Future Powertrains for luxurious and sporting vehicles in a sustainable world

Bob Joyce
Executive Director - Product Creation & Delivery

19th February 2014
Key Themes

• Company background

• Delivering technology and innovation in a fast moving world
  • Challenges –, CO2, Emissions, Fuels, Electrification, Complexity
  • JLR Strategy – Technology for Clean and Capable Cars

• Recent investments in propulsion innovation

• The role of game changing technology products - C-X75
**Recent Company Highlights**

**Investment in operations and recruitment**

- **£1.5 billion profit** in 2011/12 all re-invested into new products

- **Circa £2.75 billion** investment in products and facilities to March 2014

- Significant investment in **three UK manufacturing sites** and further investment in **new advanced engine manufacturing facility**

- More than **9000** recruited in the last 2 years – **312** Graduates and more than **200 advanced apprentices (level 3)** taken on in 2012

- **7000** Engineers & Designers

- JLR received a Corporate Responsibility Index **Platinum Award** (March 2012)

- JLR has established the **largest electric/hybrid** engineering team in UK – **approximately 240 engineers**
2013 Retail Sales
Growth across every region

North America
21% vs last year

UK
14% vs last year

EUROPE
6% vs last year

Asia Pacific
30% vs last year

Overseas
23% vs last year

425,006 sales. +19% 2012 vs 2013

80% Sales to Export
## Jaguar Land Rover

### In numbers

<table>
<thead>
<tr>
<th><strong>£2.75bn</strong></th>
<th><strong>26,000</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Investment</td>
<td>Employees</td>
</tr>
<tr>
<td>• Jaguar Land Rover will invest this in product creation and CAPEX in the year to March 2014</td>
<td>• Largest UK automotive employer</td>
</tr>
<tr>
<td></td>
<td>• 80,000 in supply chain, including 10,000 in dealerships</td>
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<td></td>
<td>• 190,000 UK jobs supported in total (incl. wider economy)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>£11bn per annum</strong></th>
<th><strong>&gt; £4bn per annum</strong></th>
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<tbody>
<tr>
<td>Export Revenue</td>
<td>UK Material spend</td>
</tr>
<tr>
<td>• Jaguar Land Rover accounts for over 20% (£1.9bn) of total UK exports to China</td>
<td>• £400m (per annum) worth of supply contracts were awarded for the Range Rover Evoque</td>
</tr>
<tr>
<td></td>
<td>• Over 40 companies in the UK</td>
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</table>
Vehicle assembly and stamping presently at three UK locations.

All products designed and engineered in the UK. Largest investor in automotive R&D and engineering in the UK and a major employer and exporter.
## The Global Challenges

### COMPLIANCE & GLOBALISATION
- FE and CO2
  - US, EU, China…..
- Emissions Tightening
  - SULEV spread…
- Environmental and Market Robustness
- Fuel Diversity

### MEGA TRENDS
- Sales Growth in Developing Markets
- Low Carbon Economy and Electrification
- Rightsizing and Efficiency Improvement
- Intelligence and Connectivity

### COMPETITIVENESS
- Improve Fuel Economy
- Increase Performance Status
- Enhance Premium Attributes

### PROFITABILITY
- Lean and Flexible Delivery
- Complexity Reduction
- Premium brand and product identity
Greenhouse gas levels; CO2

Weight reduction must combine with improved efficiency

Source: ADAC 10/2013
Emission challenge; Diesel Example

Test procedures besides legislation

Air quality in a congested world requires emission technology advances
EU6c RDE regulation requires emission compliance across most of the engine map
- Extension of EGR envelope for Diesel engines
- Higher exhaust aftertreatment conversion efficiencies required, higher Urea consumption
- Enrichment not acceptable in broad operating range for gasoline engines

Real world Air quality is demanding comprehensive emission technology application
Fuel and oil quality; Diesel sulphur content

Fuel variation threatens durability of emission technology
Alternative Fuels; Increasing Variety

Future bio-fuel variation and greater gas availability bring greater complexity and uncertainty.
Sources of Energy; Timescales

- **Seconds**: Photovoltaic Electricity
- **Minutes**: Direct Solar Heating
- **Hours**: Wind
- **Days - Weeks**: Water Power
- **Months - Years**: Biomass
- **Millions of Years**: Fossil Fuel (Coal N Gas Oil)

Renewable Sources:

- Sun

[Source: http://www.apsenergyconservation.org/PDF/MS-FormationOfFossil.pdf]
Energy Transfer Functions

Primary Energy Source  Energy Vector  Powertrain

- Coal: Fischer Tröpsch Gasification
- Crude Oil: Reforming
- Natural Gas: Steam Reforming
- Liquid Biofuel: Trans-esterification Fermentation
- Biomass: Fischer Tröpsch
- Wind
- Solar
- Hydro
- Geothermal
- Nuclear

Energy Vectors:
- Gasoline
- Diesel
- LPG
- CNG
- Ethanol
- Hydrogen
- Electricity

Powertrains:
- ICE
- Hybrid ICE
- Plug-in Hybrid ICE
- Fuel Cell
- Electric

Slide courtesy Ricardo
Future road transport; major role for ICE

Hybrid Electric-ICE powertrain are expected to dominate in future, with high liquid fuel usage

Source: ERTRAC Strategic Research Agenda
# Hybrid Types and Functions

<table>
<thead>
<tr>
<th>Functions</th>
<th>Stop Start</th>
<th>Mild Hybrid</th>
<th>Medium Hybrid</th>
<th>Full Hybrid</th>
<th>Plug in Hybrid</th>
<th>Range Extended Electric Vehicle</th>
<th>Electric Vehicle</th>
<th>Kinetic Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuts off the engine when the vehicle is stopped</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Shuts off and re-starts the engine when not required</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Stores braking energy for re-use later</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild use of stored energy to assist a conventional engine</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significant use of stored energy to assist a conventional engine (Enough to enable downsizing of primary power unit)</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Can drive for a limited time using stored energy (~3kM)</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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</tr>
<tr>
<td>Can drive for a significant time using stored energy (~40kM)</td>
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<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Can drive for a long time using stored energy (~160kM)</td>
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<td></td>
<td>X</td>
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<tr>
<td>Batteries can be recharged using mains electricity</td>
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<td></td>
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<td></td>
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<td>X X X</td>
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Battery cost/weight challenge

$66/kWh * LiNi$_{0.33}$Mn$_{0.33}$Co$_{0.33}$O$_2$

0.570 kWh/kg

$295/kWh * EV cell

0.150 kWh/kg

$663/kWh * Total pack

0.080 Wh/kg

X10 $/kWh

1 Wh/kg
Functional challenge of Battery design

Areas of failure modes for battery

<table>
<thead>
<tr>
<th>Performance</th>
<th>Durability and robustness</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (&lt;-0°C)</td>
<td>High temp cycle</td>
<td>Over voltage</td>
</tr>
<tr>
<td>voltage</td>
<td>High temp Key off</td>
<td>Over Discharge</td>
</tr>
<tr>
<td>High Current</td>
<td>Large No. cycles</td>
<td>Temperature</td>
</tr>
<tr>
<td>Long pulse time</td>
<td>High Voltage</td>
<td>Deformation</td>
</tr>
<tr>
<td></td>
<td>Wide voltage window</td>
<td>Internal short circuit</td>
</tr>
<tr>
<td></td>
<td>Storage time</td>
<td>External short circuit</td>
</tr>
<tr>
<td></td>
<td>Vibration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High voltage storage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low voltage storage</td>
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</table>
Jaguar Land Rover
Technology & Innovation Focus

Our focus for today's presentation
## Jaguar Land Rover Technology & Innovation Focus

<table>
<thead>
<tr>
<th>Capable on-road</th>
<th>Capable off-road</th>
</tr>
</thead>
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<tr>
<td>• Vehicle Capability</td>
<td>• Vehicle Capability</td>
</tr>
<tr>
<td>• Technologies to support an “amongst the leaders” position in Vehicle Dynamics &amp; Refinement for Jaguar</td>
<td>• Technologies to support a leadership position in Off-Road and ‘Breadth Of Capability’ for Land Rover/Range Rover.</td>
</tr>
</tbody>
</table>
Jaguar Land Rover
Technology & Innovation Focus

Clean

- CO₂ Reduction/Electrification
- Relentless legislative pressure likely to be sustained until mid century.
- Most territories tracking an 80% reduction by 2050.
- Major cities could act faster and more radically in a race to be ‘Green’
Todays Technology Solutions
Clean and capable
Active driveline
Hybrid vehicle
Evoque – Friction Reduction
Active Driveline system

PTU

RDU

Hydraulic feed to synchroniser

Triple cone synchroniser

Motor

Pump

Valve block

Clutches
Transparent Connection
Enhanced Capability

RDU Twin Clutch architecture enables Torque Vectoring
JLR Hybrid Technology
Range_e; XJ_e; CX75; Range Rover Hybrid

Range Rover & Range Rover Sport
World's first premium diesel SUV hybrids
16,000km Silk Trail expedition to India

- Visits 12 countries over 53 days and takes in some of the world’s most challenging roads, passes and trails
- Includes part of the ancient Silk Road trade route
- 1st hybrids to ever attempt this route
Mud
Sand
Rock
Snow
Water
Altitude 5360m above sea level
100m below
Range Rover Fuel Efficiency

1974: 30 miles
1994: 40 miles
2001: 45 miles
2012: 75 miles
2014: 95 miles

How far will 10 litres get you?
Innovative Future

Clean and capable
Emissions
Downsizing
Hybridisation
Future Emission - SULEV 30

Diesel Low Emission Research Vehicle demonstrates SULEV 30
Exhaust emissions – Complexity and Cost

**AdBlue® doser**
- Water cooled

**AdBlue® mixer**

**SCR catalyst**
- V = 2.0 l
- 400 cpsi, Cu-zeolite

**eDOC (EHC)**
- V = 1.8 l
- 130/600 cpsi

**I4 diesel engine**
- 2.2 l 140 kW CR
- 1TC HP-EGR

**Integrated SCR/DPF**
- V = 2.5 l
- 300 cpsi, Cu-zeolite

Challenging Cost and Complexity to achieve very low diesel emissions
Extreme Downsizing

Ultraboost collaborative project (supported by Technology Strategy Board) sought a 23% more efficient engine by 60% downsizing.

Resulting in 35% reduced CO2 when combined with vehicle changes (Range Rover 10MY to 13MY).

First assembled UB100 engine - prove combustion.

Data from McAllister and Buckley, 2009.
Target Torque Curve equal AJ133 5.0l V8

Corrected Power / [kW]

Corrected Torque / [Nm]

Engine Speed / [rpm]

283 kW
380 bhp at 6500 rpm

515 Nm at 3500 rpm
32.4 bar

400 Nm at 1000 rpm
25.1 bar

415 Nm at 6500 rpm
26.1 bar

‘Ultraboost’ is a 2.0 litre engine with torque curve of the Jaguar Land Rover 5.0 litre V8

‘Ultraboost’ is a 2.0 litre engine with torque curve of the Jaguar Land Rover 5.0 litre V8
UB200 Air System Technology

- Supercharger
- Intake Manifold
- 1st Stage Charge
- Air Cooling
- Air Inlet manifold
- Outlet Manifold
- U-Pipe
- Clutched Eaton R410 Supercharger
- Supercharger Intake Manifold
- 2nd Stage Air Charge cooling
- Pulse-divided aluminium water-cooled exhaust manifold
- 1st Stage Charge Air Cooling
- First assembled UB200 engine
- Honeywell GT30 Turbocharger
Advanced e_Drives

Interior Permanent Magnet Machines (IPMs)
- Reduced rare earth material volume
- Competitive torque and power density levels

Low Cost Electric Drives
- Ferrite PM machines reduce cost for small rise in volume
- High speed Switched Reluctance machines contain no magnets and provide a credible alternative

Inverter Design and Integration
- Future packaging concepts investigated through electro-thermal modelling.
- Capability to model high level ‘vehicle architecture’ system, down to switching over-voltages in IGBTs.
Pushing the boundaries with Innovative Partnership
What is **C-X75**?

A plug in parallel hybrid hypercar. AWD. 7speed AMT transaxle. Active aerodynamics.

- As fast as an XKR in electric mode.
- As fast as they get in Hybrid mode.

JLRs first carbon structure. Tub, frame, closures, reinforcements with aluminium crush cans.

The highest torque & power density electric motors in production.

Highest specific power production engine.

The most extreme specification of any mobile battery in development.
Technology Stories

• Battery
  • The most extreme specification of any mobile battery in development
  • Formula 1 battery technology - liquid-cooled lithium ion NMC cells
  • Very high power and energy density. 30Ah cell, 3.7v nominal
  • The size of an A5 sheet, 10mm thick. 2 packs of 87 cells.
  • 174 cells used to generate a 644V pack at 19Ah and 300Kw

• Vehicle Control Module
  • Advanced hybrid control system
  • The brain of the vehicle responding to driver inputs
  • Manages the hybrid vehicle systems, the entire propulsion system, front to rear torque split, traction control and yaw control
  • A development of a Williams F1 control module
Technology Stories

• Engine

  • Aggressively downsized race-derived engine
  • Explores the limits of downsizing technology
  • Turbocharged & supercharged 4 cylinder, 1.6 litre
  • Highest production engine specific power output of >300 bhp / litre
  • 500Bhp @10000rpm, 360Nm @8500rpm

• Electric Motors

  • The highest torque & power density electric motors in production
  • Compact and light package
  • 18kg and 160kW. Just 278mm in diameter, 67mm deep.
Investing in the UK
Jaguar Land Rover Manufacturing

- £500m investment - 100,000 m²
- Sustainability target: BREEAM Excellent
- 52 state-of-the-art CNC machining centres
- Petrol and diesel engines produced on the same assembly line
- Engine completed in clean room environment
- Engines in production from 2015
£94m overall investment (£50m Jaguar Land Rover)
27,000m² collaborative research facility, including powertrain labs, design studios and rapid prototyping technologies
500 Jaguar Land Rover employees based onsite
2014 construction start, for 2016 opening

Collaborative “hub” for SMEs, ESPs, T1s, Unis across all Innovation themes.

World-class collaboration environment with state of the art facilities.

Education, training and open innovation are key elements.

Skills developed through education centre and skills programmes.
What does the Customer really want?

A Car that's instantly at a comfortable temperature
that drives silently
that run's on zero CO2 fuel
that's grips on any ground
that sounds powerful when I want it
that charges and fuels without any effort
that never wastes energy
that's vibration free never disturbing

Delivered by Technical Innovation
Thank you - Questions?