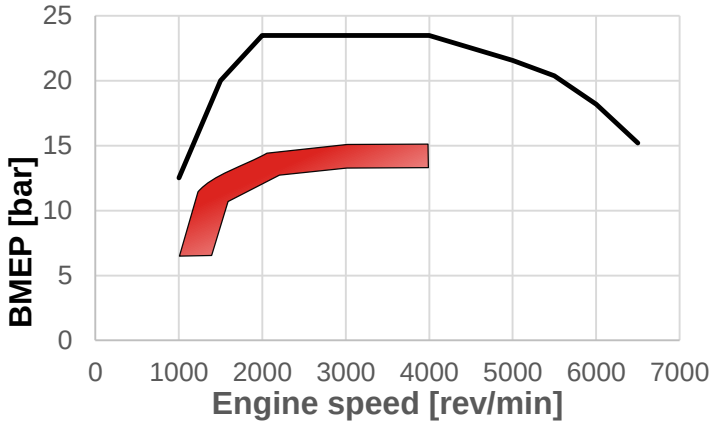
Full Hybrid

Series Hybrid

REEV



High efficiency wide operating range ICE



Low-cost very high efficiency limited operating point ICE

Engine operating range

Wide operating-range lamba 1 engines have lower potential for efficiency gains compared with focused efficiency engine

Two paths aligned to different xEV solutions

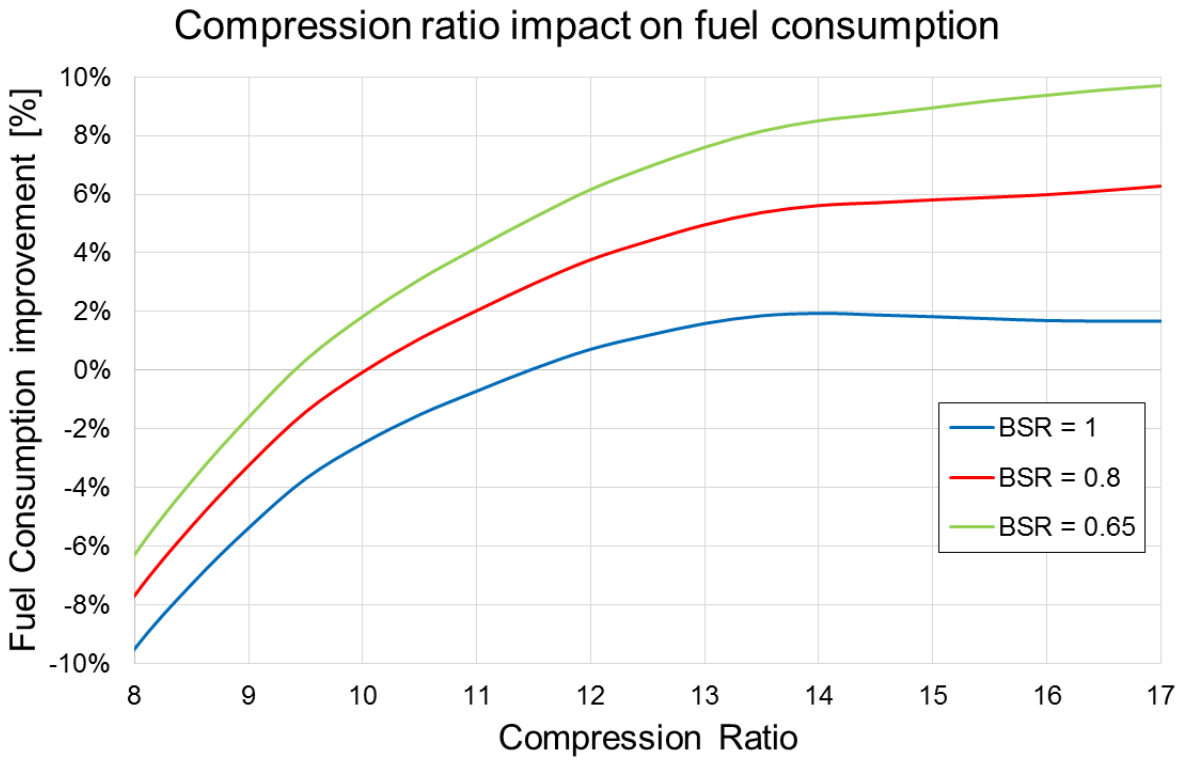
	High efficiency wide operating range ICE			*Low-cost very high efficiency limited operating point ICE*	
Engine operating range					
Current examples	VW EA211 EVO  **38.2% BTE** 222 g/kWh	Audi EA888 3B  **38.5% BTE** 220 g/kWh	Toyota TNGA 2.5  **40.0% BTE** 212 g/kWh	Nissan HR12DE e-Power  **38.0% BTE** 223 g/kWh	**Dedicated Hybrid Engines** **45+% BTE** Target
Technology options	High CR Miller cycle; CVVL and CDA; VCR; Cooled EGR; Lean burn; Water injection			Long stroke; Very high CR; Combustion insulation; Cooled EGR; Lean burn; Water injection	
	Target: 40 – 43% BTE 212 – 197 g/kWh			**Target: 42 – 45% BTE** 202 – 188 g/kWh	

Source: Ricardo

Engine geometry is the key to benefits at high compression ratio

Increase CR → Long stroke

- For a square engine (BSR = 1) there is little benefit in raising compression ratio above 13 – 14:1
  - Increased surface area to volume ratio leads to higher heat losses
- As bore/stroke ratio reduces, further increases in compression ratio continue to provide benefit
  - Target for bore/stroke ratio for Magma xEV is **0.70**
  - Target compression ratio of ~**17:1**

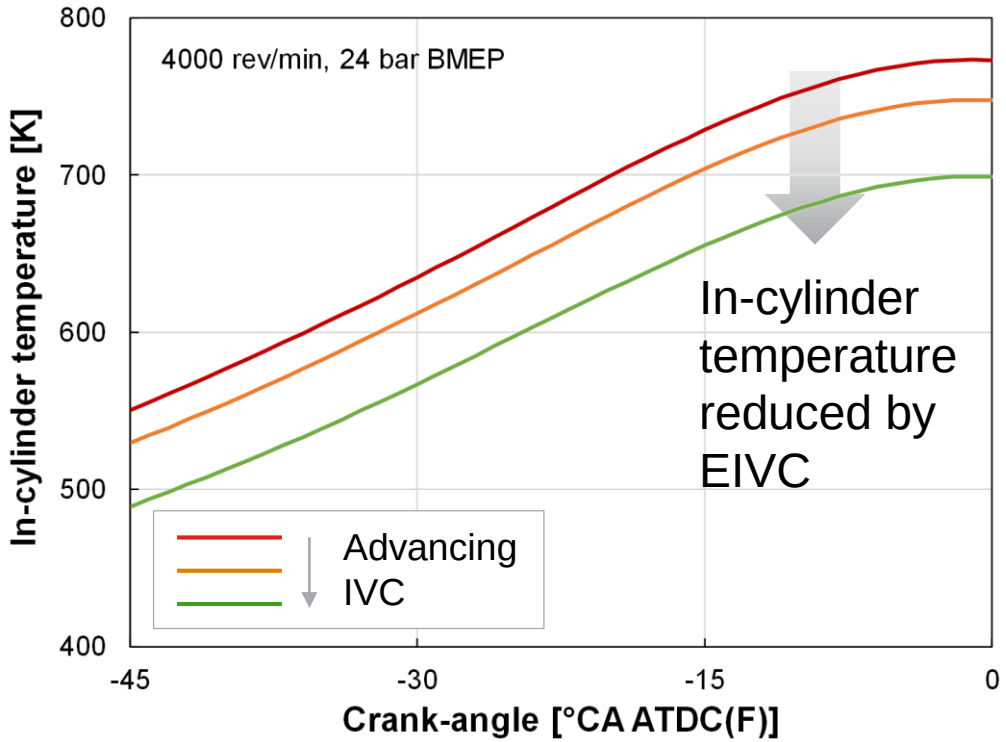


Source: Ricardo

At very high compression ratio, significant knock mitigation is required

Increase CR → Long stroke → Knock mitigation

- Miller cycle
- Water injection
- Lean burn
- Cooled EGR



- Miller cycle valve events (EIVC) are used to reduce in-cylinder compression ratio and therefore end-of-compression temperature
- At this high CR, additional knock mitigation is required
  - Water injection, lean homogeneous operation and cooled EGR have been investigated
  - **Lean homogeneous combustion was found to be the key enabler for combined knock mitigation and high efficiency**

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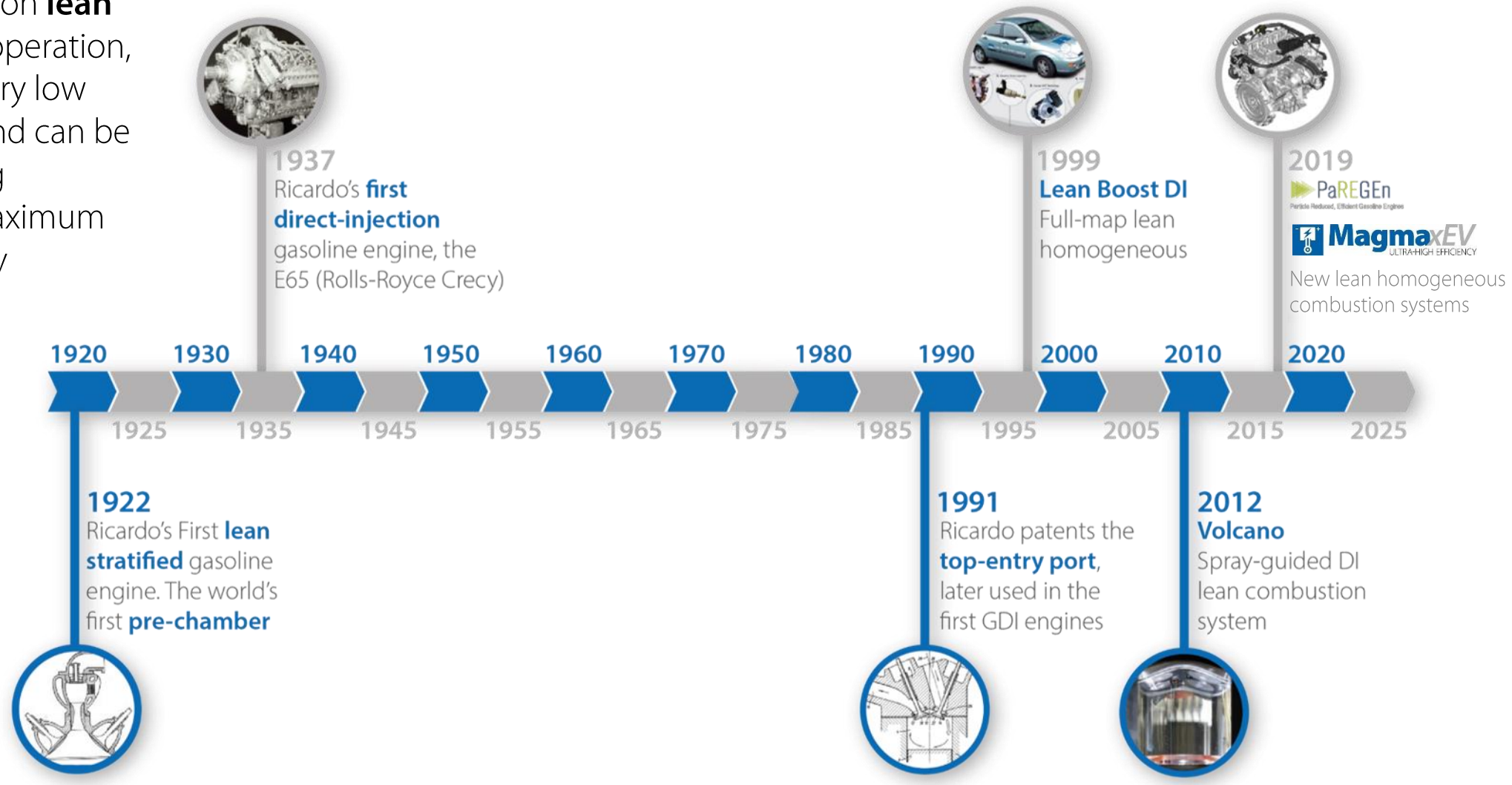
Ricardo has a long history in the development of lean-burn gasoline engines

- The focus is now on **lean homogeneous** operation, which delivers very low NOx emissions and can be used at operating conditions for maximum thermal efficiency



Ricardo Magma xEV engine architecture

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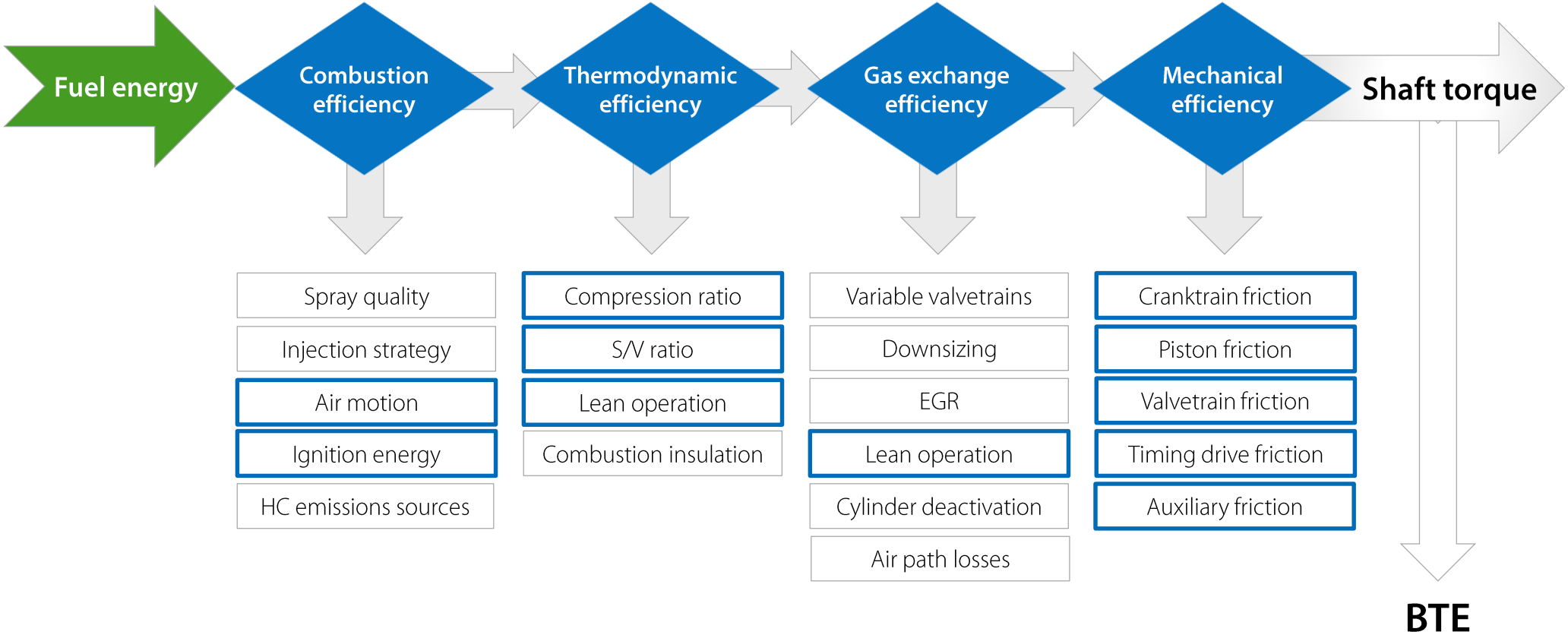
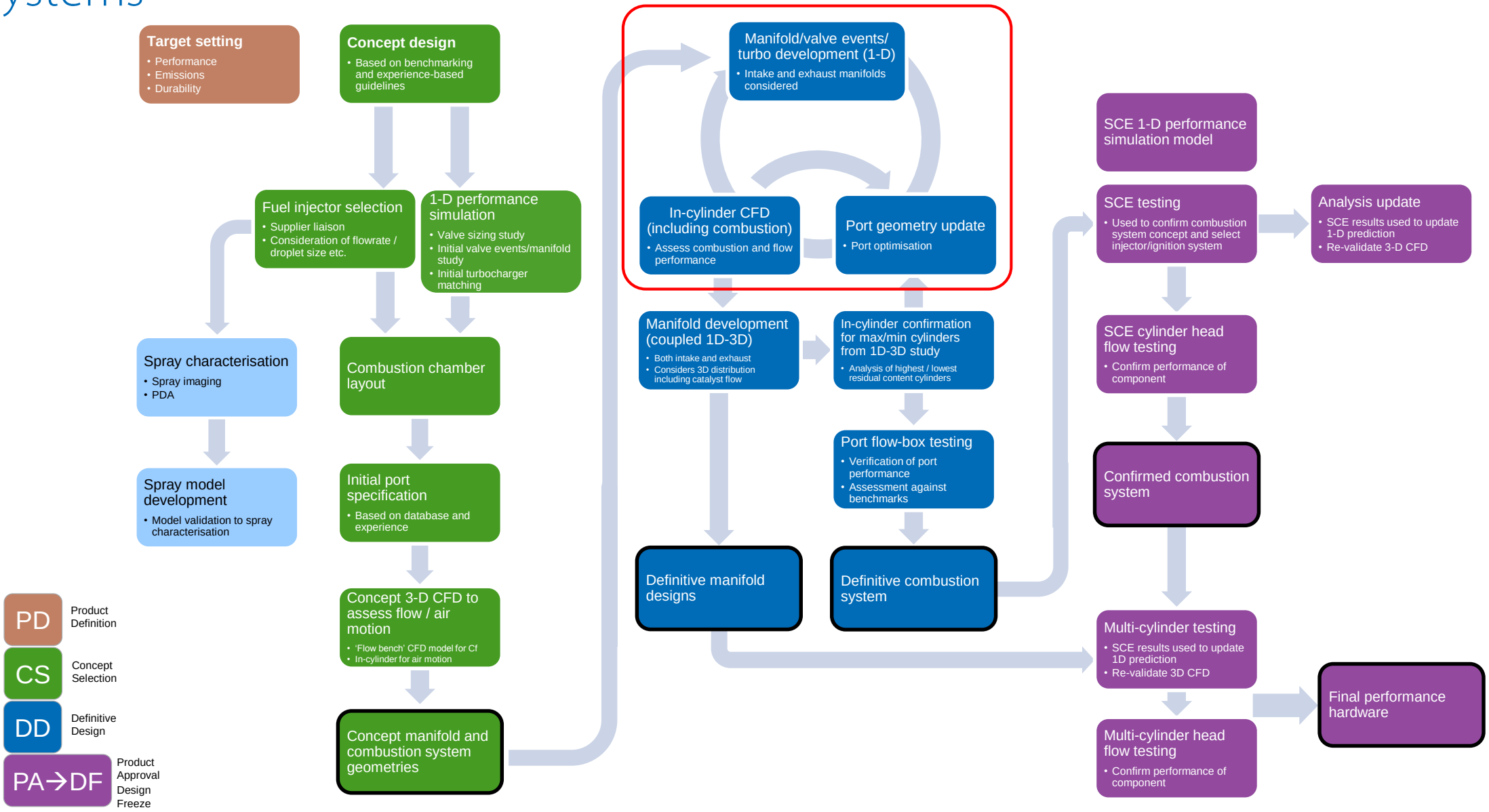
Brake thermal efficiency reflects all aspects of an engine – Magma xEV delivers gains through thermodynamic improvements



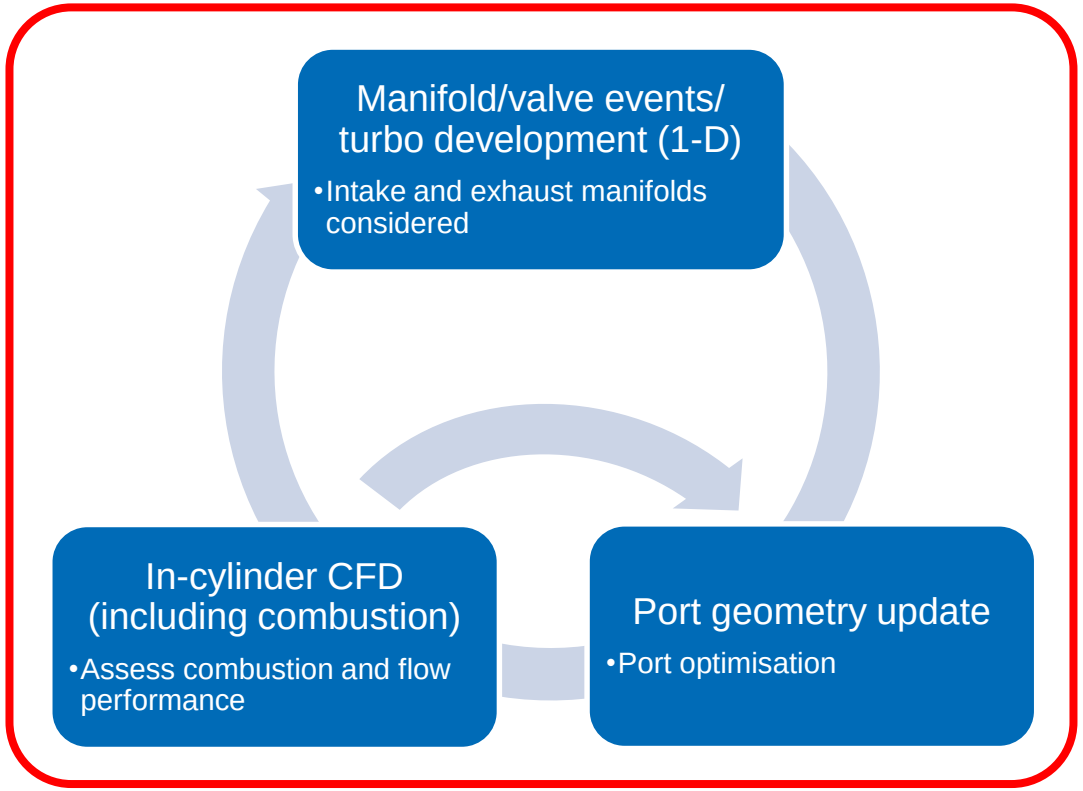
Leading TGDI	97%	43%	98%	96%	**39%**
MagmaxEV	95%	50%	99%	95%	**~45%**

The Ricardo process for the development of gasoline combustion systems



A validated approach is used to develop engine architecture and combustion system specification to get the detail right

- Enabled by the reduced engine operating area, the compression ratio and bore-to-stroke ratio combined with lean homogenous combustion offer a significant step in efficiency
- Simulation is the key to optimising efficiency and performance while minimising emissions

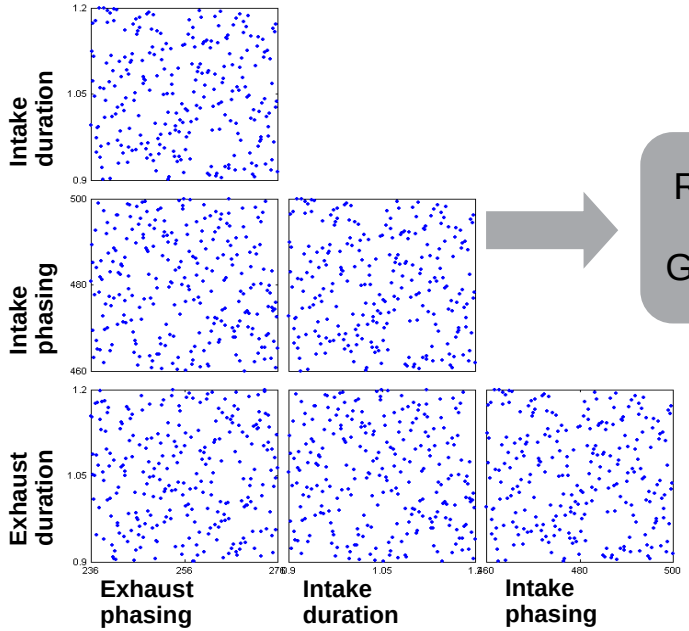


- The toolchain used comprises:
  - 0-D calculations
  - 1-D WAVE simulation studies
  - 3-D VECTIS simulation studies

Ricardo have used 1-D simulation to define the key engine specification

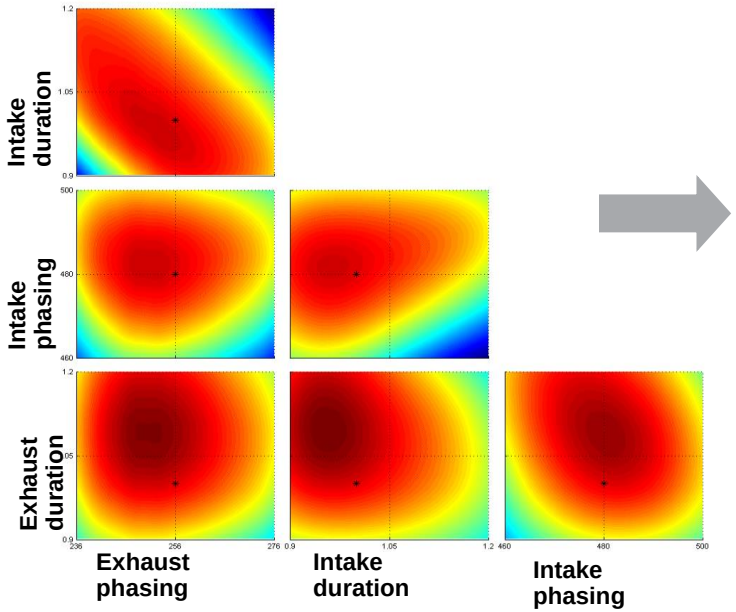
- WAVE 1-D simulation enables quick assessment of key engine parameters and building blocks:
  - Bore-to-stroke ratio, compression ratio, valve events, air-path, port flow impact, friction
- First step in pre-calibration of the system
  - VVT settings, fuel injection timing, water injection quantity and timing
- 1-D models are the key source of boundary conditions for 3-D simulations (port flows, wall temperatures, injection rates)

Example of a 4-variable DoE Design



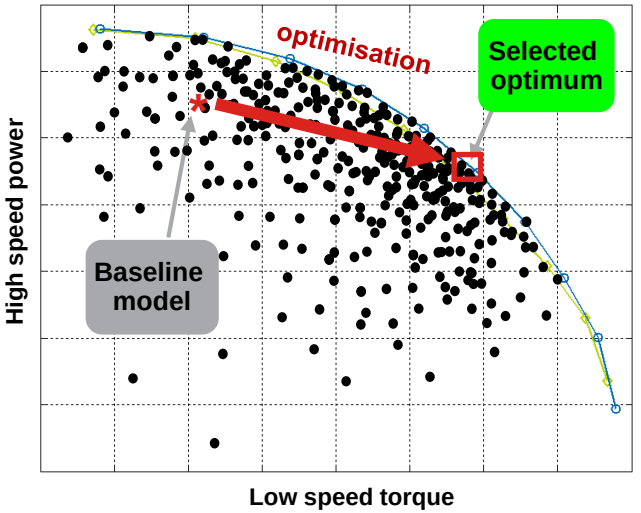
Response Surface Generation

Model response visualised in 3-D



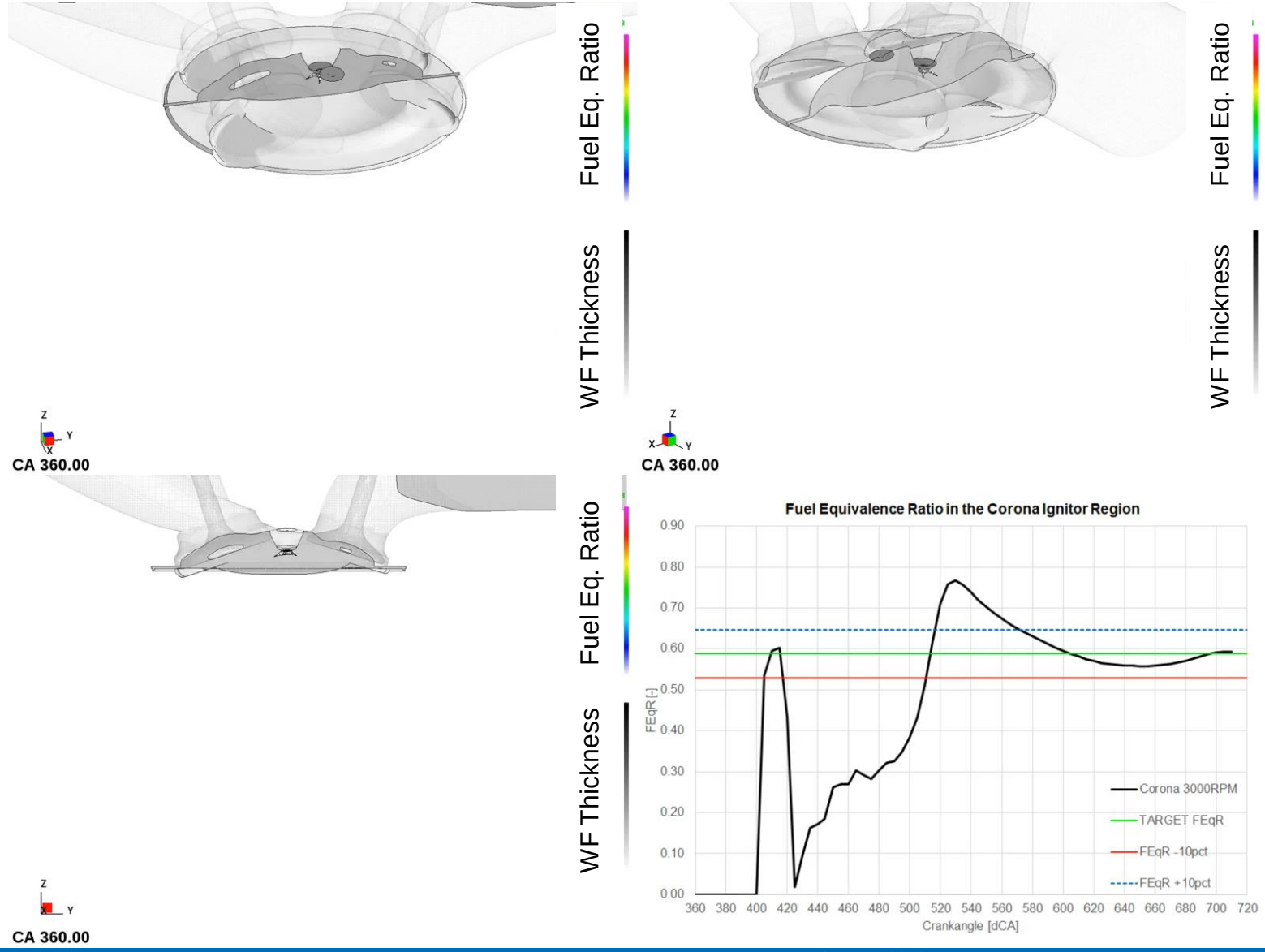
Optimisation

Optimization, Trade-off Analysis



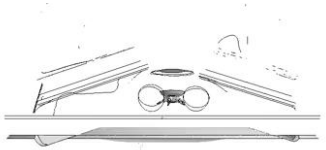
3-D CFD simulation is used to develop in-cylinder mixing and combustion

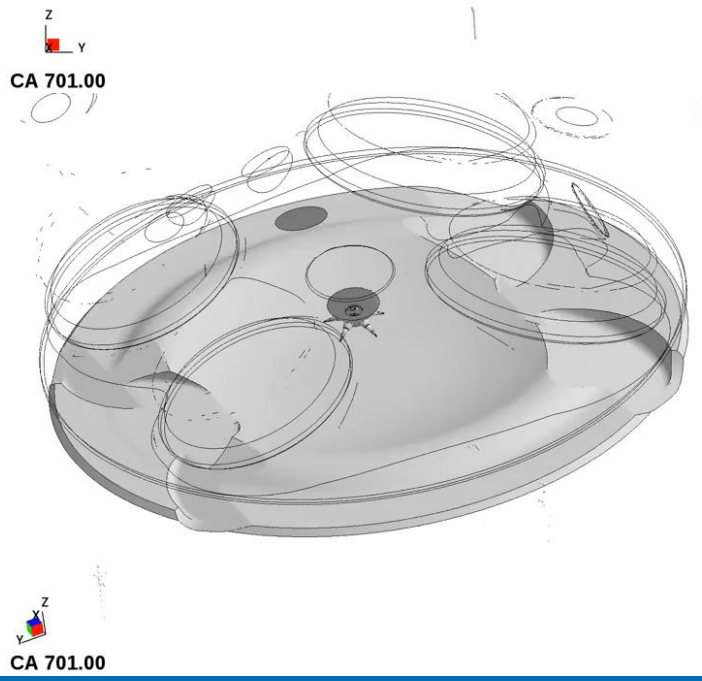
- The full engine cycle is simulated, enabling the early assessment of:
  - Fuel injector targeting
  - Air-fuel mixing
  - Risk of fuel-in-oil dilution
- The simulation has shown very uniform mixture at the start of combustion, and little wall film
- Operation at 3000 rev/min, 10.4 bar BMEP with corona discharge ignition

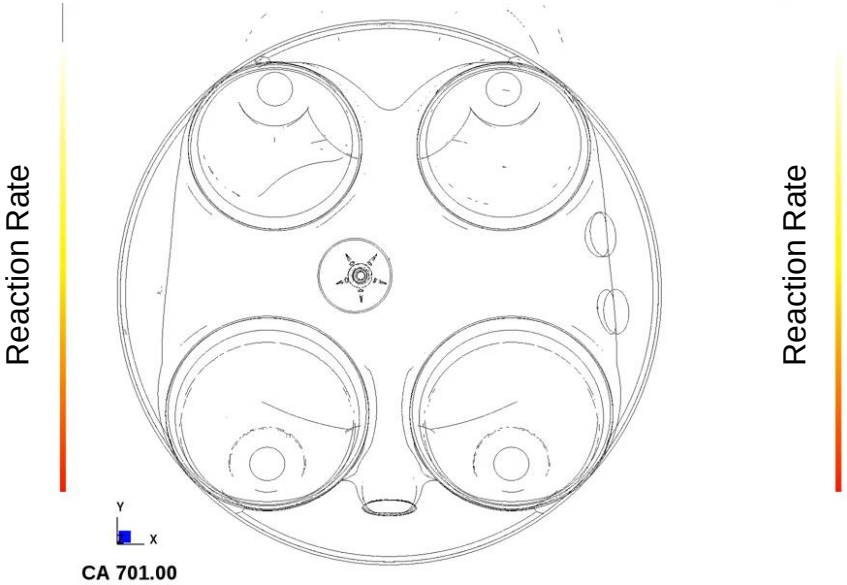


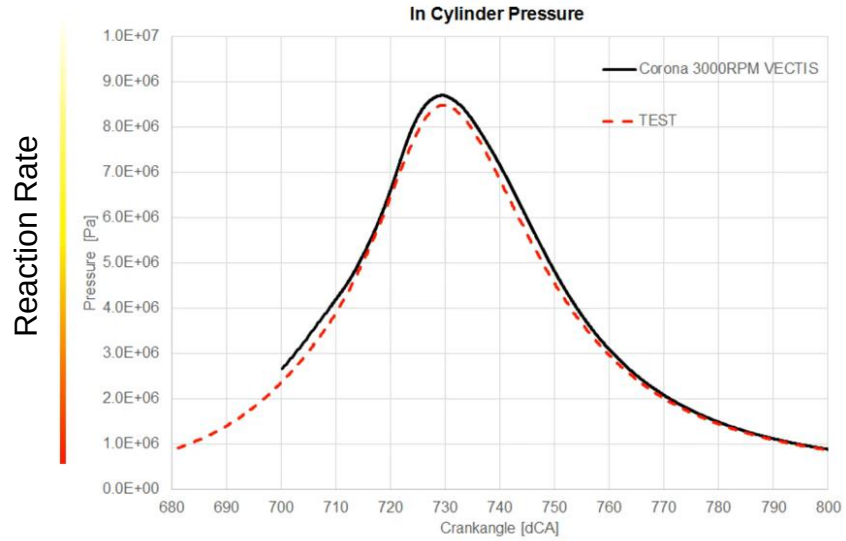
The 3-D CFD tool VECTIS has the capability to simulate the corona discharge ignition and combustion process

- Energy output to the mixture is critical for successful ignition
- Animation shows the volumetric plot of the reaction rate, indicating the flame front
- Operation at 3000 rev/min, 10.4 bar BMEP with corona discharge ignition



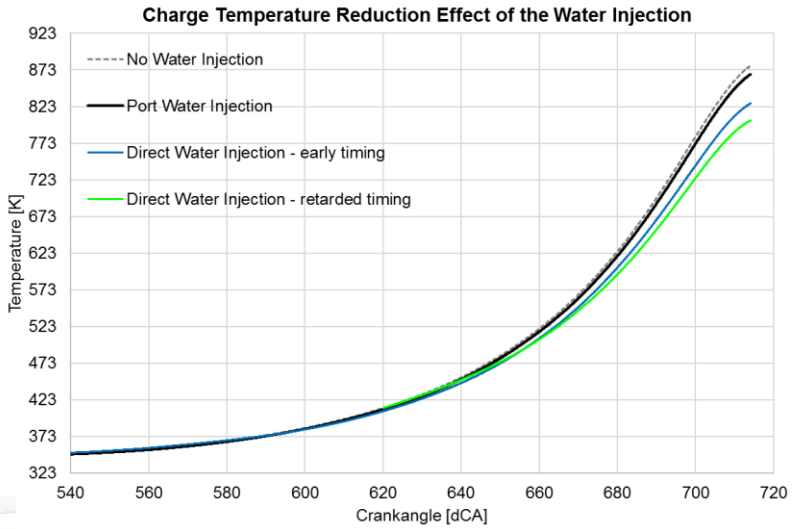


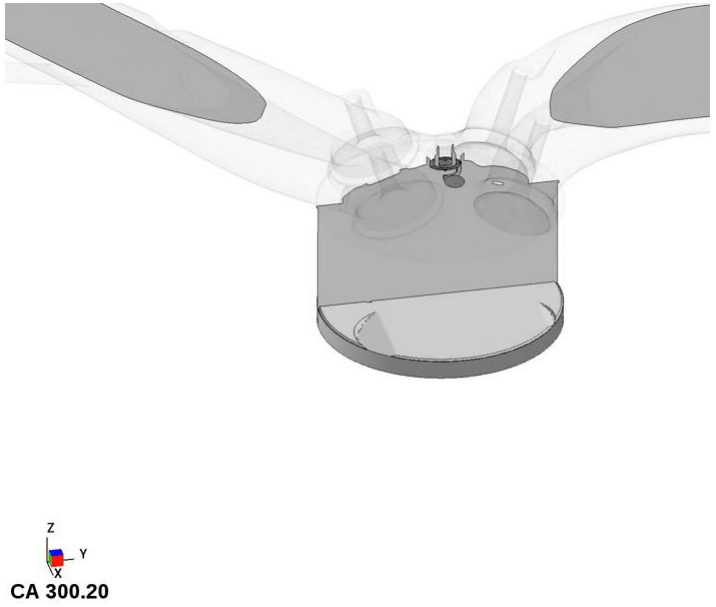


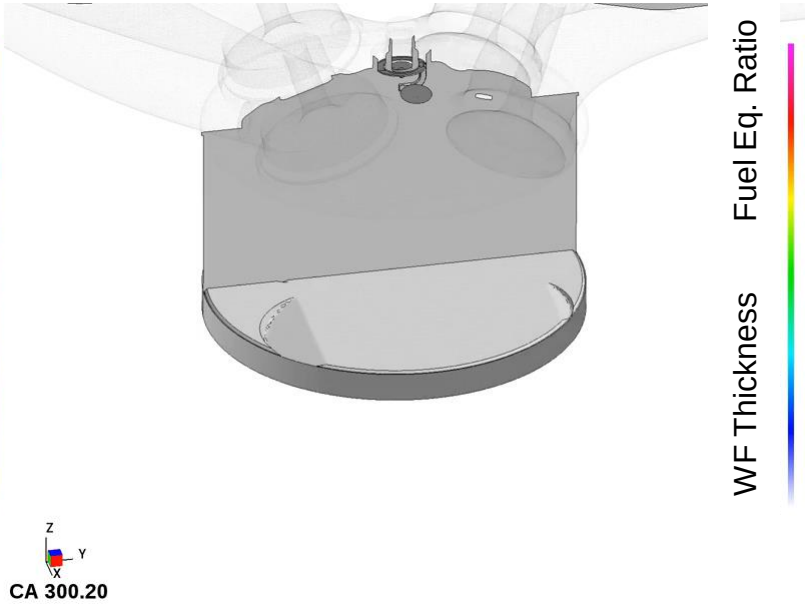


Simulating the effect of water injection on in-cylinder temperature

- Direct injection of water provides more effective cooling compared with port water injection
- The injection timing is also significant, with relatively late water injection being most efficient
  - A larger proportion is evaporated from airborne droplets instead of from the wall film







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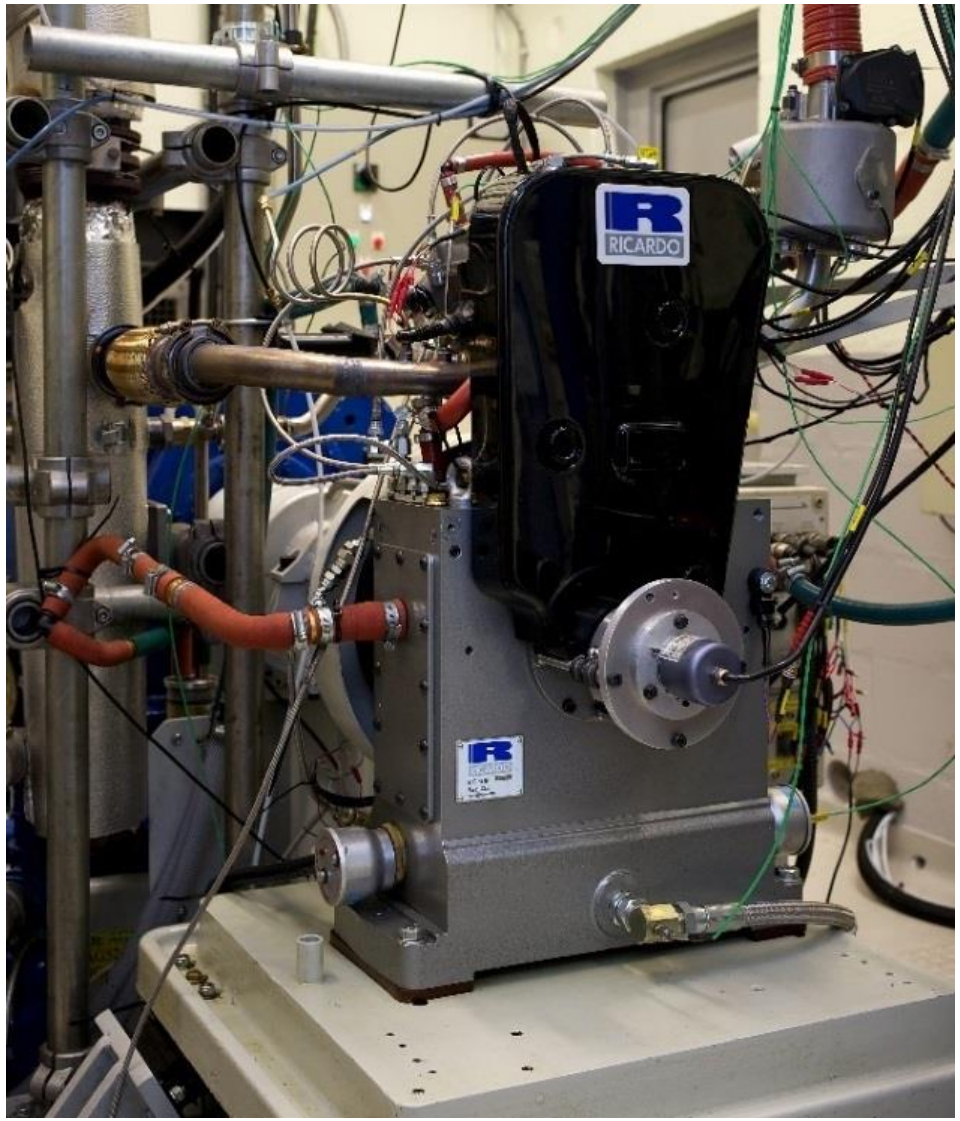
Ricardo have integrated Magma xEV into multi-cylinder engine concepts and have also used single-cylinder engines for combustion studies

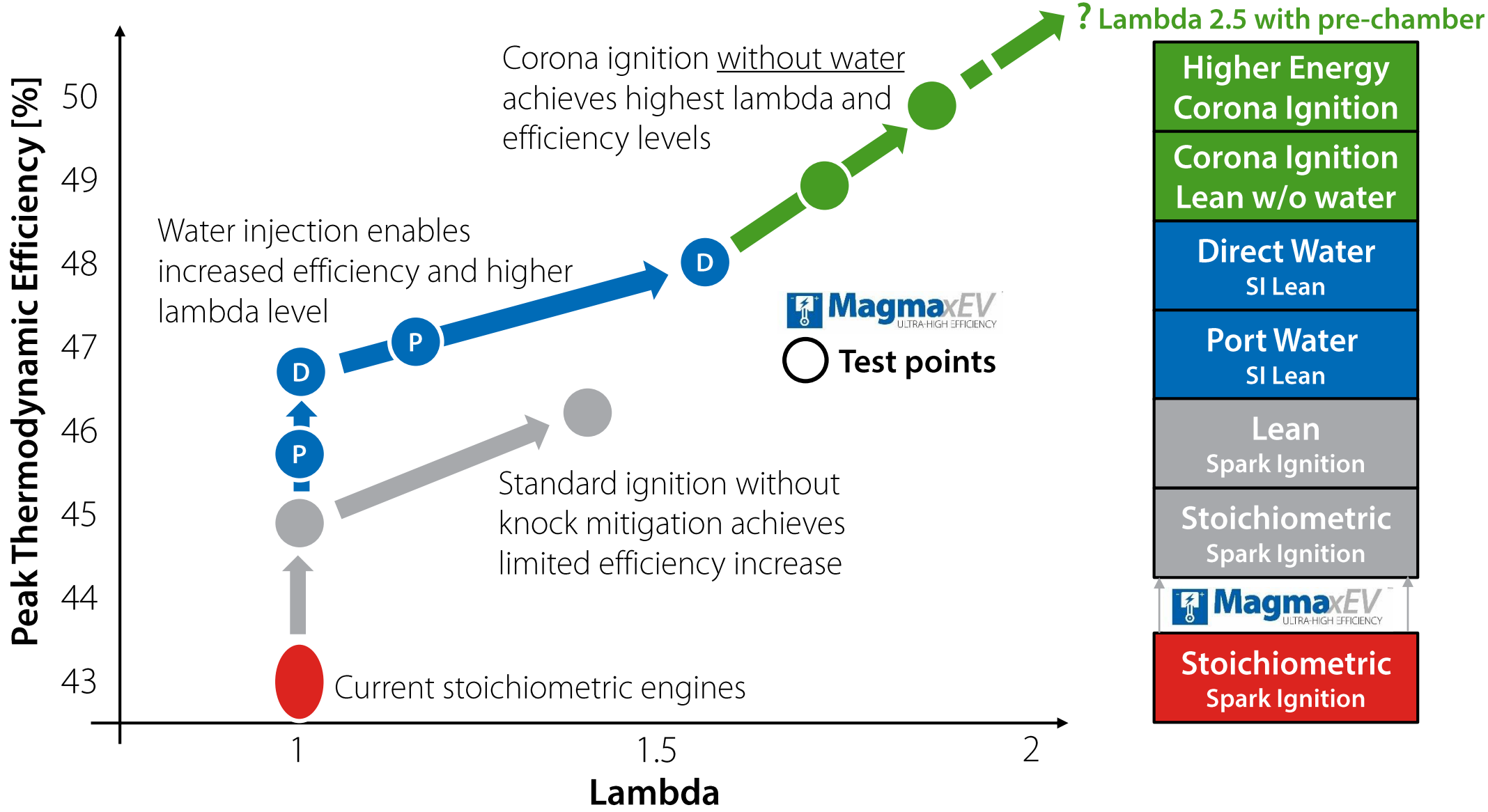


- Confirming the performance of different technology combinations is key to continuing on the right path for further development

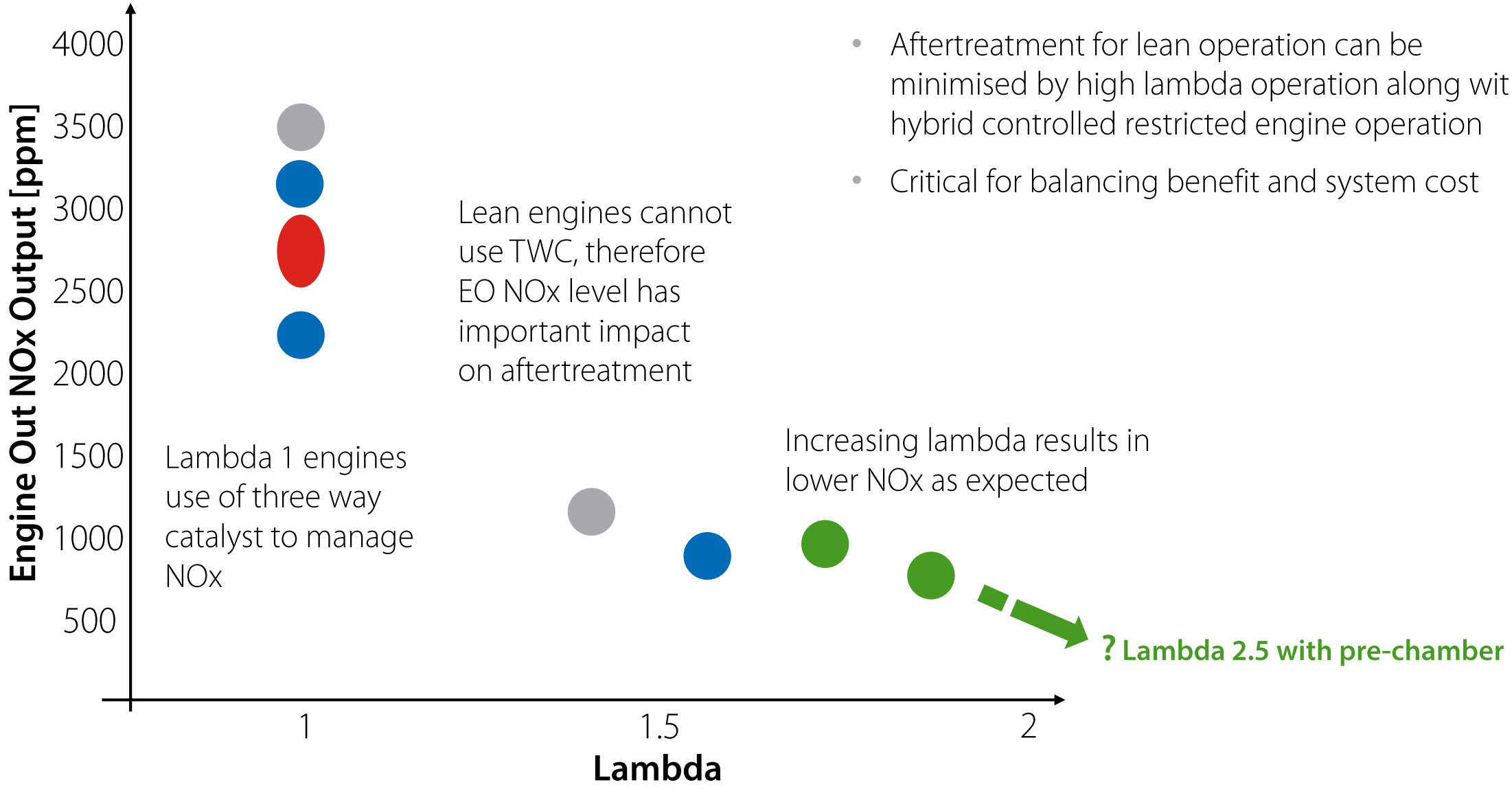
- Ricardo have tested the Magma xEV architecture:
  - Set-up and testing of the building blocks
  - Demonstrates the thermal efficiency trend is most strongly linked to lambda increase
  - Advanced ignition becomes critical
  - NOx trend improves with higher lambda

- Ability of the combined architecture and lean combustion to deliver 'future' engine

Test results allow us to confirm the performance of the Magma xEV combustion system & technology contribution on the efficiency walk

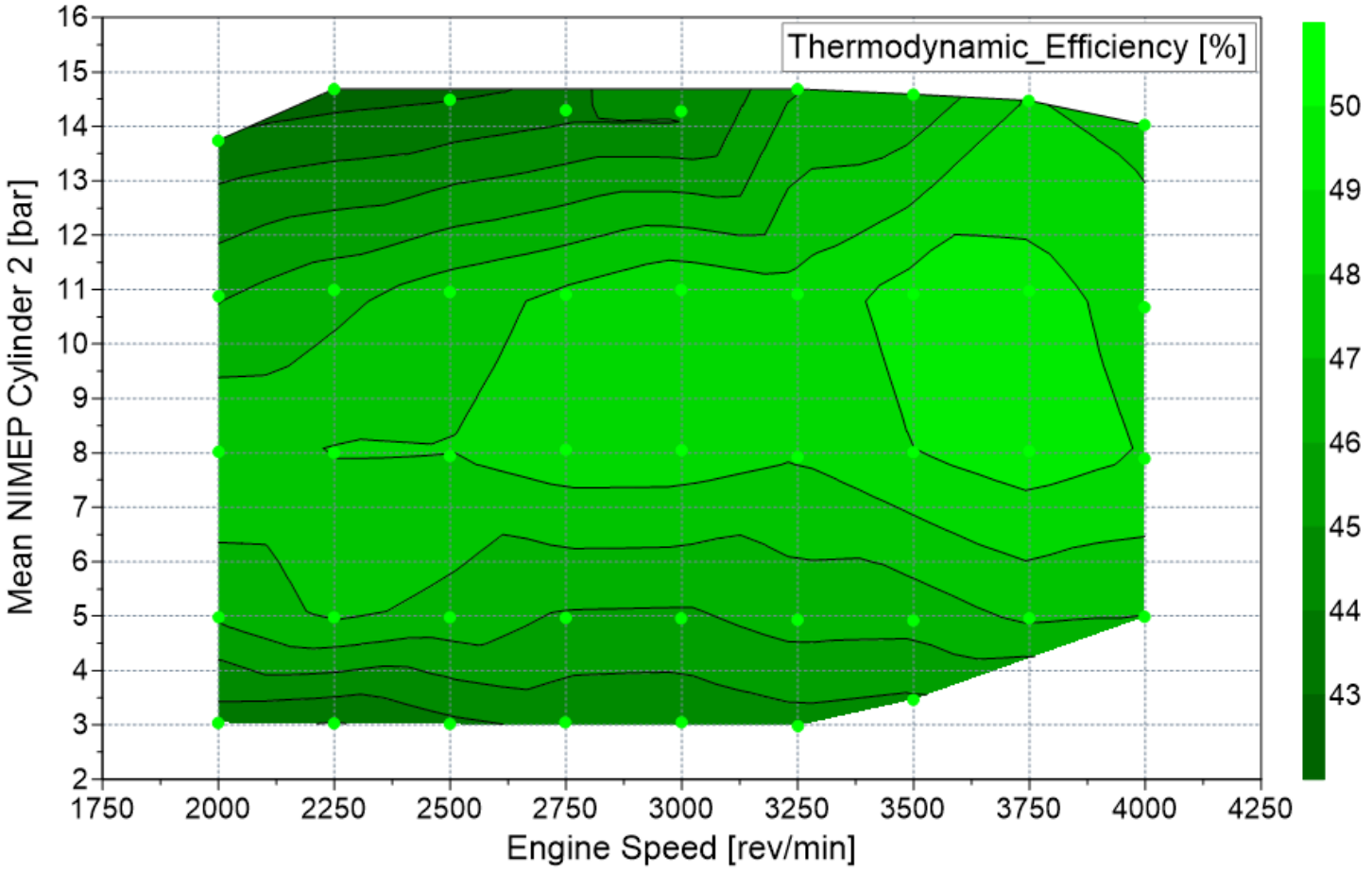


NOx emissions also improve with lambda, showing future target to maximise efficiency and reduce aftertreatment is lambda > 2



- Aftertreatment for lean operation can be minimised by high lambda operation along with hybrid controlled restricted engine operation
- Critical for balancing benefit and system cost

Wide range lean homogenous mapping completed showing good performance making use of maximum lambda levels



- The system supports stable combustion at very lean conditions over a significant operating range
- This creates a useable architecture for realistic application of lean applications
- Wider operating range with lower Compression Ratio possible
- Future path towards ultra-lean conditions above lambda 2 for further enhancement and NOx reduction

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Ricardo vision for dedicated hybrid engines is to enable maximum system efficiency with the lowest cost and complexity

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- **Integrate into existing platforms or clean-sheet concepts**
- **Smart simulation enables reduced development time and cost**
- **Synergies with wider electrification of the powertrain**
- **Technology content selected by HEV type and engine operating profile**

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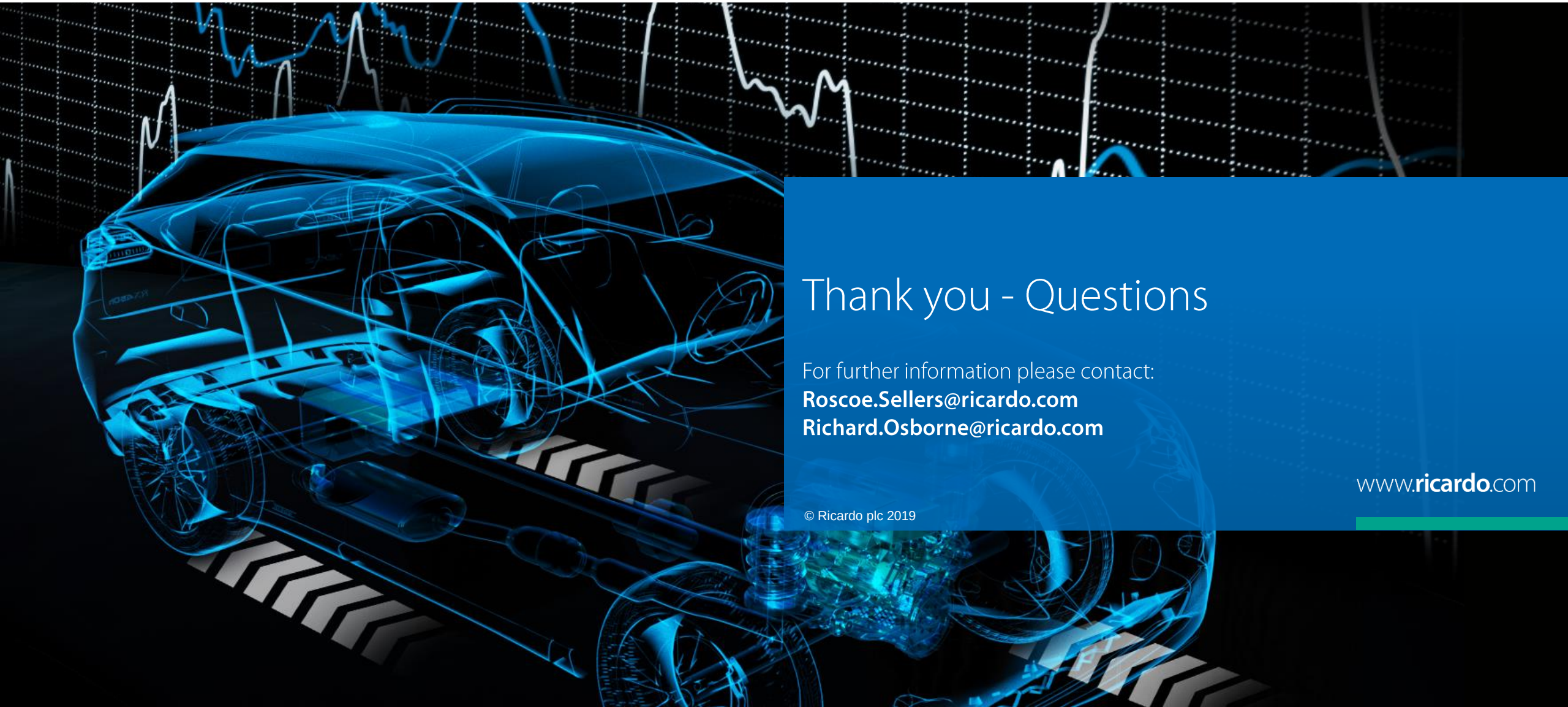

Thank you - Questions

For further information please contact:

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