

Delivering Excellence Through
Innovation & Technology

The background features a dark blue field with colorful line-art illustrations. On the left, a high-speed train is shown in profile, with a yellow and orange battery pack mounted on top. Below the train, three cars are depicted in a row, each with concentric curved lines around them representing wireless signals. To the right of the cars is a stylized fuel pump. In the upper right, a yellow and orange car is partially visible. The overall theme is automotive technology and connectivity.

Ricardo plc Preliminary Results Presentation

Year ended 30 June 2017
Presented September 2017

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HIGHLIGHTS – for the year ended 30 June 2017

- Record order book at £248m and strong order intake at £366m
- Revenue up 6% to £352m
- Resilient performance across the business with underlying PBT at £38.3m in line with expectations, despite disrupted flow of orders in automotive
- Good performance from EE, Rail and PP:
 - Energy & Environment, good order intake and performance, with high profile support to COP22
 - Rail, fully integrated with good levels of order intake and performance
 - PP, good performance, 10,000th McLaren engine delivered and Aston Martin Valkyrie contract award
- Good order flow in Automotive for hybrid/EV activity (17% of Group total) and engines
- Acquisition of Exnovo in the year and Control Point completed post year-end
- Outlook remains positive with a good platform for growth



	Year ended 30 June 2017	Year ended 30 June 2016	Year-on-Year Movement
Order intake (£m)	£366m	£361m	£5m
Order book (£m)	£248m	£231m	£17m
Operating profit margin ⁽¹⁾ (%)	11.6%	11.9%	(0.3)%
Effective tax rate (%)	23.0%	22.4%	0.6%
Basic earnings per share (pence) ⁽¹⁾	55.7p	55.2p	0.5p
Full year dividend (pence)	19.3p	18.1p	1.2p
Net (debt)/funds (£m)	£(37.9)m	£(34.4)m	£(3.5)m
Pre-tax pension deficit (£m)	£22.2m	£21.5m	£0.7m
Closing headcount incl. subcontractors (no.)	2,927	2,905	22

(1) excluding specific adjusting items, which comprise amortisation of acquired intangible assets, acquisition-related expenditure and reorganisation costs. In the prior year, non recurring income for claims under the Research and Development Expenditure Credit ('RDEC') scheme in respect of previous years were also included.

£m	Year ended 30 June		Year-on-Year Movement
	2017 Underlying ⁽¹⁾	2016 Underlying ⁽¹⁾	% change
Revenue	352.1	332.4	6%
Gross profit	132.9	129.8	2%
Administration costs	(92.1)	(90.2)	2%
Operating profit	40.8	39.6	3%
Net finance costs	(2.5)	(1.9)	32%
Profit before tax	38.3	37.7	2%
Taxation charge	(8.8)	(8.6)	2%
Profit for the year	29.5	29.1	1%

(1) excluding specific adjusting items, which comprise amortisation of acquired intangible assets, acquisition-related expenditure and reorganisation costs. In the prior year, non recurring income for claims under the Research and Development Expenditure Credit ('RDEC') scheme in respect of previous years were also included. A full income statement including these items is included in the Appendix.

Revenue by customer location

External Revenue	Year ended 30 June	Year ended 30 June
£m	2017	2016
UK	144.5	154.2
Germany	27.6	24.7
Netherlands	21.8	18.5
Rest of Europe	43.9	22.7
Europe total	237.8	220.1
US	38.6	39.2
China	32.7	21.4
Japan	16.3	18.1
Rest of Asia	17.9	26.7
Asia total	66.9	66.2
Rest of the World	8.8	6.9
Total	352.1	332.4

Full year ended 30 June

£m	Revenue earned		Underlying operating profit ⁽¹⁾		Underlying operating profit ⁽¹⁾ margin	
	2017	2016	2017	2016	2017	2016
Technical Consulting	280.5	267.9	32.8	32.5	11.7%	12.1%
Performance Products	71.6	64.5	8.0	7.1	11.2%	11.0%
Total	352.1	332.4	40.8	39.6	11.6%	11.9%

(1) excluding specific adjusting items, which comprise amortisation of acquired intangible assets, acquisition-related expenditure and reorganisation costs. In the prior, non recurring income for claims under the Research and Development Expenditure Credit ('RDEC') scheme in respect of previous years were also included.

Segmental results on a constant currency basis



Full year ended 30 June

£m	Revenue earned		Underlying operating profit ⁽¹⁾		Underlying operating profit ⁽¹⁾ margin	
	2017	2016	2017	2016	2017	2016
Technical Consulting	266.4	267.9	32.9	32.5	12.3%	12.1%
Performance Products	70.5	64.5	7.8	7.1	11.1%	11.0%
Total	336.9	332.4	40.7	39.6	12.1%	11.9%

(1) excluding specific adjusting items, which comprise amortisation of acquired intangible assets, acquisition-related expenditure and reorganisation costs. In the prior, non recurring income for claims under the Research and Development Expenditure Credit ('RDEC') scheme in respect of previous years were also included.

£m	Year ended 30 June	
	2017	2016
Underlying operating profit	40.8	39.6
Depreciation and amortisation	12.3	10.5
Working capital increase	(19.6)	(13.2)
Dividends	(9.8)	(8.9)
Tax paid	(7.6)	(8.4)
Capital expenditure	(11.9)	(14.7)
Proceeds from sale of PPE	4.0	0.0
Pension charge and funding	(4.4)	(4.4)
Cash flow hedges, FX, interest/other	(2.9)	(0.4)
Cash inflow excluding acquisition-related costs	0.9	0.1
Acquisition-related costs	(4.4)	(48.8)
Cash outflow	(3.5)	(48.7)
Opening Cash Balance	(34.4)	14.3
Closing Cash Balance	(37.9)	(34.4)

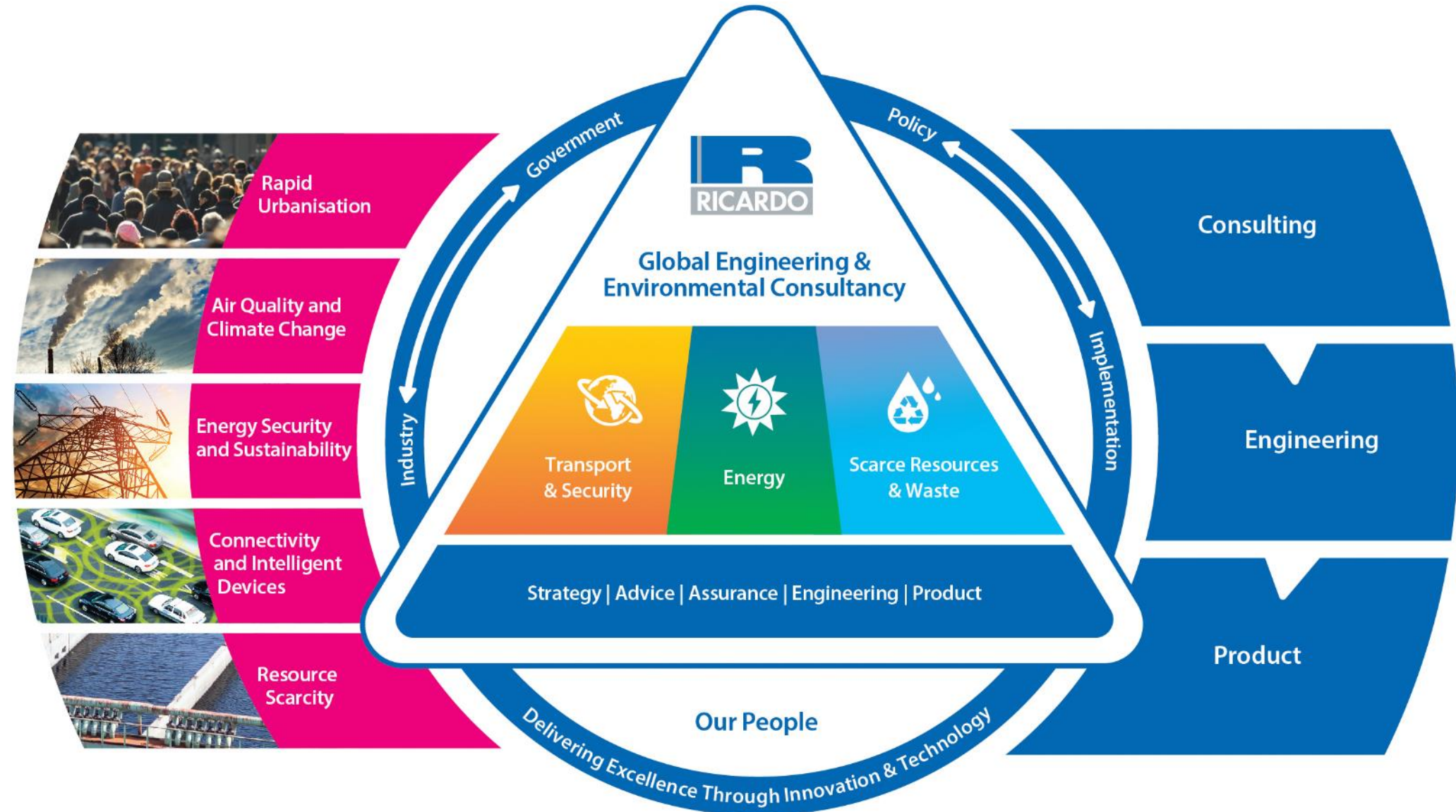
£m	30 June 2017	30 June 2016
Tangible non-current assets	48.0	53.6
Intangible non-current assets	94.4	92.3
Inventories, trade and other receivables	151.5	125.3
Assets held for sale	2.8	0.0
Net (debt)/funds	(37.9)	(34.4)
Trade and other payables	(82.1)	(72.5)
Pension deficit (net of tax)	(18.1)	(17.5)
Other	(2.9)	(7.3)
Net assets	155.7	139.5

Control Point acquisition

- Control Point acquired on 8th September 2017
- US full-service classified status engineering business which operates principally in the defence sector with 90 people
- Significantly expands the range of defence opportunities Ricardo can now pursue
- Control Point will bring crucial skills in:
 - “Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance” (C4ISR) systems engineering
 - cyber security
 - fleet management technologies
 - vehicle management systems
- Cash consideration of \$10.2m including performance and retention elements. Annualised revenue of c. \$15.0m



Our strategic mission is to be the world's leading brand for engineering and environmental consultancy in our core competencies of transport and security, energy, and scarce resources and waste



- Referendums, multiple elections
- Volatile currencies
- Uncertainty and change
- Prolonged decision making
- Industrial change



Market focus and Ricardo performance

ENERGY & ENVIRONMENT



- COP22 into implementation and planning phase
- Strong ground support in US
- Global support elsewhere
- Very good year

RAIL



- Global infrastructure spend
- Roll out of high speed rail
- Large multi year programs
- Very good year

PERFORMANCE PRODUCTS



- High-performance cars remain in fashion
- Increase in niche-volume-supply enquiries
- Very good year

AUTOMOTIVE

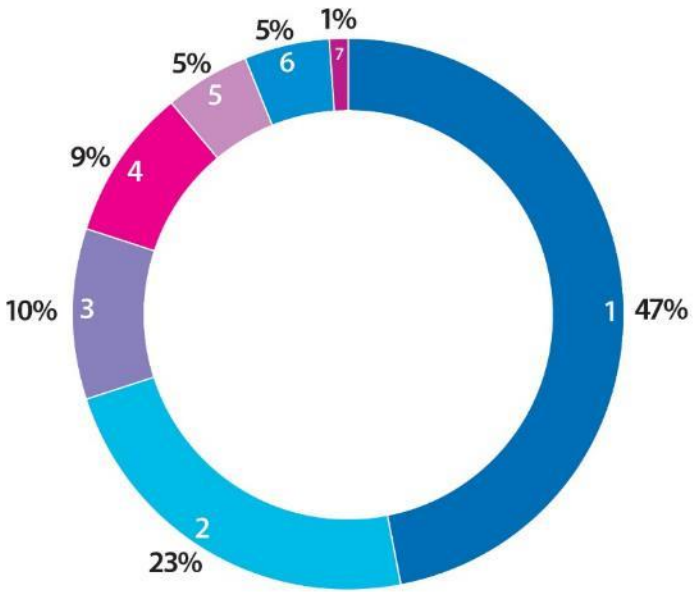


- ‘Dieselgate’ and future diesel ban?
- Move to electrification being embraced
- Busy year for hybrid and ICE
- Ricardo US in transition
- Disrupted year

A continued good balance of order intake and pipeline from across the globe

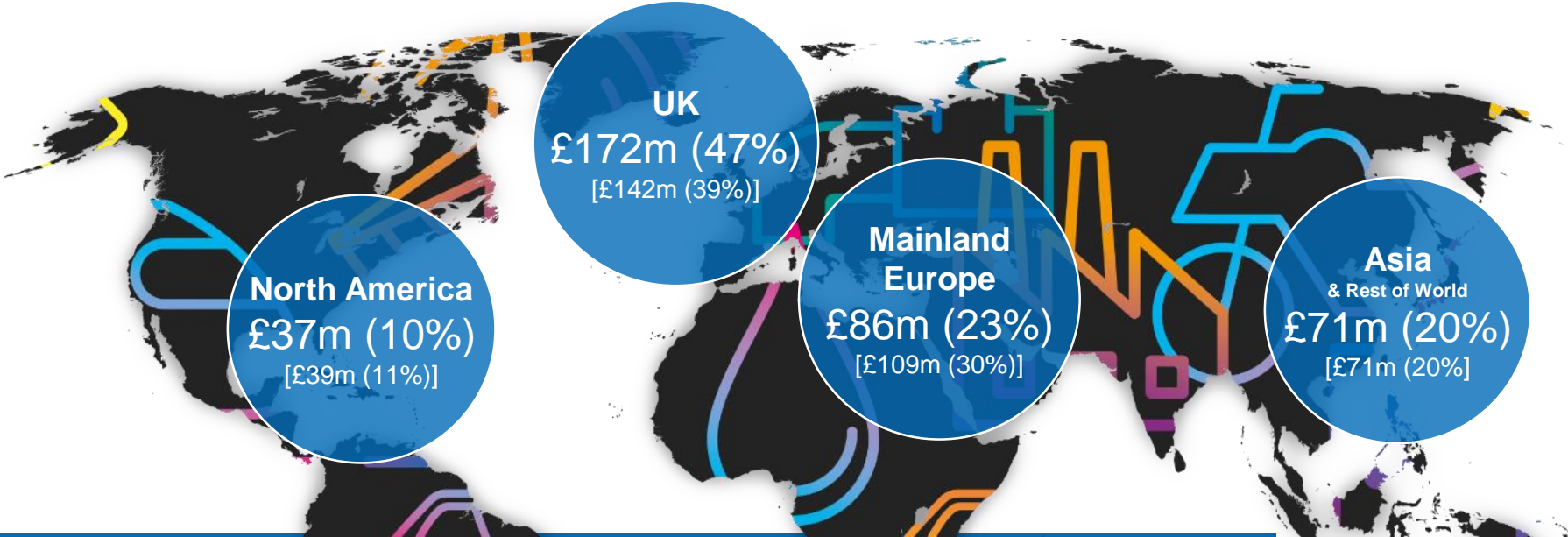


1. UK
2. Mainland Europe
3. North America
4. China
5. Japan
6. Rest of Asia
7. Rest of World



FY 2016/17
 Order Intake £366m

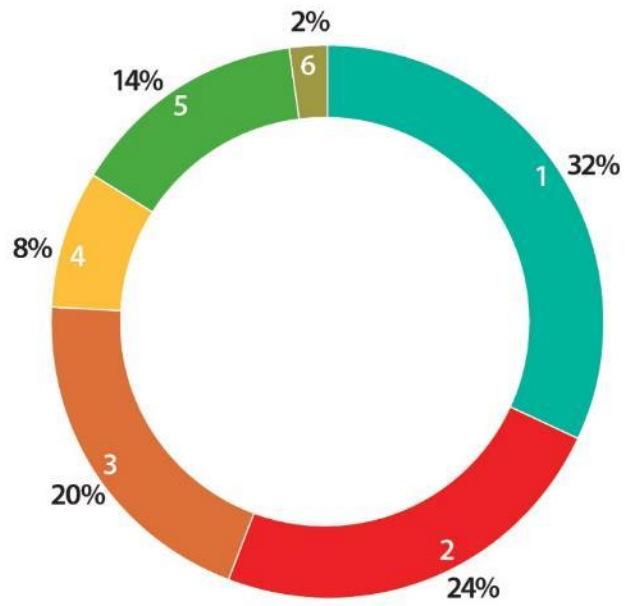
[FY 2015/16
 Order Intake £361m]









Well balanced market sector order intake with a strong year for High Performance Vehicles & Motorsport



- 1. Automotive
- 2. High Performance Vehicles & Motorsport
- 3. Rail
- 4. Off Highway & Commercial Vehicles
- 5. Energy & Environment
- 6. Defence



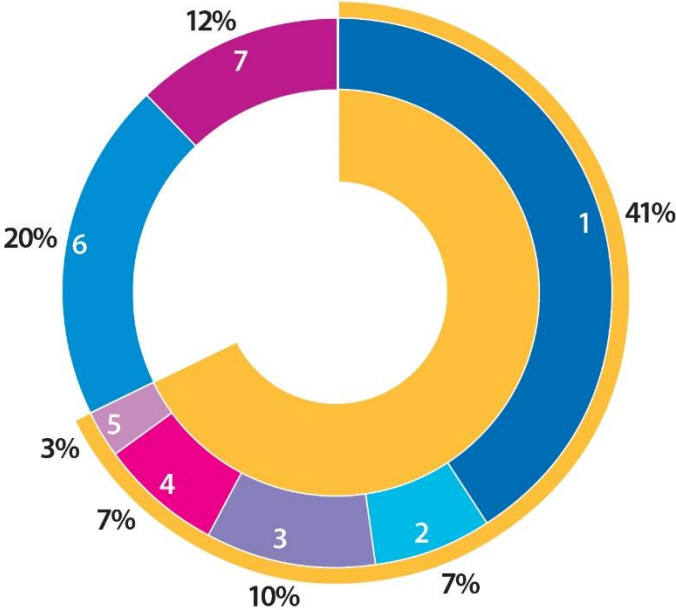
FY 2016/17
 Order Intake £366m
 [FY 2015/16
 Order Intake £361m]

Rail	Automotive	E&E	Off-Highway & CV	HPV&M	Defence
					
£73m [£58m]	£116m [£113m]	£53m [£47m]	£30m [£27m]	£88m [£97m]	£6m [£19m]

Orders and pipeline well-balanced across products and services

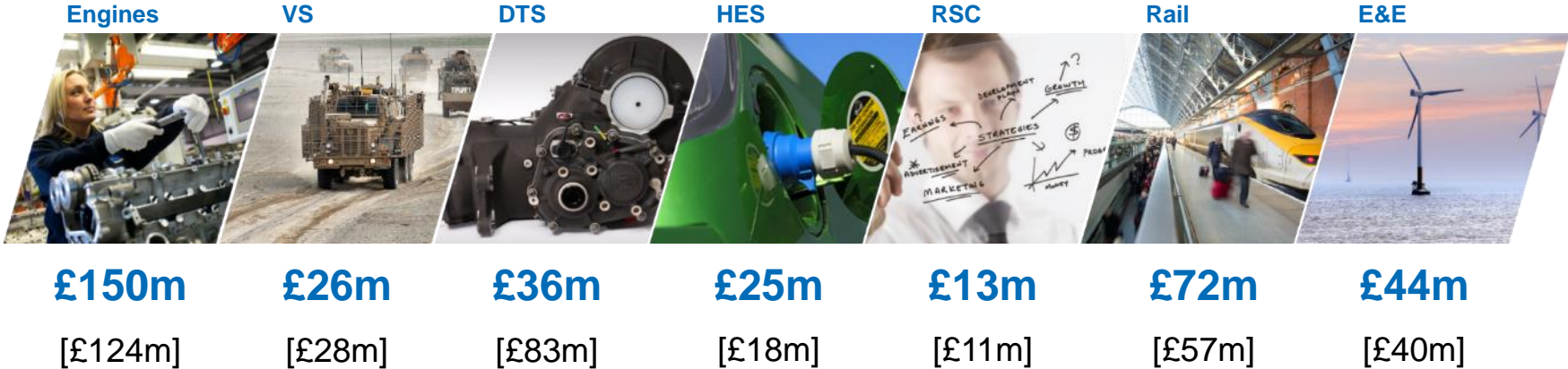


- 1. Engines
- 2. Vehicle Systems
- 3. Driveline & Transmission Systems
- 4. Hybrid & Electric Systems
- 5. Strategic Consulting
- 6. Rail
- 7. Energy & Environment



1-5 contains order intake relating to electric or hybrid vehicles of £64m (17% of total order intake)

FY 2016/17
Order Intake £366m
 [FY 2015/16
 Order Intake £361m]



Electrification – order intake relating to electric or hybrid vehicles is £64m or 17% of Group order intake



- Our hybrid electric vehicle activity features in a range of our products and services and is increasing

Powertrain
strategy

Battery
Design

Motor Design

Power
Electronics

Transmissions

Engines

Powertrain
integration

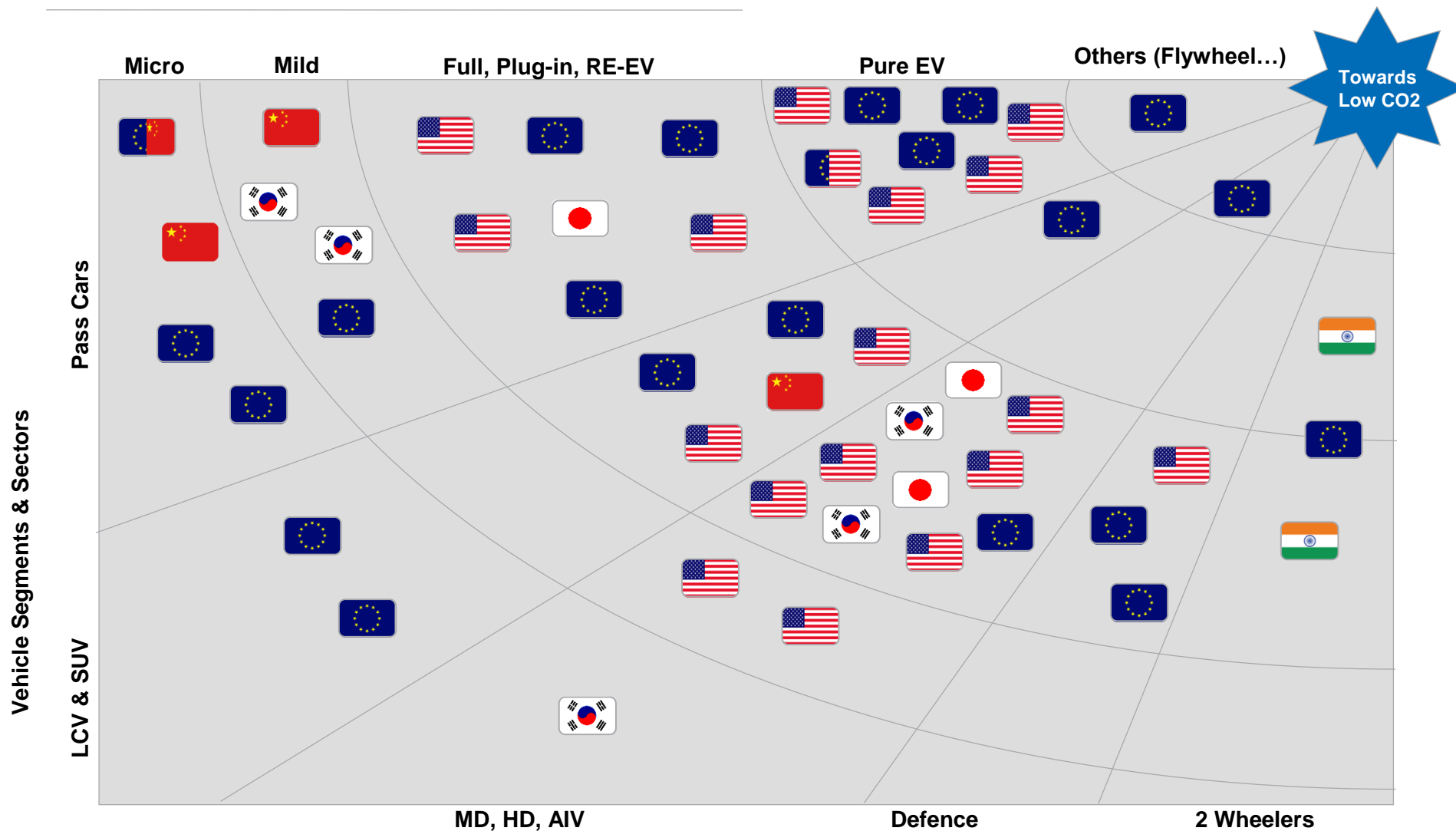
Vehicle
systems
integration

Vehicle
attribute
development

Ricardo has developed significant expertise in H&EV with well over 200 projects delivered across all industry sectors over the last decade



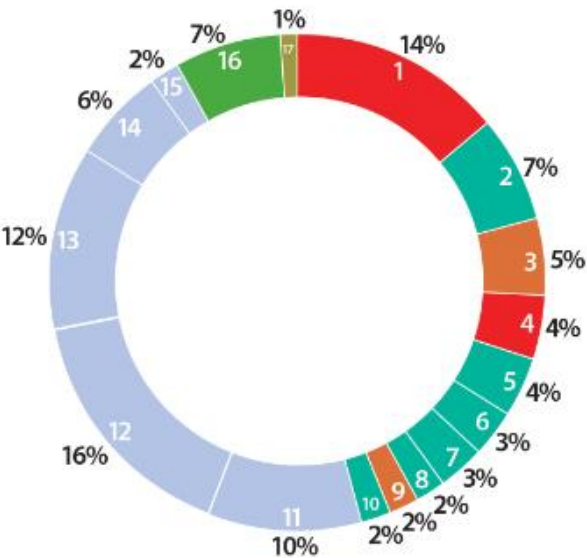
Selection of Key H&EV completed projects



Diverse customer mix, with a good level of multi-year business

Our top 3 customers are spread across Performance Products, Automotive and Rail

Ricardo plc External Order Intake by Customer for Year Ended 30 June 2017



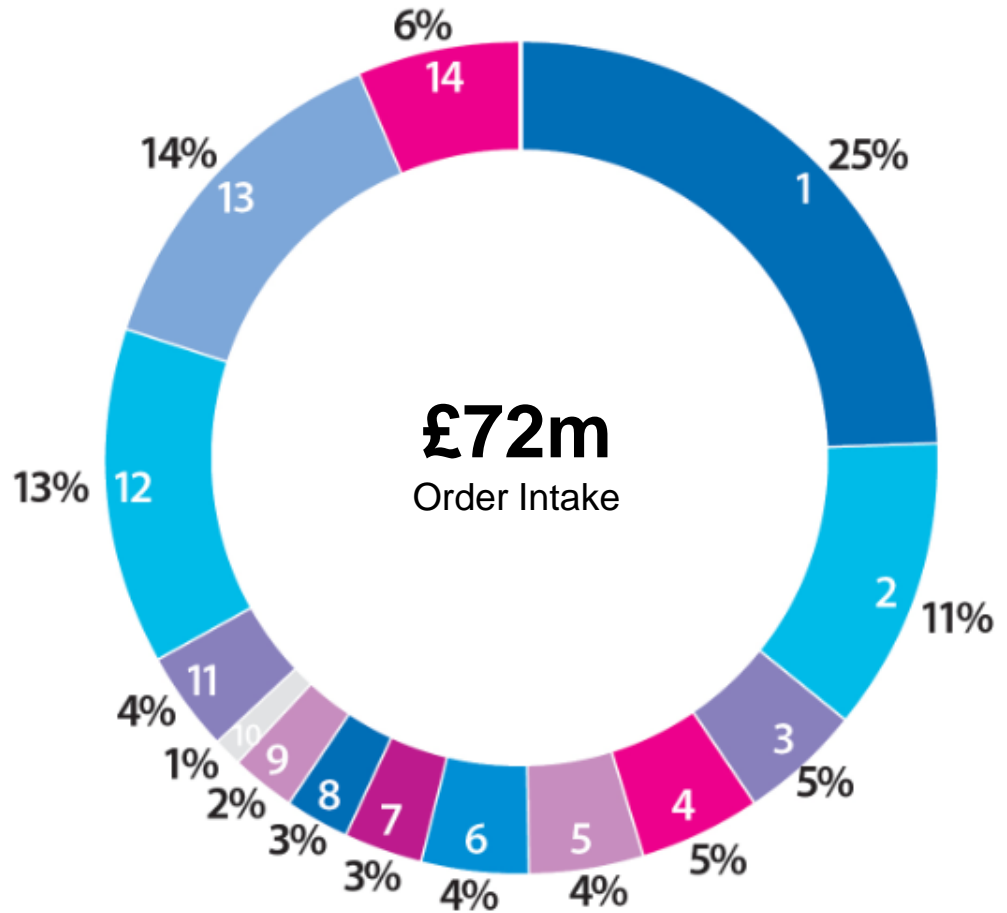
- 1. Key Client 1
- 2. Key Client 2
- 3. Key Client 3
- 4. Key Client 4
- 5. Key Client 5
- 6. Key Client 6
- 7. Key Client 7
- 8. Key Client 8
- 9. Key Client 9
- 10. Key Client 10
- 11. Rest of UK
- 12. Rest of Asia
- 13. Rest of Europe
- 14. Rest of North America
- 15. Rest of World
- 16. UK Government
- 17. US Defence



FY 2016/17
Order Intake £366m

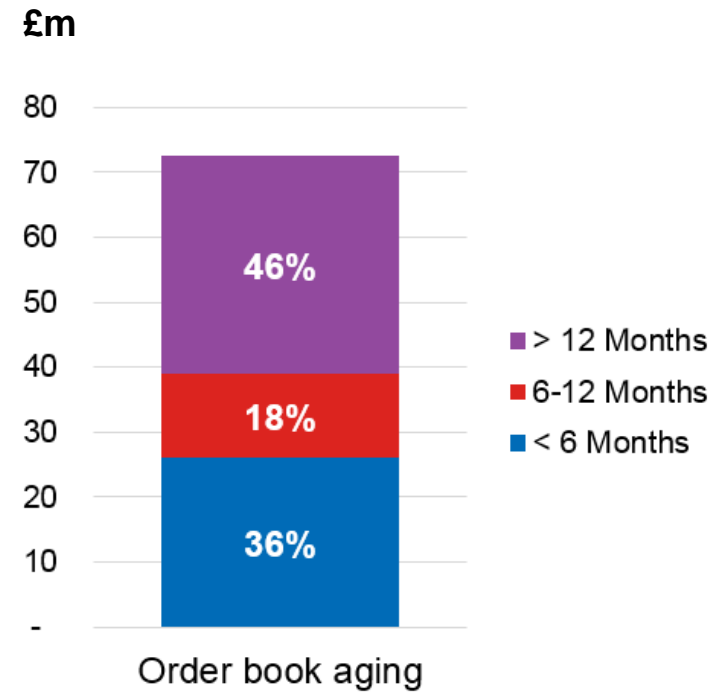
[FY 2015/16
 Order Intake £361m]

Focus on Rail – Technical Consulting



- | | | |
|-----------------|-------------------|--------------------|
| 1. Key Client 1 | 6. Key Client 6 | 11. Rest of UK |
| 2. Key Client 2 | 7. Key Client 7 | 12. Rest of Asia |
| 3. Key Client 3 | 8. Key Client 8 | 13. Rest of Europe |
| 4. Key Client 4 | 9. Key Client 9 | 14. Rest of World |
| 5. Key Client 5 | 10. Key Client 10 | |

- Over 1,300 live projects
- No of people – 580
- Revenue of c. £60m



Ricardo Rail – Global Safety Critical Systems Assurance

London



Ricardo Certification is providing accredited assessment services for the central section of London's forthcoming Elizabeth Line – role extends across design, construction and commissioning

Riyadh



As the ISA, Ricardo will deliver the necessary assessments to provide Arriyadh Development Authority with confidence the new system will operate safely upon its opening.

Beijing



Independent Safety Assessment (ISA) for the driverless vehicles on Beijing's Yanfang Line, the city's first automated metro and the first in China to use sub-systems developed by domestic manufacturers.

Delivering Excellence Through Innovation and Technology

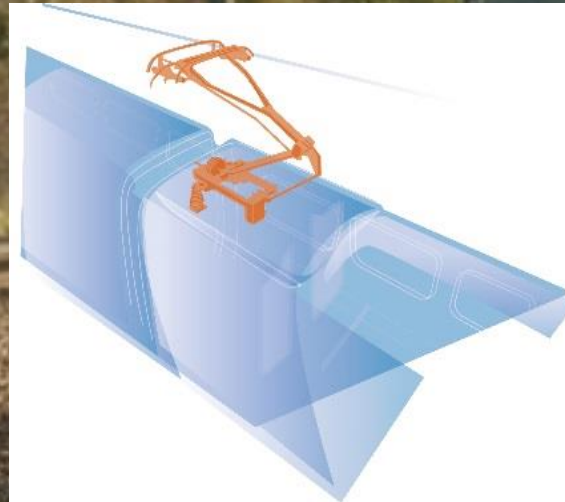
Ricardo Rail – Global Safety Critical Systems operations

Safety management



We provided an international team of experts to review the Safety Management System of KORAIL's high speed network, with recommendations for long term improvements

Condition monitoring



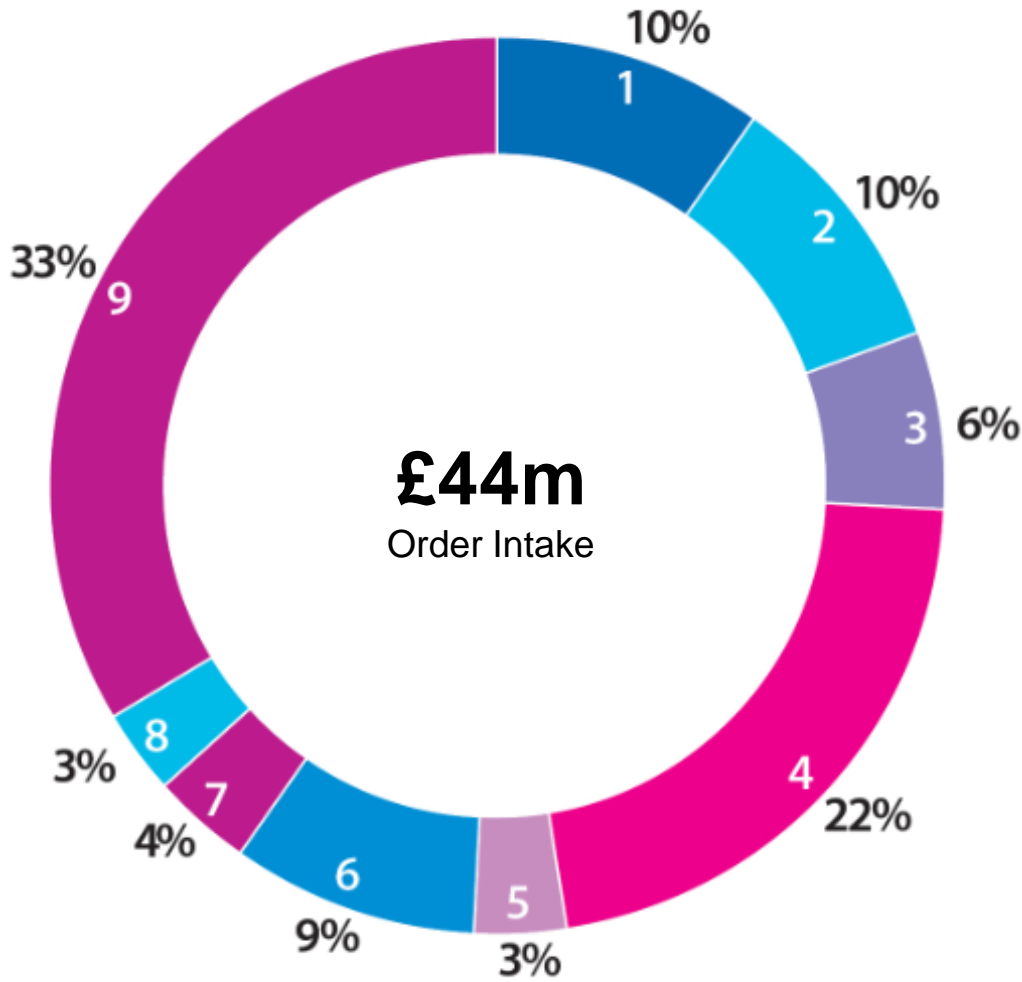
Using a combination of radar, laser, video and photo technology, PanMon can monitor the condition of individual pantographs on traffic passing at speeds of up to 250 km/hr.

Danish resignalling



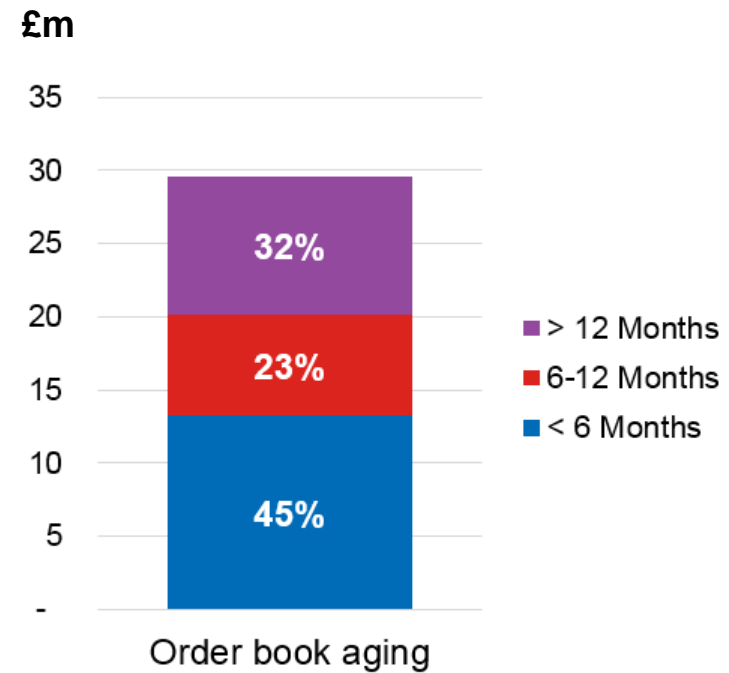
We are overseeing the safety assessment of the migration of the entire Danish network to ERTMS signalling technology – the largest programme of its kind Europe has ever seen.

Focus on Energy and Environment – Technical Consulting



- 1. Key Client 1
- 2. Key Client 2
- 3. Key Client 3
- 4. Rest of UK
- 5. Rest of Asia
- 6. Rest of Europe
- 7. Rest of North America
- 8. Rest of World
- 9. Rest of UK Gov

- Over 600 live projects
- No of people – 460
- Revenue of c. £45m



Delivering Excellence Through Innovation and Technology

National Atmospheric Emissions Inventory

As the UK's designated Inventory Agency, Ricardo Energy & Environment compiles data on greenhouse gas and air pollutant emissions for all UK sectors.

The data are used to assess UK government policies, monitor progress against emissions targets, report to the UNFCCC and UNECE and, ultimately, safeguard the health and well-being of the UK's population and the environment.



Deriving transport benefits from big data and the internet of things

Ricardo Energy & Environment provided advice to the Department for Transport on the potential for big data and the internet of things to transform mobility in smart cities.

Our research covered potential applications, barriers and enablers, new business models and the feasibility of open data architectures.



Implementing Nigeria's National Climate Action Plan (Nationally Determined Contribution (NDC))



A high-profile project to develop sectoral climate change action plans for Government of Nigeria, funded by UNDP



- Agriculture
- Industry
- Oil & Gas
- Power
- Transport



- Mitigation
- Adaptation
- Finance
- Governance
- MRV (tracking)



An example of applying our technical, policy and finance expertise to help countries deliver on the Paris Agreement



Inputs	Outputs
<p>High calibre consulting resources (engineering and stakeholder engagement)</p>	<p>3,000 professionals in the Power Sector trained :</p> <ul style="list-style-type: none"> ➤ <i>Advanced Power System Planning</i> ➤ <i>Smart Grids and Innovative Technologies</i> ➤ <i>Renewable Energy</i> ➤ <i>Sectoral Governance and Planning</i> ➤ <i>Operation & Maintenance of Assets</i>
<p>Outcomes</p>	<ul style="list-style-type: none"> ➤ Institutional Development ➤ Technical capacity development ➤ Improved sectoral governance ➤ Facilitate Government of Bangladesh goals of Electricity Access for All by 2020
<p>Impacts</p>	<ul style="list-style-type: none"> ➤ Long term sustainability of the Power Sector in the country ➤ Greater access of population to electricity networks



Airports

IATA forecasts passenger demand to double 2015 - 2035

Multidisciplinary airports team supporting clients across their environmental improvement lifecycle

Ricardo working with 13 UK airports





Delivering Excellence Through Innovation and Technology

Critical Program Recovery: Siemens Gamesa

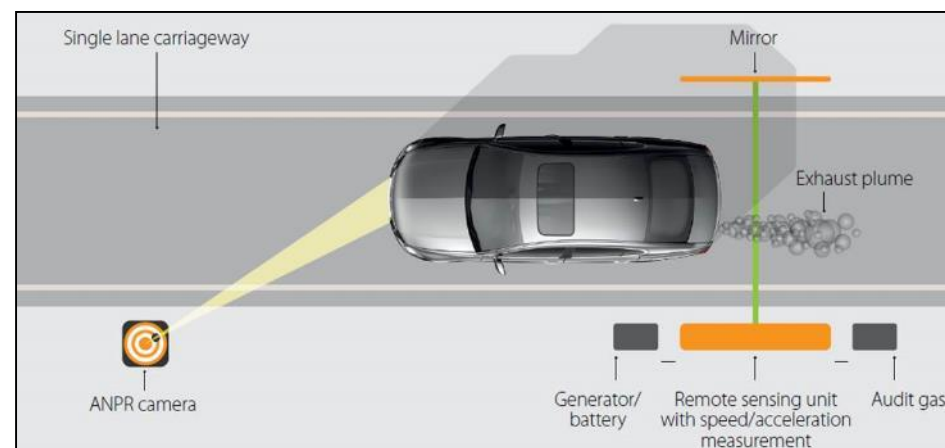
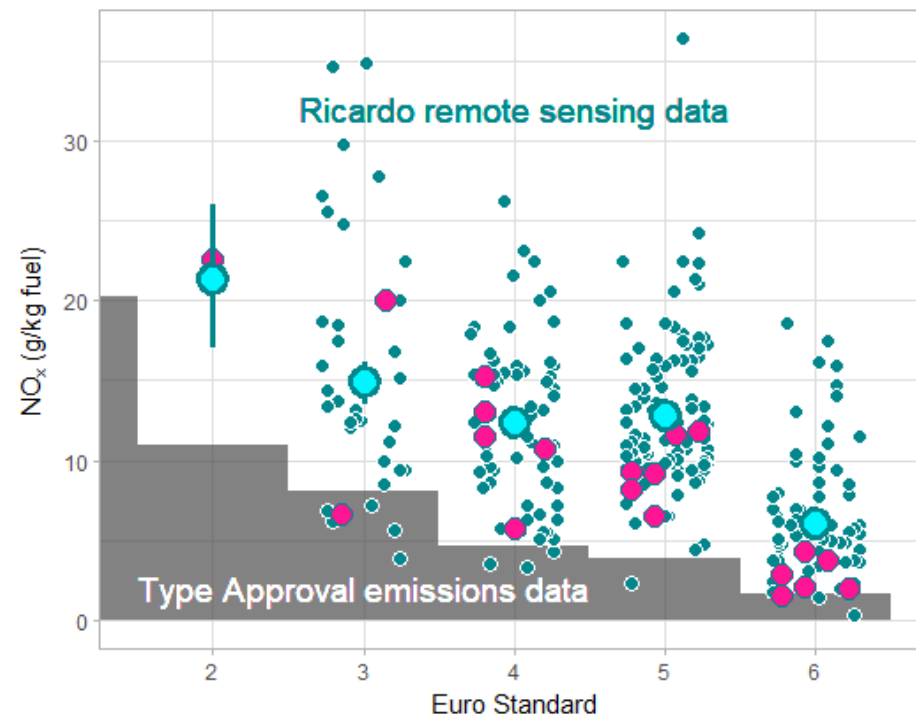
- ✓ Production launch of nacelles in Brande, DK
- ✓ Ramp up of blade production in Aalborg, DK and Hull, UK
- ✓ Global cost reduction of blades in CN, DK, USA



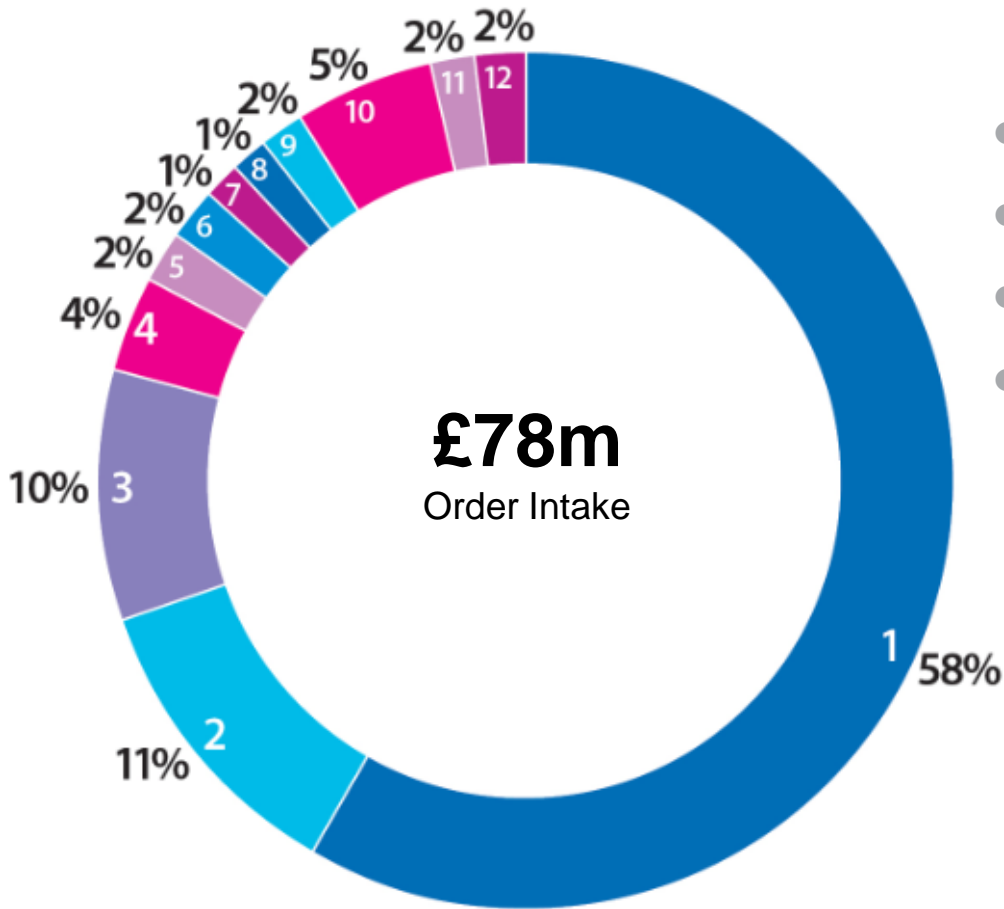
Vehicle Emission Remote Sensing

- Measuring vehicle emissions under real driving conditions
 - UV/Infrared beam to measure emissions
 - Measures 1000s vehicles per day
- Ricardo owned database ~50,000 and growing
- Complementary to other vehicle emissions measurements (PEMS and lab based)
- Timely, with concerns over NO_x emissions, health impacts and the challenge of meeting air quality limits
- Clients – Government, Local Authorities (Clean air Zones), OEMs

Outcomes - on-road measurements typically between 3-4 times higher than laboratory measurements and can be much greater differences for individual manufacturers

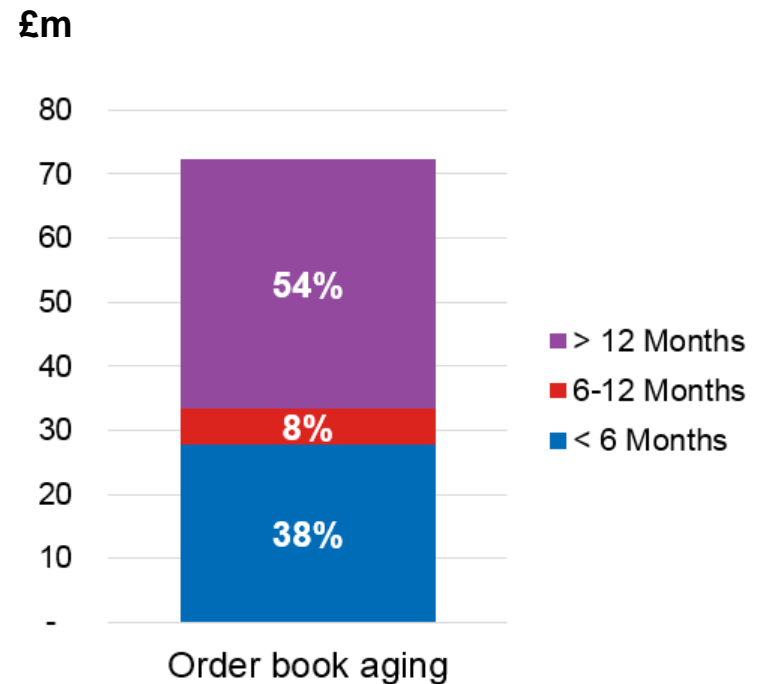


Focus on Performance Products



- Over 30 live projects
- Contracts outside of order book is > £100m
- No of people – 360
- Revenue of c. £70m

- | | | |
|-----------------|------------------|---------------------------|
| 1. Key Client 1 | 6. Key Client 6 | 11. Rest of Europe |
| 2. Key Client 2 | 7. Key Client 7 | 12. Rest of North America |
| 3. Key Client 3 | 8. UK Gov | |
| 4. Key Client 4 | 9. Rest of UK | |
| 5. Key Client 5 | 10. Rest of Asia | |





Delivering Excellence Through Innovation and Technology

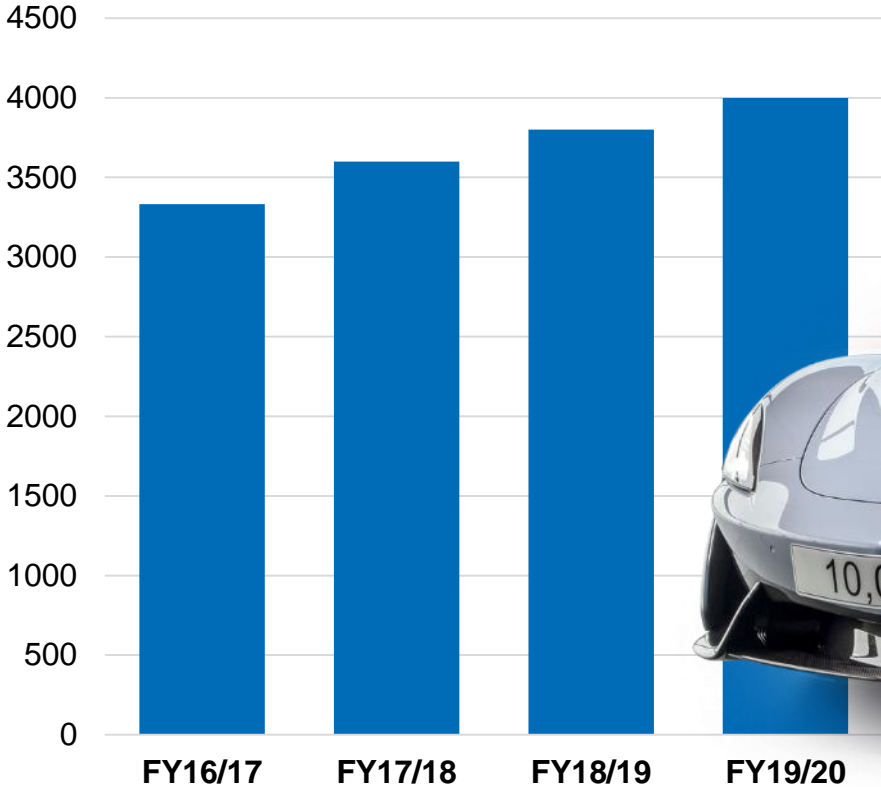
Ultimate performance transmission

Ricardo's Performance Products division is working with Aston Martin, to create the seven-speed transmission system for the truly spectacular Aston Martin Valkyrie. The new bespoke seven-speed paddle-shift transmission is being designed and manufactured by Ricardo in accordance with the vehicle's demanding specifications, channeling the huge power of the Aston Martin Valkyrie's 6.5-litre naturally aspirated V12 engine.



- 10,000th McLaren engine delivered in FY1617

McLaren Engine Volumes



- New derivatives under discussion

Delivering Excellence Through Innovation and Technology

Water Systems Innovation

Ricardo Software and the Energy & Environment team are working together in partnership with a major UK Water Utility to develop the IGNITE tool to model water supply network - hence transferring automotive expertise into the water sector





Delivering Excellence Through Innovation and Technology

Real-Time Virtual Vehicle

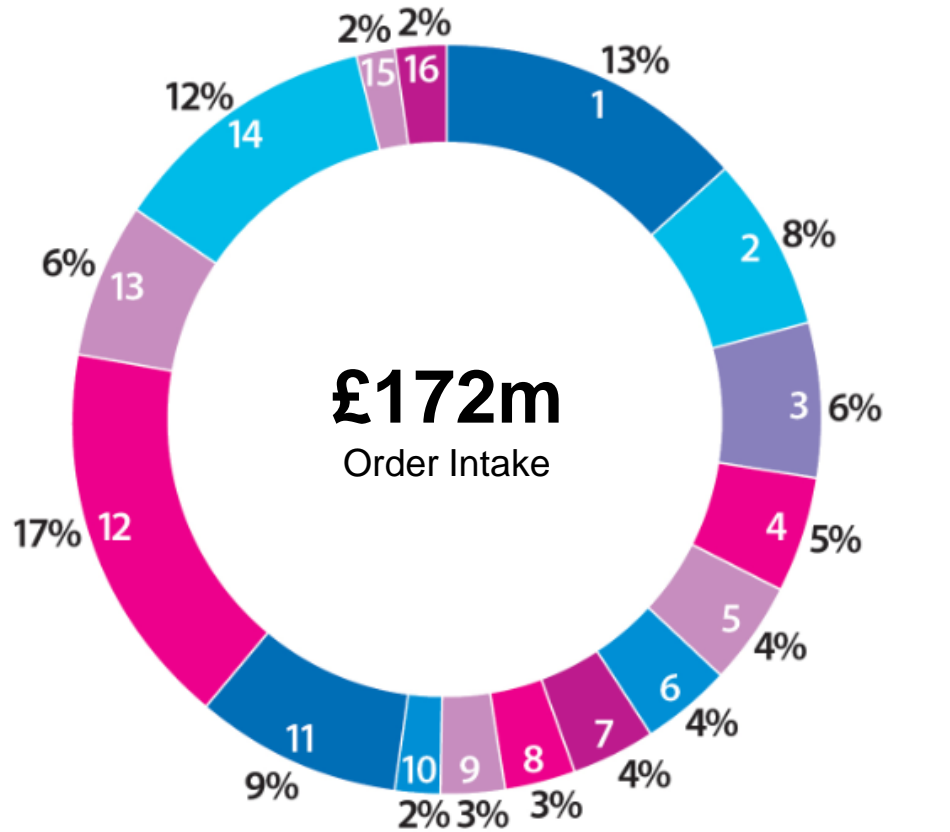
Ricardo Software is working with a number of global OEMs to develop a real-time running 1D 'Virtual Vehicle' on their HiL stations connecting WAVE-RT together with vehicle dynamic, driveline and control strategy models from other vendors

The global OEMs now plans to roll-out WAVE-RT within the 'virtual calibration' toolchain to drive significant reductions in testbed and vehicle prototype utilisation



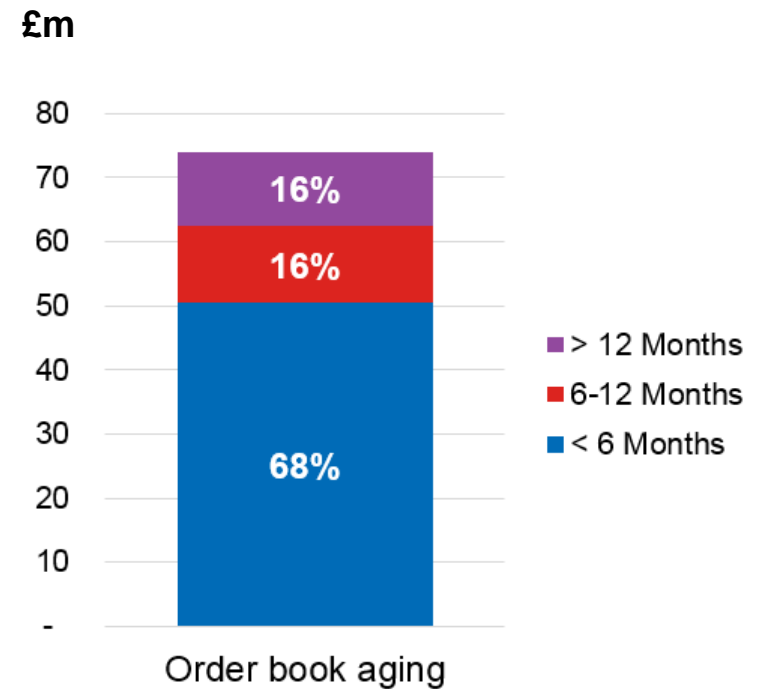
RICARDO

Focus on Global Automotive – Technical Consulting



- | | | |
|-----------------|-------------------|---------------------------|
| 1. Key Client 1 | 7. Key Client 7 | 13. Rest of Europe |
| 2. Key Client 2 | 8. Key Client 8 | 14. Rest of North America |
| 3. Key Client 3 | 9. Key Client 9 | 15. UK Gov |
| 4. Key Client 4 | 10. Key Client 10 | 16. US Defence |
| 5. Key Client 5 | 11. Rest of UK | |
| 6. Key Client 6 | 12. Rest of Asia | |

- Over 700 live projects
- No. of people - 1,460
- Revenue of c. £175m





Ricardo has previously partnered with DAF Trucks on the European EcoTwin project

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UK truck platooning trials

Ricardo is participating in a consortium of partners including DAF Trucks, TRL, and logistics specialist DHL, that will deliver the first real-world operational trial of platooned vehicles on UK roads. Ricardo Automotive will apply a wide range of experience gained in previous and ongoing platooning projects in both Europe and the USA, with this new UK project collecting information and independently evaluating heavy vehicle platooning under real-world operational conditions.



FIREWALL DISABLED

MALWARE

CYBER ATTA

RANSOMWARE



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Ensuring automotive cyber security

Ricardo is partnering with HORIBA MIRA, Roke, Thatcham Research and Axillium Research, in the 5*StarS in the 'Automotive Cyber Security through Assurance' project. The project will address the increased threat from cyber security with the proliferation of connected and autonomous road vehicles, with the ultimate aim of developing a 5-star type consumer rating framework analogous to existing EuroNCAP safety ratings.

SECURITY BREACH

VIRUS DETECTE



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Project Portal Class 8 Hydrogen Fuel Cell

Ricardo supported Toyota with the integration of 2 Mirai fuel cell systems (fuel cell stacks, Hydrogen storage tanks, e-machines, batteries and transmission) into a class 8 glider. Resulting in a Proof of Concept vehicle that has gone through validation testing and will be used in port service to evaluate the technology for larger scale application.

HIGHLIGHTS – for the year ended 30 June 2017



- Record order book at £248m and strong order intake at £366m
- Revenue up 6% to £352m
- Resilient performance across the business with underlying PBT at £38.3m in line with expectations, despite disrupted flow of orders in automotive
- Good performance from EE, Rail and PP
- Good order flow in Automotive for hybrid/EV activity (17% of Group total) and engines
- Acquisition of Exnovo in the year and Control Point completed post year-end
- Outlook remains positive with a good platform for growth





Income Statement – Underlying and total Group

£m	Year ended 30 June						Year-on-Year growth	
	2017	2017	2017	2016	2016	2016	Underlying ⁽¹⁾	Total
	Underlying ⁽¹⁾	Specific adjusting items	Total	Underlying ⁽¹⁾	Specific adjusting items	Total		
Revenue	352.1	-	352.1	332.4	-	332.4	6%	6%
Gross profit	132.9	-	132.9	129.8	-	129.8	2%	2%
Administration costs	(92.1)	(6.1)	(98.2)	(90.2)	(4.7)	(94.9)	2%	3%
Operating profit	40.8	(6.1)	34.7	39.6	(4.7)	34.9	3%	(1)%
Net finance costs	(2.5)	-	(2.5)	(1.9)	-	(1.9)	32%	32%
Profit before tax	38.3	(6.1)	32.2	37.7	(4.7)	33.0	2%	(2)%
Taxation charge	(8.8)	1.4	(7.4)	(8.6)	1.2	(7.4)	(2)%	-
Profit for the year	29.5	(4.7)	24.8	29.1	(3.5)	25.6	1%	(3)%

(1) excluding specific adjusting items, which comprise amortisation of acquired intangible assets, acquisition-related expenditure and reorganisation costs. In the prior, non recurring income for claims under the Research and Development Expenditure Credit ('RDEC') scheme in respect of previous years were also included.

Specific adjusting items



£m	Year ended 30 June	
	2017	2016
Amortisation of acquisition-related intangible assets	4.0	3.4
Acquisition-related expenditure associated with LR Rail	0.1	1.6
Other acquisition-related expenditure	1.6	1.2
Reorganisation costs	0.4	0.0
Non-recurring income for RDEC claims in respect of prior years	0.0	(1.5)
Total specific adjusting items	6.1	4.7

Global tailpipe and CO₂ emissions legislation adherence are “must haves” in the development budget of many of our clients



Vehicle	Region	2010	2015	2020	2025	
Automotive & LCV	Europe	Euro 5	Euro 6a	Euro 6b	Euro 6d-TEMP - WLTP & RDE	Euro 6d - WLTP & RDE
		Passenger Cars: 130 gCO ₂ /km			Passenger Cars: 95 gCO ₂ /km	
	US (49 States)	Tier 2		Tier 3		
		2012-2016 standards		2017-2025 standards		
	California	LEV II		LEV III		
		LEV II standards (2009-2016)		LEV III (2017-2025, consistent with EPA standards)		
	China	China IV (Euro 4)		China 5 (Euro 5)		China 6a - WLTP & RDE
	Phase 2	Phase 3	Phase 4 (Passenger Cars; new standards for LCVs from 2018)		China 6b - WLTP & RDE	
India	Bharat Stage IV (Euro 4 equivalent)				Bharat Stage VI (Euro 6 equivalent)	
				2017 standards	2022 standards	
Japan	Post New Long Term		WLTP based standards (proposed)			
	2010 standards		2015 standards		2020 standards	
Motorcycle & Personal Transportation	Europe	Euro 3		Euro 4		
				Euro 5		
	US (49 States)	Tier 2 for Class III; Tier 1 for classes I and II (harmonised with California)				
	California	California Motorcycle Limits: Tier 2 for Class III; Tier 1 for classes I and II				
	China	China III			China IV - WMTC	
	India	Bharat Stage III		Bharat Stage IV		Bharat Stage VI
	Japan	2010 standards			Euro 4 based standards	
Taiwan	Euro 3 based standards		Euro 4 based standards		Euro 5 based standards	
Commercial Vehicles (Medium & Heavy-Duty Trucks)	Europe	Euro V		Euro VI		
				Euro VII		
	US (49 States)	EPA 10				
				Phase 1 federal standards	Phase 2 (2018-2027) federal standards	
	California	EPA 10		Optional low NOx limits	Compliance of older vehicles to EPA 10	
				Phase 1 federal standards	Phase 2 (2018-2027) federal standards	
	China	China IV		China V		China VI (proposed)
	Phase 1 standards		Phase 2 standards		Phase 3 standards (proposed)	
India	Bharat Stage IV				Bharat Stage VI	
	Introduction of regulation being considered					
Japan	Post New Long Term		2016 standards			
	2015 standards					
Off-Highway	Europe	Stage IIIB		Stage IV		
				Stage V		
	US	Tier 4 Interim				
		Tier 4 Final				
	China	Stage II		Stage III (Nationwide) - Stage IV (Beijing)		Stage IV Nationwide (proposed)
India	Bharat Stage III (Tractors and CEV)					
Japan	2006 Non-Road Standards		2011 Non-Road Standards		2014 Non-Road Standards	
Rail	Europe	Stage IIIA		Stage IIIB		
				Stage V		
	US	Tier 2		Tier 3		
		Tier 4 Switch & Line Locomotives				
India	Not yet regulated					
Australia	Not yet regulated					
	Proposed standards under discussion					
	Studies ongoing to adopt US legislation					



Global Automotive Electrification Case Studies

Delivering Excellence Through Innovation & Technology

www.ricardo.com

Ricardo has a strong track record of working successfully with global vehicle OEM's to deliver hybrid and electric vehicle systems



MAJOR xEV VEHICLES PROGRAMMES ONLY (2005 onwards)											Technology / Activity Area								
Sector	#	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014+	Concept Definition	System Specification & Design	Component Specification and Design	Control System Development	Driveline development	System Integration	Prototype Build and Testing	
PASS CAR	1	BSG & ISG for A5											✓	✓	✓	✓		✓	✓
LCV	2						Diesel RE-EV						✓	✓		✓			
PASS CAR	3				Mild Hybrid BSG + AT								✓	✓		✓		✓	
SUV	4						EV & RE-EV						✓	✓	✓	✓	✓	✓	✓
PASS CAR	5				RE-EV Electric rear axle								✓			✓	✓	✓	✓
HPV	6						Premium P-							✓	✓			✓	✓
PASS CAR	7				Multi-mode electric drive axle										✓	✓	✓	✓	✓
PASS CAR	8							Plug-in PowerSplit HEV					✓			✓			✓
DEF	9				FTTS Full								✓	✓	✓	✓	✓	✓	✓
HD CV	10					Class 8 dual-mode										✓	✓	✓	✓

Concept to Production

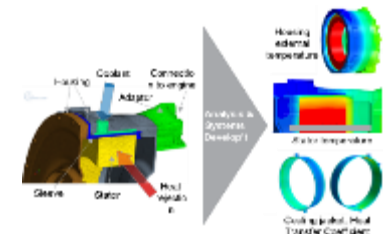
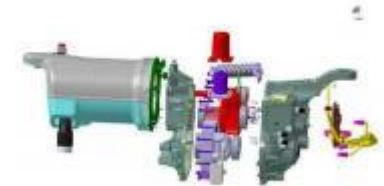
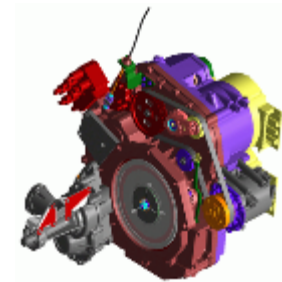
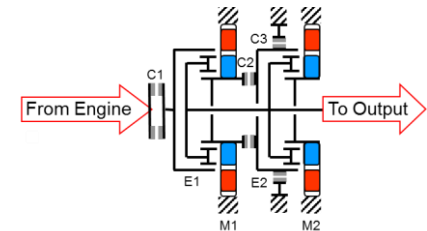
Concept to Prototype

Research (to Demonstrator)

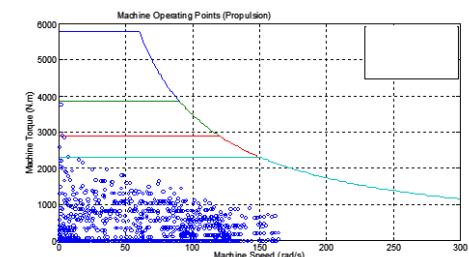
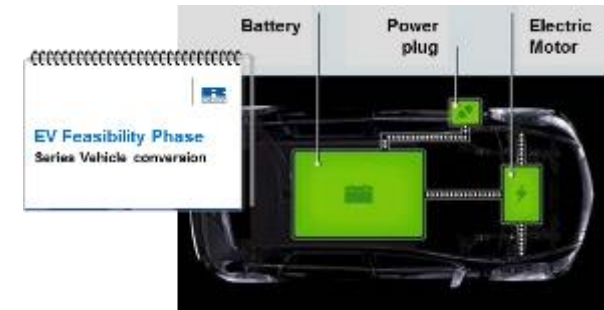
Summary

- The following case studies from 2000 are a snap shot of significant electrification related projects completed
- This is supported by many other smaller more focused projects not covered here

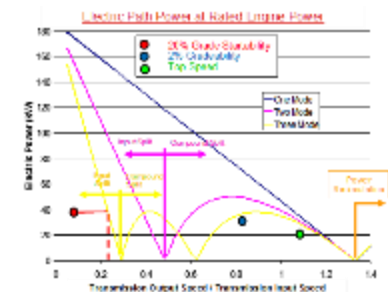
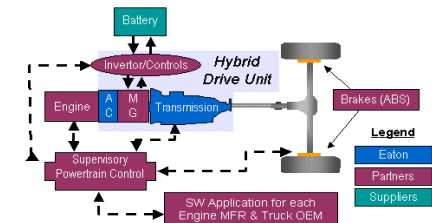
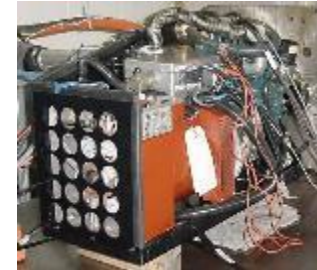
- Year 2000 - 2005 for major OEMs and Suppliers
 - **1) Power Split hybrid transmission simulation and control strategy development**
 - 8% improvement in economy, excellent performance, cost saving from motor optimization
 - **2) Dual Motor, Dual clutch transmission concept**
 - Multiple hybrid mode functionality and good driving feel for EU customers
 - Cost benefits analyzed, concept designed
 - **3) Electric Vehicle Rear Drive Module**
 - Concept design, analysis, manufacture, testing
 - Finished product in 8 months and supplier process engineering support for high volume
 - **4) Electric Motor Cooling Analysis**
 - Improved cooling system for existing electric motor and made design recommendations to successfully cool



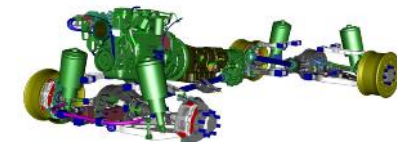
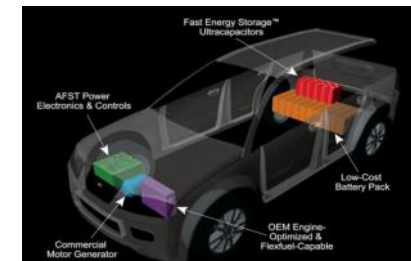
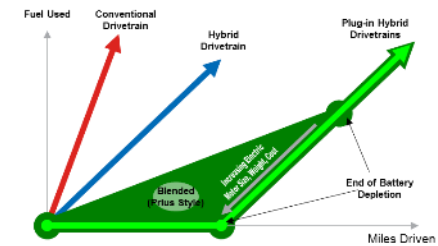
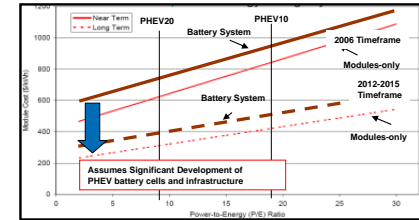
- Year 2005 - 2010 for major OEMs and Suppliers
 - **5) EV Conversion study**
 - Definition of requirements and market feasibility
 - Optimization of specifications and costs
 - **6) Defence Systems parallel hybrid demo vehicle**
 - Clean sheet vehicle designed by Ricardo
 - Parallel hybrid system selection, development and application along with high mobility chassis
 - Fast 29 week delivery meeting all requirements
 - **7) Hybrid Powertrain for Agricultural Application**
 - Feasibility study for performance improvement
 - Energy audit, technology comparison and simulation
 - 3% fuel economy improvement and added benefits
 - **8) Heavy Duty Hybrid Motor Technology Evaluation**
 - Advanced simulation techniques to assess technology
 - Development of hybrid control strategies
 - Costings and supplier recommendations for production



- Year 2005 - 2010 for major OEMs and Suppliers
 - **9) High Efficiency APU development**
 - Requirments, specs and technology selection
 - Hardware design procurement and test
 - Hardware installed in a truck showing 4% FC improvement
 - **10) Advanced Heavy Duty Hybrid System integration**
 - \$7M Government project, Ricardo partner
 - Support analysis of hybrid configuration, develop control system and assist build, commissioning and calibration
 - **11) Medium & Heavy Duty – Refuse Truck Application**
 - Advanced simulation of hybrid systems
 - Developed solutions showed 33% FC improvement
 - **12) On-Highway Truck Powersplit hybrid analysis**
 - Advanced simulation assessing CVT and motor
 - Optimisation of parameters for motor and transmission
 - Delivery of control strategies in Simulink



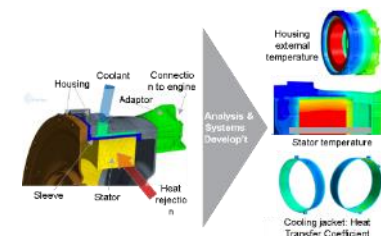
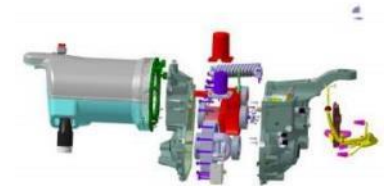
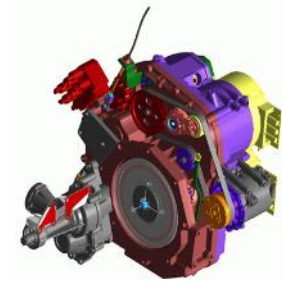
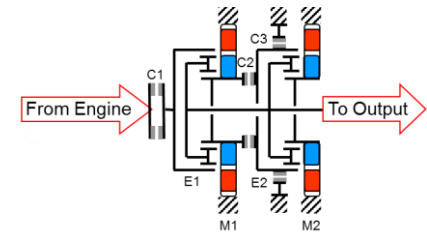
- Year 2005 - 2010 for major OEMs and Suppliers
 - **13) Plug-in Hybrid - Lifecycle cost model development**
 - Technology and cost of ownership modeling in 2006
 - Led to wide scale development of PHEVs in the market after 2010
 - **14) Detailed analysis of the PHEV Market in the US**
 - Business, supplychain, technology regulatory and Consumer study for adoption of PHEVs in the USA
 - Optimum launch date, target market and system recommendations
 - **15) Plug-in Hybrid Development program with dual energy storage plus transmission development**
 - Novel PHEV technology demonstrator specification
 - Design, build and deliver vehicles in 15 months
 - **16) Defence Fuel Efficient Demonstrator**
 - Comprehensive systems simulation, development and build
 - 12V ISG for energy recovery
 - Vehicle built and tested showing >70% FC improvement



- Year 2010 - 2017 for major OEMs and Suppliers
 - **17) Wireless Charging Systems Integration**
 - Demonstration of 7kW systems
 - Full electrical and network integration
 - Two projects
 - **18) Class 8 Fuel Cell Truck build for Toyota**
 - Turn-key engineering and build
 - Complete system responsibility
 - Commissioning and CATIA approval
 - Customer allowed publication
 - **19) Wide Band Gap semiconductor Inverter**
 - Novel semiconductor technology for very high efficiency
 - No cooling required at 2kW and 110V AC output
 - **20) EV Charging Point Hardware Development**
 - Complete charge point development, test and prototyping
 - Handover for high volume manufacture



- Year 2000 - 2005 for major OEMs and Suppliers
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- **Full Production 48V Mild Hybrid Programme**

- 48V architecture enabling focussed electrification coupled to a downsized TGD engine
- Project propels Ricardo's R&D activities on HyBoost into production
- The project features control of cross-divisional resource across multiple locations; Shanghai, UK and the client facilities in China



- **McLaren P1 Battery Pack Design & Development**

- Ricard packaged the battery pack in the vehicle, selected cell type and defined the module concept based on 3D thermal and CFD analysis for cooling design
- Ricardo undertook the complete mechanical design of modules, pack, internal hardware components and turn-key development of BMS hardware & software
- Delivered the World's most power-dense battery pack into production - 1.25 kW/kg – helping the McLaren P1 vehicle achieve phenomenal performance



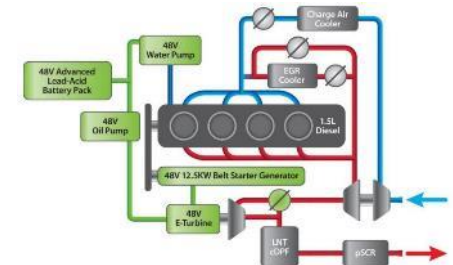
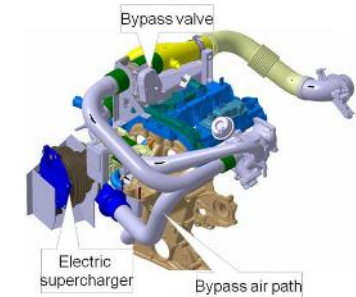
- **SARTRE – Developing Autonomously Controlled Vehicles that Operate in a Platoon on Public Highways**

- System implemented with control system enhanced using real-time V2V data
- Based on existing technologies (ACC, EPAS, sensors) with software enhancements, combined with advanced control software
- 5-vehicle mixed platoon successfully tested on test tracks & demonstrated on public roads in Spain with fuel saving of 8% for lead vehicle and 16% for following vehicle

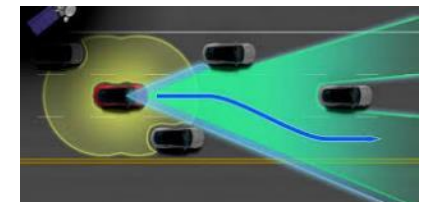
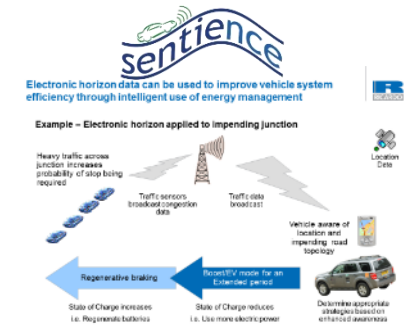


EMEA Case Study Summary for Significant Vehicle Level Electrification Projects

- **1) Efficient_C - PSA's 1st Full Hybrid demonstrator**
 - UK “EST” call to demonstrate a ~90g/km car – Partners: Ricardo, PSA Peugeot Citroen and QinetiQ – project funded by partners and EST
 - 30% FC improvement (combined) and CO₂ emissions relative to state-of-the-art diesel vehicle
- **2) Development of EV and REEV Demo Platforms**
 - EV/hybrid supervisory controller hardware platform and design of APU generator for integration into Ricardo Generic Technology Validator (GTV)
 - Land Rover Freelander EVs GTV vehicle built, and demonstrated
- **3) Hyboost – 12+xV Mild Hybrid Demonstrator**
 - 46% CO₂ reduction achieved, with driveability of 2.0L NA using a 1.0L gasoline, with ‘12+x’V micro-hybrid system consisting of 6kW Belt Starter Generator, Electric Supercharger and ‘12+x’V supplied from 12V battery with supercapacitors
- **4) ADEPT - 48V mild-hybrid Diesel C-segment vehicle Demonstrator**
 - 48V is being taken up by high percentage of global OEMs – ADEPT technology is being used by Ricardo in some
 - With targets of 75 g/km vehicle demonstrator, with roadmap to 70 g/km (base vehicle 88 g/km) using 1.5L gasoline, with 48V mild-hybridization consisting of 12.5kW Belt Starter Generator, low-cost advanced lead-carbon battery pack and electric ancillaries



- **1) Sentience uses “Electronic Horizon” to improve fuel economy**
 - Ricardo lead program to develop systems using “electronic horizon” (future road slope, curvature, speed limits, etc.) data
 - Vehicle fuel efficiency improved by 9% over NEDC cycle
 - Technology leader project when undertaken in 2007-2010
- **2) European Truck Platooning Challenge – EcoTwin**
 - Truck OEMs from around Europe drove their various platooning systems on European highways
 - Ricardo delivered the safety case for on-road use for ETPC and safety case by sub selection of standards and use of pre-existing documentation and processes
- **3) Support for L3 Pass Car Highway Pilot for 2020 Production**
 - In a L3 system the vehicle requires multiple redundancy including redundant sensing/steering and braking systems with an architecture to support fail operational behaviour
 - Ricardo is supporting during the development of the lidar/camera fusion system and to ensure appropriate quality is followed for developing the L3 system to production



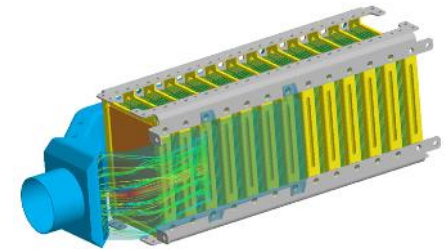
- **1) Ricardo Battery management System**

- Flexible system with master Battery Control Module interfacing with up to 32 slave Voltage Temperature and Balancing Modules
- BMS can measure up to 16 cells (or parallel sets) and is adaptable for any cell type and chemistry over large voltage range (16V – 1,000V)
- It is easily integrated to vehicle with multiple communication networks available



- **2) RevB – Lithium Sulphur Battery collaborative project**

- Ricardo increased the capability and functionality of its existing BMS, capable of running Model based battery management to optimally manage cells within a battery should permit increased pack working life, reduced pack size & better prediction of pack life
- Thermal & mechanical management of pack design



- **3) Fuel Cell Vehicle Concept Design for major Asian OEM**

- Simulation predictions of EV- & H₂ range, acceleration & gradability
- Design of 700 bar fuel system, component identification and safety validation

Confidential

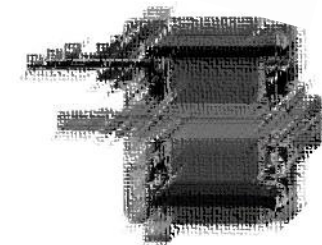
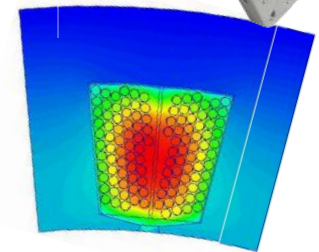
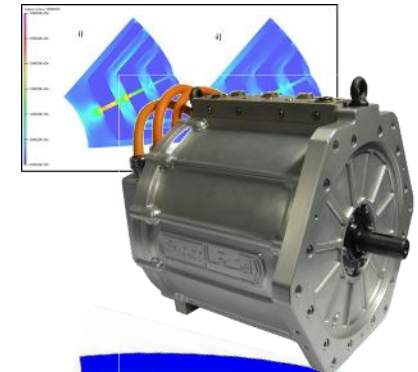
- **4) Enhanced Fuel Cell System collaborative project**

- Fuel cell system specification based on customer consultation prepared and delivered
- Fuel cell RE-EV vehicle simulation studies



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- **1) RapidSR – Rare Earth Material Free eMachine Design**
 - Ricardo developed a water cooled Synchronous Reluctance machine adapted for high speeds
 - Design was low cost good efficiency across a wide speed range with conventional stator and winding for manufacture
 - Challenges includes conflicting mechanical and magnetic requirements
- **2) Oil spray cooling of eMachine end windings**
 - New approach to cooling end windings of eMachine to increase power density for Asian OEM
 - Using knowledge of spray approach and modelling systems the Ricardo team supported improved, compact, eMachine design approach
- **3) High power 48V eMachine for propulsion system**
 - Significant improvement in peak power compared to 1st generation products so 48V can be a real alternative to high voltage systems in small to medium sized vehicles
 - >20% powertrain efficiency improvement compared to current vehicle
- **4) ISG development for early hybrid vehicle**
 - Development of ISG eMachine for hybrid vehicle to support Beijing Olympic Games
 - Design and development within Ricardo in the UK with productionisation for the Chinese market



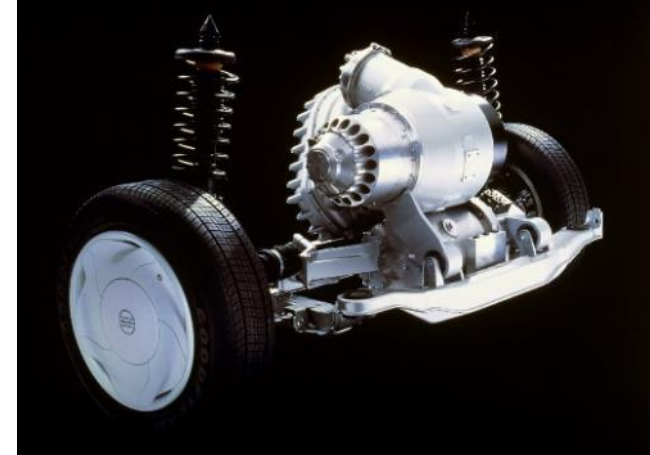
Electric Motor

Ricardo Hybrid Vehicle R&D projects



- The following R&D projects show that we have a long history of involvement in electrification innovation

- **1992 - Volvo ECC (Environmental Concept Car)**



The first high level hybrid vehicle simulation environment

Ricardo supported Volvo in optimising the powertrain system and control via a new Matlab/Simulink fully transient simulation programme, including gas turbine model. Good correlation obtained between vehicle operation and simulated data using US FTP75 drive cycle. (Ricardo DP 92/0160)

- 2000 - Ricardo i-MoGen Mild Hybrid Diesel vehicle demonstrator



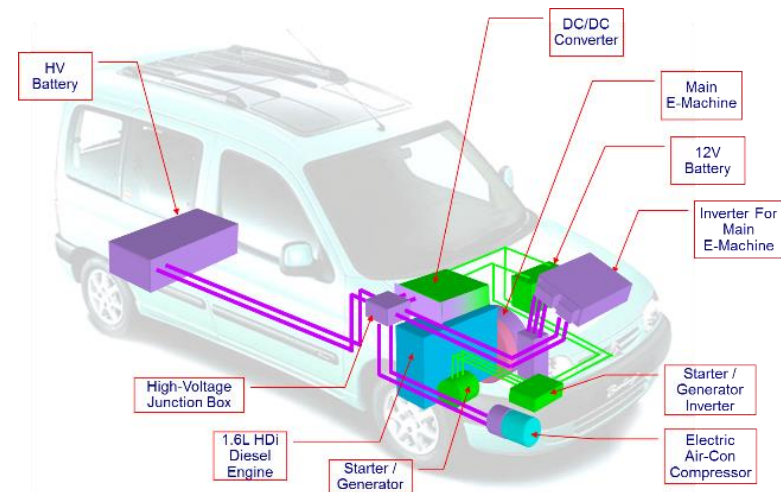
Major collaborative R&D programme with Valeo delivering bespoke 1.2 litre turbo-diesel combined with 42 Volt mild hybrid integrated electric motor/generator system. 42 Volt Nickel Metal Hydride battery. All electric ancillaries including variable speed pumps and fans, electric heating/air conditioning and actuators. Awarded RAC Dewar Trophy for technical innovation. Delivered 30% fuel economy improvement over base vehicle (Ricardo DP 02/2142)

- 2004 - Ricardo HyTrans vehicle



Collaboration with Ford & Valeo and part funded by UK Energy Savings Trust. 36 Volt advanced (VRLA) lead acid battery, 42 Volt belt starter generator system integrated with 2.0 litre diesel offering stop/start, regenerative braking and torque assist. Between 15-25% fuel economy improvement over typical urban delivery drive cycle (SAE 2005-01-1161)

- 2005 - Ricardo Efficient-C



Part funded by UK DfT Ultra Low Carbon Car Challenge, collaborating with PSA Peugeot Citroen. 288 volt li-ion battery, 1.6 litre diesel engine, 12 Volt belt mounted starter/generator, automated transmission and 25 kW motor/generator fitted to transmission. Electric heating/air conditioning. 35% fuel economy improvement over baseline vehicle. (see “Appropriate technology strategies for Hybrid vehicles – the key to successful products” 14th Aachen Colloquium “Automobile and Engine Technology”, October 2005)

- **2007 - Ricardo Sentience vehicle demonstrator**



Use of electronic horizon data to improve fuel efficiency of hybrid vehicles. Collaborative programme with Jaguar Land-Rover, Orange, TRL and Ordnance Survey with part funding from UK DfT. Fully automated vehicle speed control and energy system optimisation (including electric heating/air conditioning) using e-horizon and 3D GPS position data. Estimated fuel economy benefits of 14% during real world driving. (see Ricardo RD.07/403401.1)

- 2010 - Ricardo Electric SUV demonstrator



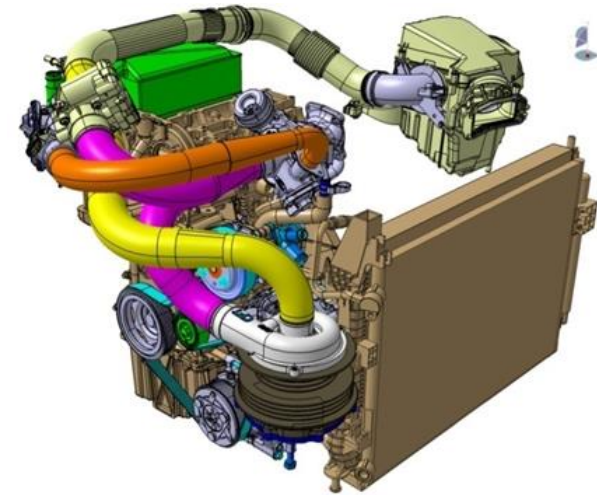
Collaborative programme with 7 partners including JLR and part funded by UK Gov and EU commission. Vehicle based on a Volvo XC60 SUV with A123 22kWh Li-ion battery, EVO Axial Flux 325 kW Motor, Reinhart Power Inverters & Ricardo Transmission. Ricardo responsible for full system design, control and implementation (see R000596-01)

- 2010 - Ricardo Range Extended EV



Using modified Fiat Twin Air 875cc Turbo-gasoline engine as APU with Ricardo designed integrated generator. Collaborative programme with 7 partners including JLR and part funded by UK Gov and EU commission. A123 22kWh Li-ion battery, EVO Axial Flux 325 kW Motor, Reinhart Power Inverters fitted to JLR Freelander. Estimated CO2 emissions for plug-in operation 57 g/km – 130 mile/gallon equivalent (see R000596-01)

- **2011 - Ricardo HyBoost**



Collaborative programme with Ford, Valeo, Imperial College and the Advanced Lead Acid Battery Consortium part funded by Innovate UK. Ford Focus fitted with an uprated 1.0 litre ecoboost engine, 12+X Volt mild hybrid system and e-boost to deliver a 40% reduction in CO2 emissions verses a 2.0 litre gasoline vehicle baseline with similar performance. Awarded the IMechE Automotive Division prize for the Environment in 2012) (see Hyboost – An intelligently electrified optimised downsized gasoline engine concept – ImechE paper)

- 2015 - Ricardo ADEPT Mild Hybrid Diesel



Collaborative programme with Ford, Control Power Technologies, the Advanced Lead Acid Battery Consortium, Faurecia and Nottingham University, part funded by Innovate UK. Ford Focus with 1.5 litre PSA diesel engine, 12.5 kW 48 Volt Belt Starter Generator, 48 Volt coolant pump and Air Conditioning, 48 Volt e-turbine for exhaust heat recovery and advanced selective catalytic reduction emissions control technology. Ricardo system integrator and control responsibilities. Demonstrated potential for 70 g/km drive cycle CO₂ emissions, 15% improvement over baseline diesel vehicle. (see Ricardo RQ Q3 2016)