EVORA 414E HYBRID

ENGINEERING

ENGINEERING

EVORA 414E HYBRID

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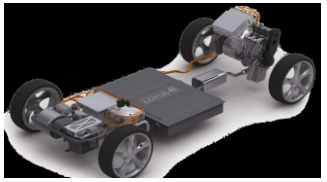
AGENDA – EVORA 414E HYBRID

ENGINEERING

- Lotus background
- Project overview, aims and timing
- Vehicle Package and System layout
- Specification - Drive system, Battery, Range extender, Cooling systems
- Driver interface and Sound Synthesis
- Safety analysis & Control systems
- Analysis & Performance



LOTUS

ENGINEERING



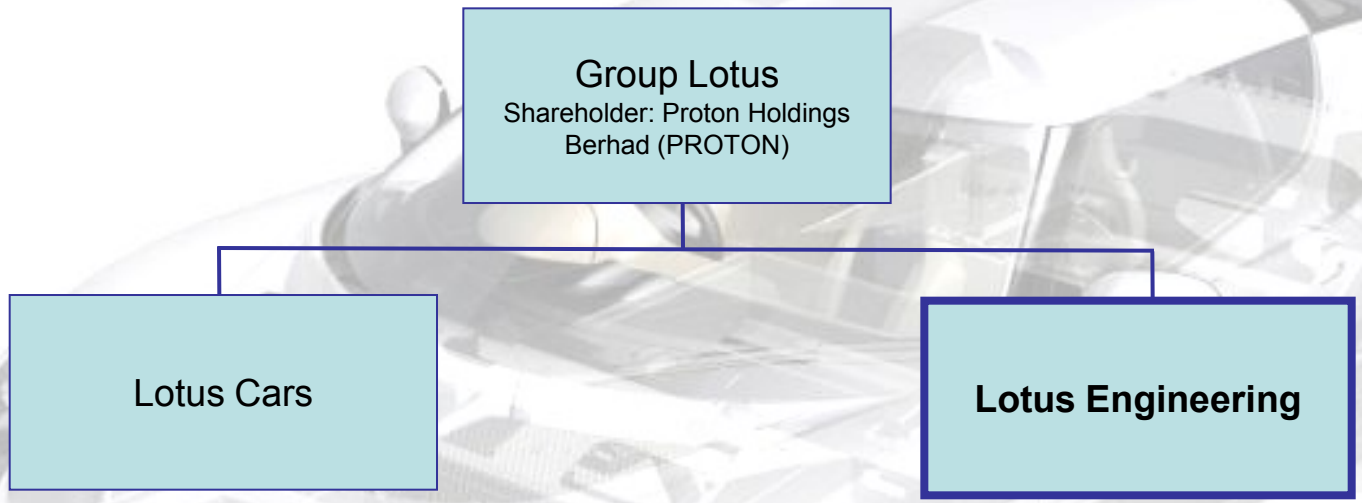


- HERITAGE
  - The 4th most successful Formula 1 team of all time
  - 60 year history of iconic sports cars
  - A tradition of performance through innovation and great ride & handling
- LOTUS CARS – A DAWN OF A NEW ERA
  - New products expanding our range of cars - Esprit (2012), Elan (2013), Elite (2014), New Elise (2015), Eterne (2015)
  - Return to motorsport - Indycar, GP2, GP3, GT2, GT3, GT4, LMP2, Lotus-Renault F1
- LOTUS ENGINEERING MOVING FORWARD
  - New engineering technologies for sustainable transport - Range Extender, Omnivore

WE UNDERSTAND ENGINEERING FOR PRODUCTION

ENGINEERING

Lotus Engineering Today

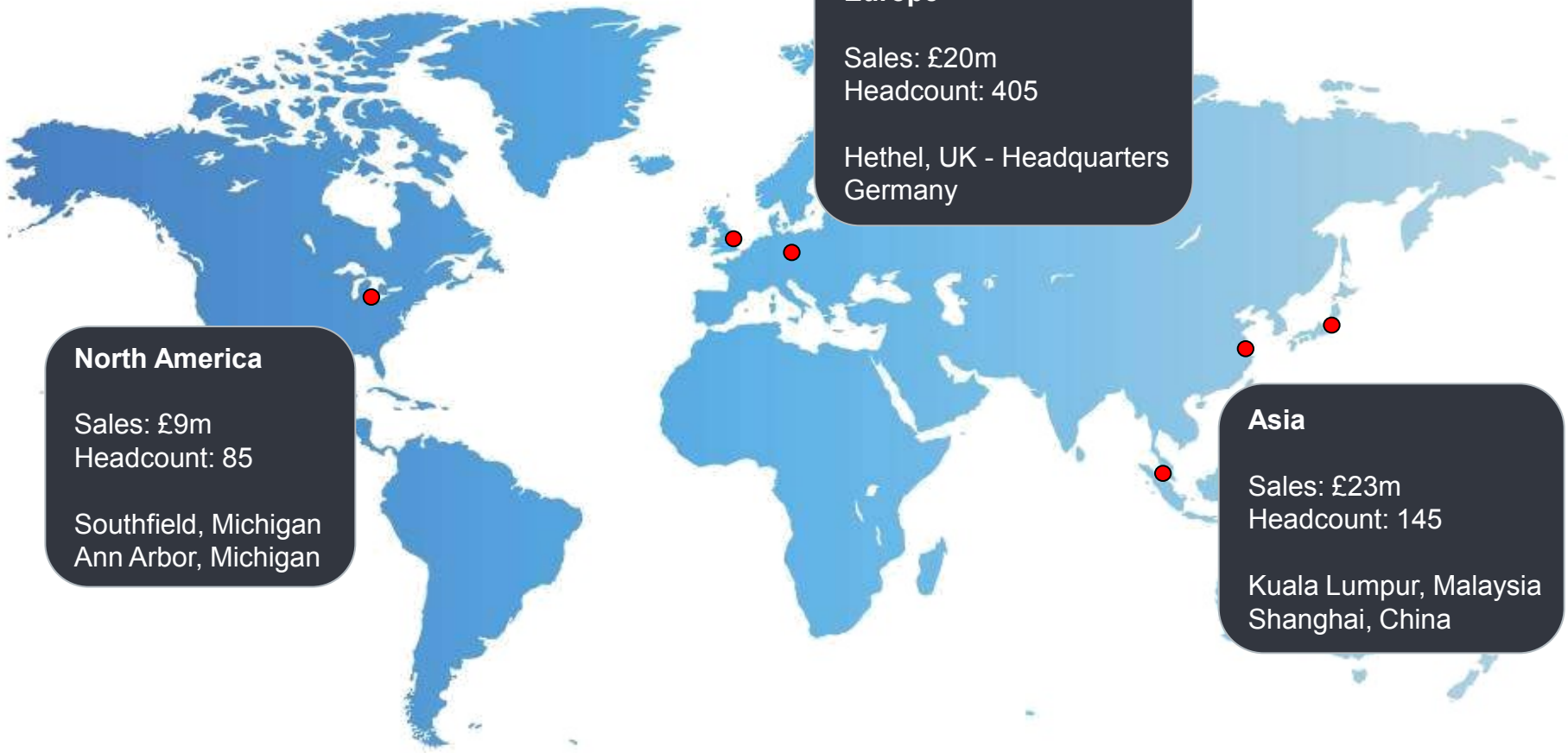


An **automotive engineering** consultancy and advanced technology company

70% of our work is for external clients

GLOBAL ORGANISATION

ENGINEERING



Europe

Sales: £20m
Headcount: 405

Hethel, UK - Headquarters
Germany

North America

Sales: £9m
Headcount: 85

Southfield, Michigan
Ann Arbor, Michigan

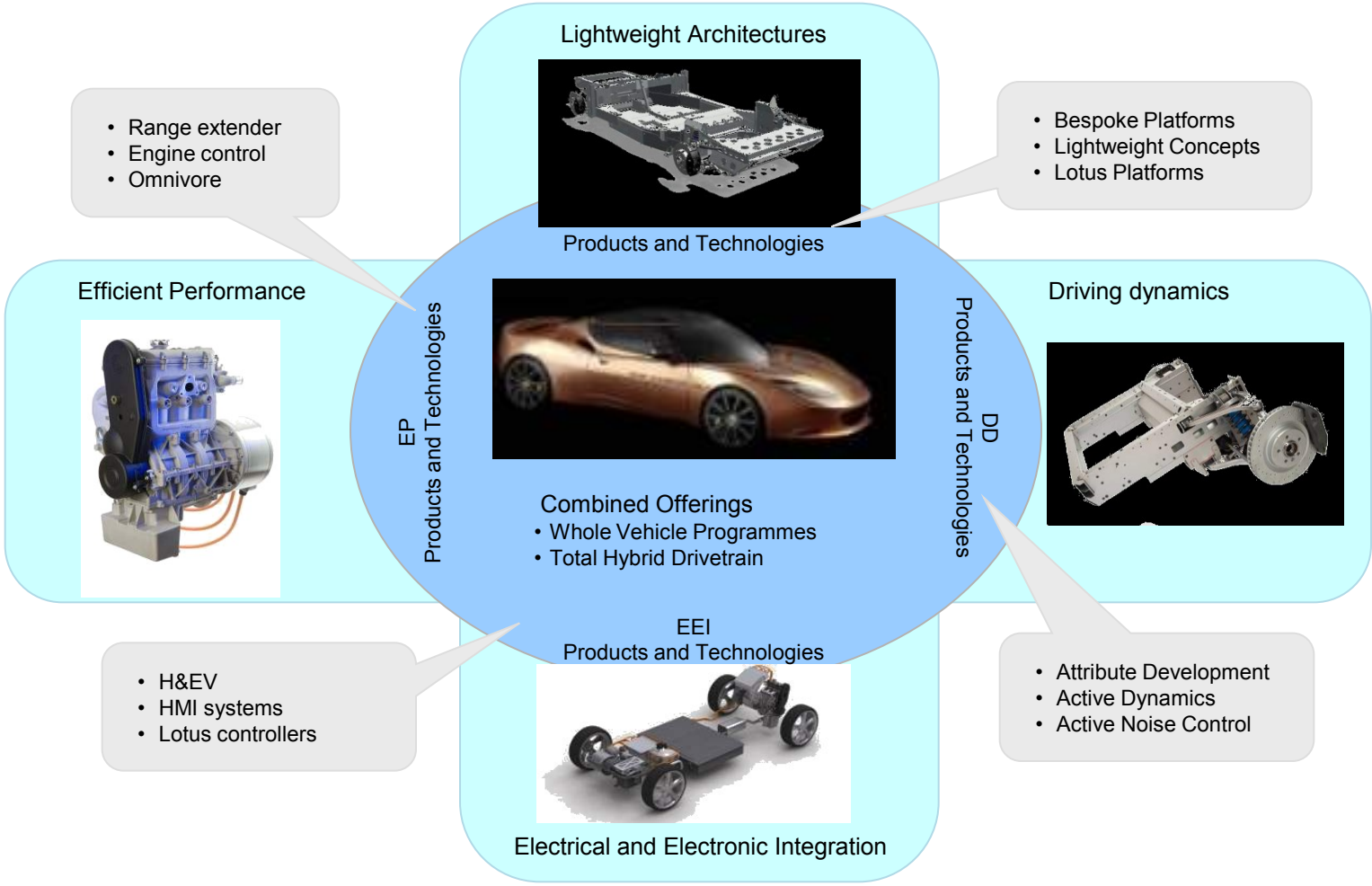
Asia

Sales: £23m
Headcount: 145

Kuala Lumpur, Malaysia
Shanghai, China

LOTUS - CORE COMPETENCIES

ENGINEERING



EVORA 414E HYBRID - PROJECT OVERVIEW

ENGINEERING

- £19 million project supported by a UK Government's Technology Strategy Board Award
- Project partners
  - Lotus Engineering / Infiniti / Jaguar Land Rover – Vehicle design, integration, build and development
  - Xtrac – Gearbox development
  - Evo Electric – Motor & generator development
  - Th!nk – Power Electronics development
  - Axeon – Battery development

EVORA 414E HYBRID – AIMS

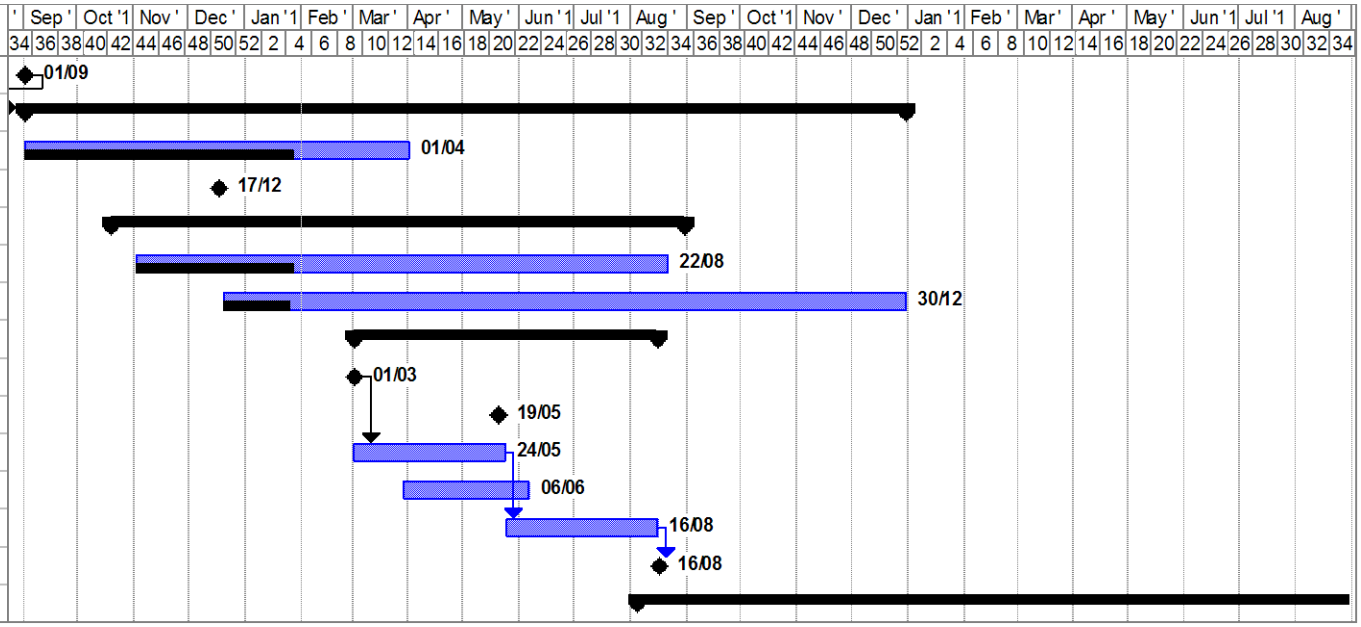
ENGINEERING

- Technology Strategy Board goal
  - To develop UK supply base in the EV market place with three car manufacturers.
- OEM Partner Aims
  - Lotus - 2 demonstrator vehicles
  - Nissan - 2 demonstrator vehicles
  - Jaguar Land Rover – 3 to 5 demonstrator vehicles
- Lotus development aims
  - Integrated high power inverter, charger, DC/DC and axial flux motor/generator
  - A high power, high energy battery pack with a high current draw capability
  - Vehicle Control systems integration and torque vectoring control
  - Simulated 7 speed paddle shift linked to HALOsonic Internal & External Electronic Sound Synthesis

EVORA 414E HYBRID - PROJECT TIMING

ENGINEERING

Name	%
Project Start	0%
Design and Procurement	**33%**
Vehicle design, analysis and procurement	70%
Design freeze	100%
Level 1 APU Programme (see WP4)	**35%**
HMI programme	30%
HALOSonic sound synthesis	10%
Vehicle build	**0%**
Vehicle Parts in Place (PIP) 1 (vehicle parts)	0%
Vehicle Parts in Place (PIP) 2 (battery)	0%
Build car 1	0%
Build car 2	0%
Shakedown and commission 2 vehicles	0%
Vehicles built and commissioned	0%
Vehicle Development	**0%**



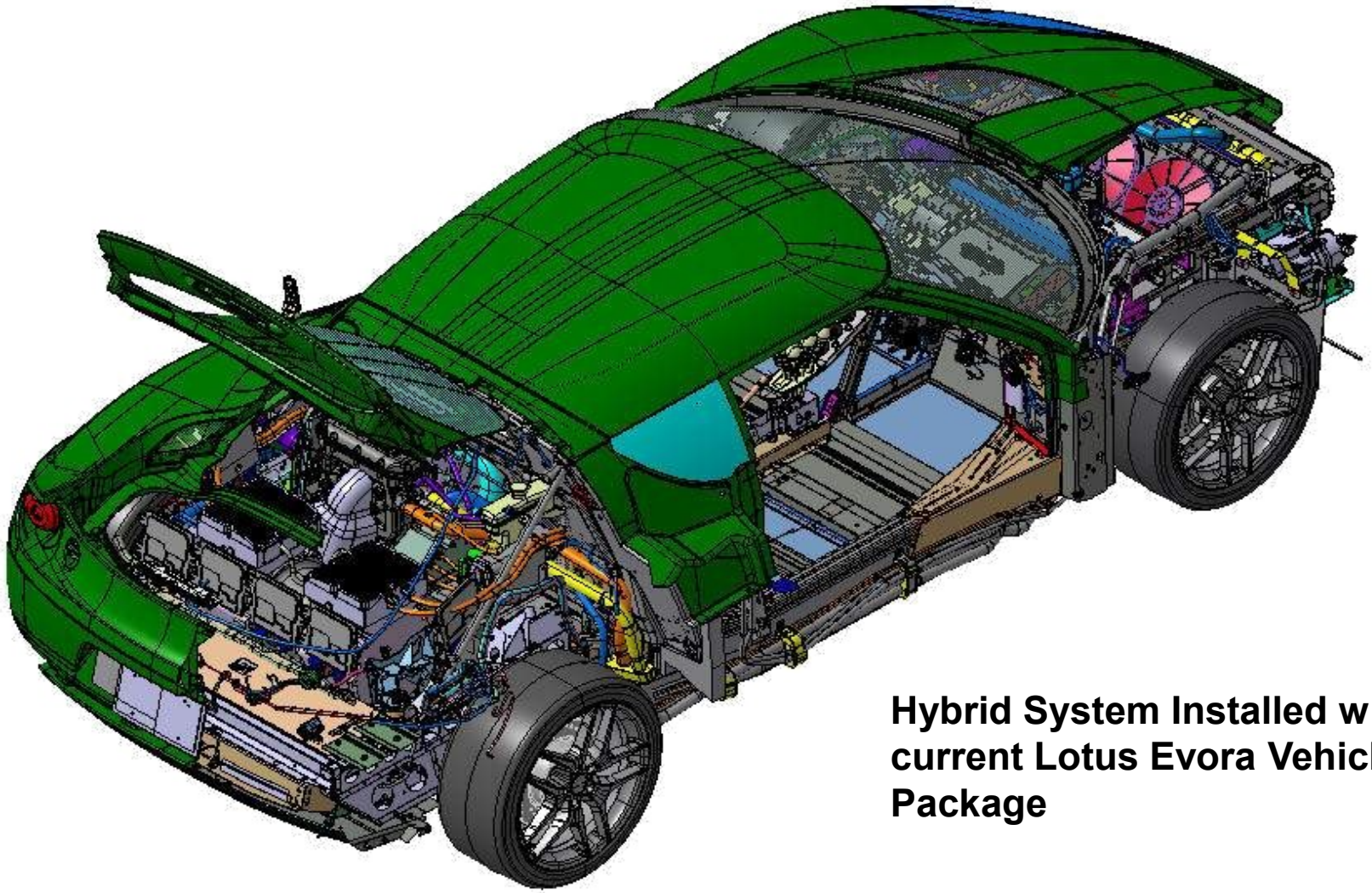
Concept Show car at Geneva Motor show - March 2010

Demonstrator project start - September 2010

Running vehicle planned - August 2011

Project completion - September 2012

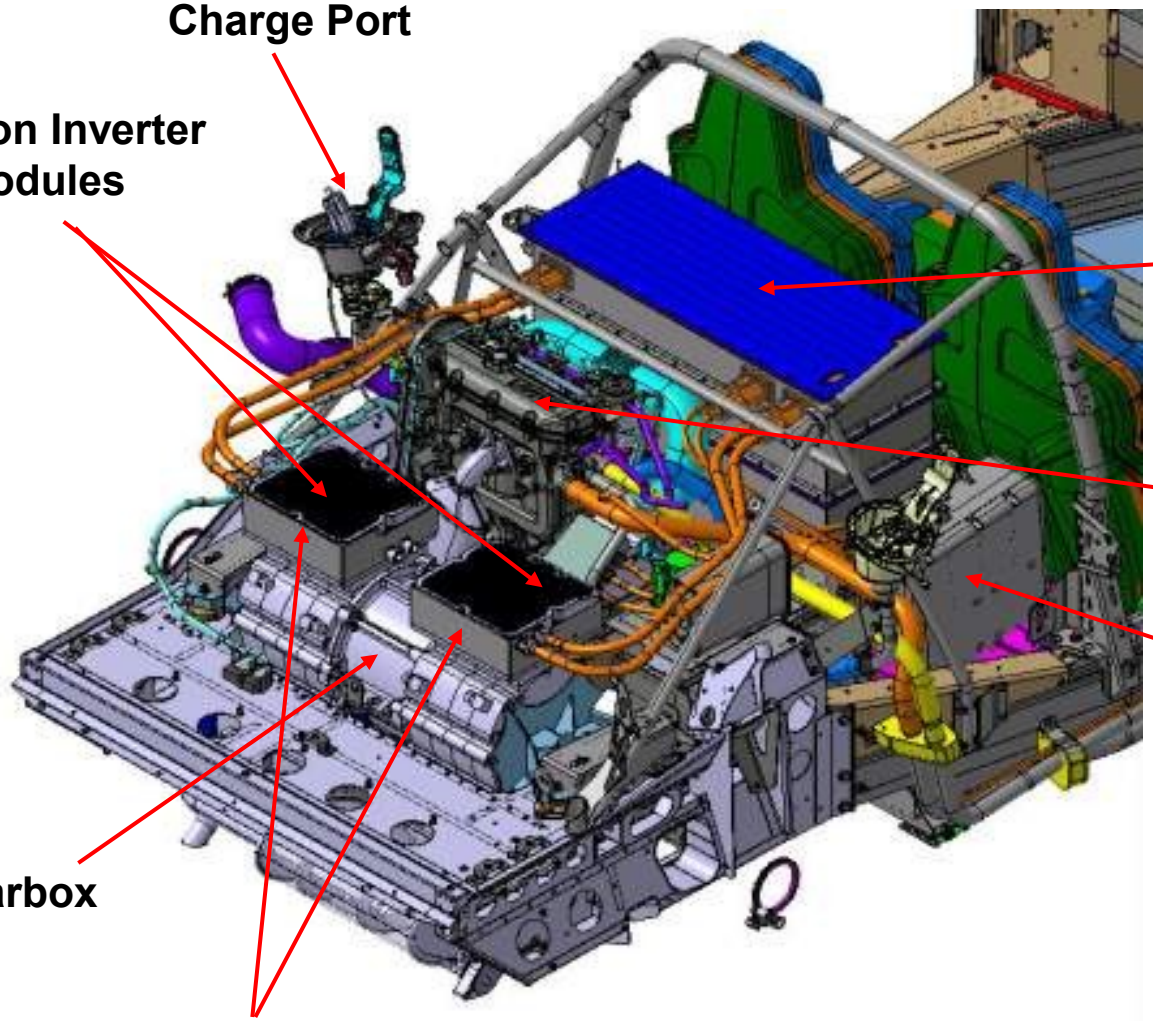
VEHICLE HYBRID SYSTEM INSTALLATION



Hybrid System Installed within current Lotus Evora Vehicle Package

EVORA 414E HYBRID - SYSTEM LAYOUT

ENGINEERING

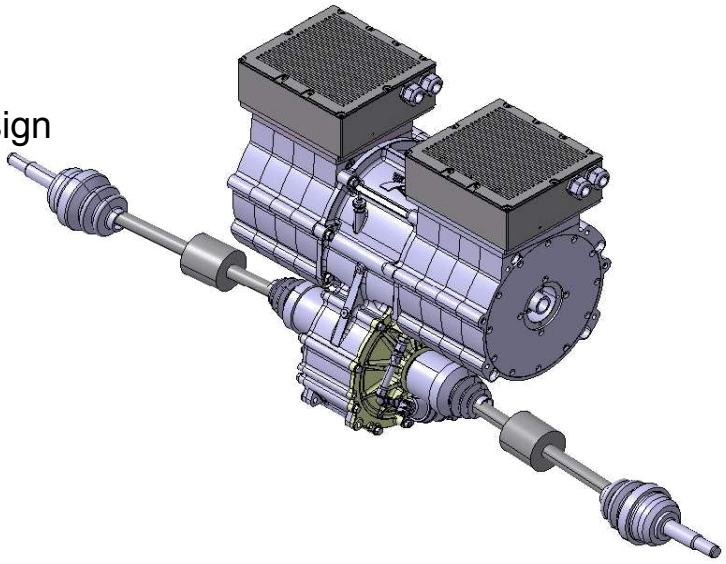


SPECIFICATION – MOTOR & GEARBOX DRIVELINE

ENGINEERING

- Drive Motors, 2 x 150kW peak, 500Nm
- Axial flux synchronous motors – High power density / compact design
- Independent rear wheel control – Torque vectoring capability
- Integrated drive Motor / Inverter package

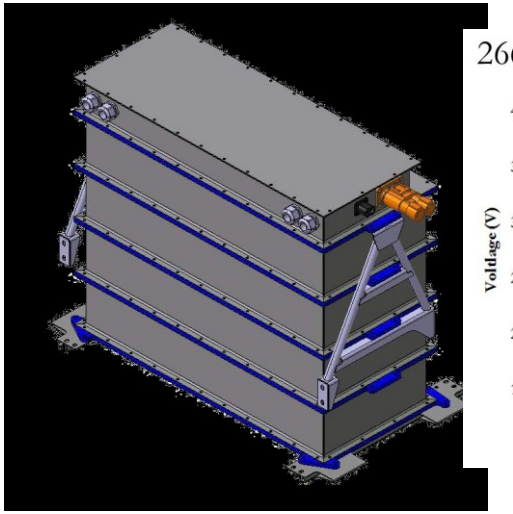
- Gear Box, 4.58:1 (single speed transmission)
- Independent drive to each rear wheel
- Electrically operated park lock

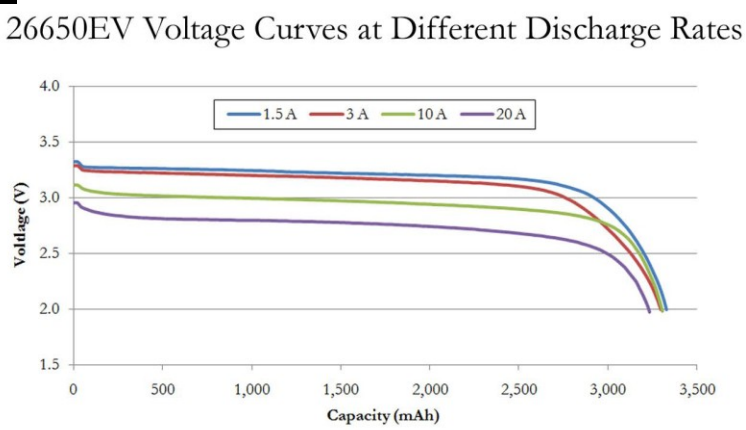


SPECIFICATION – HIGH VOLTAGE BATTERY

ENGINEERING

- Pack details
  - Energy 14.8 kWh
  - Power 300 kW
  - Mass 230kg
  - Peak Current 1000A
- BMS
  - 7 Slave modules, controlled by a master.
  - Model based state of Charge estimation.
  - Continuous cell balancing
  - Earth leakage monitoring
- Cell
  - Configuration 112 series, 16 parallel.
  - Lithium iron phosphate (26650).
  - Liquid thermal management.

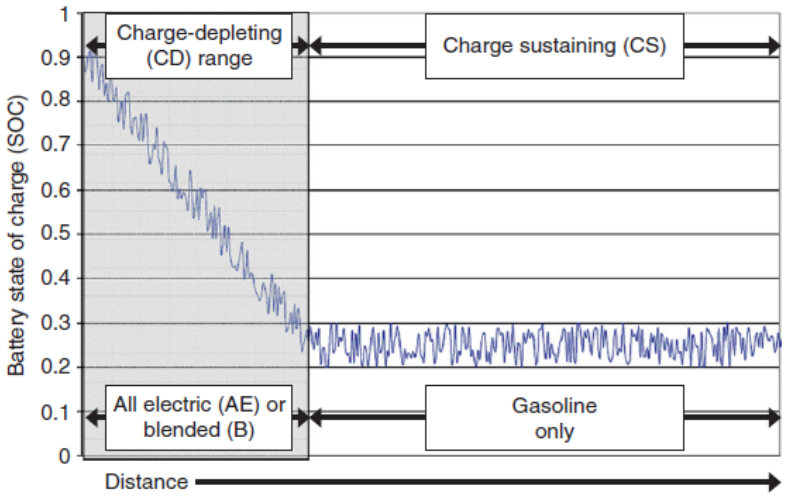


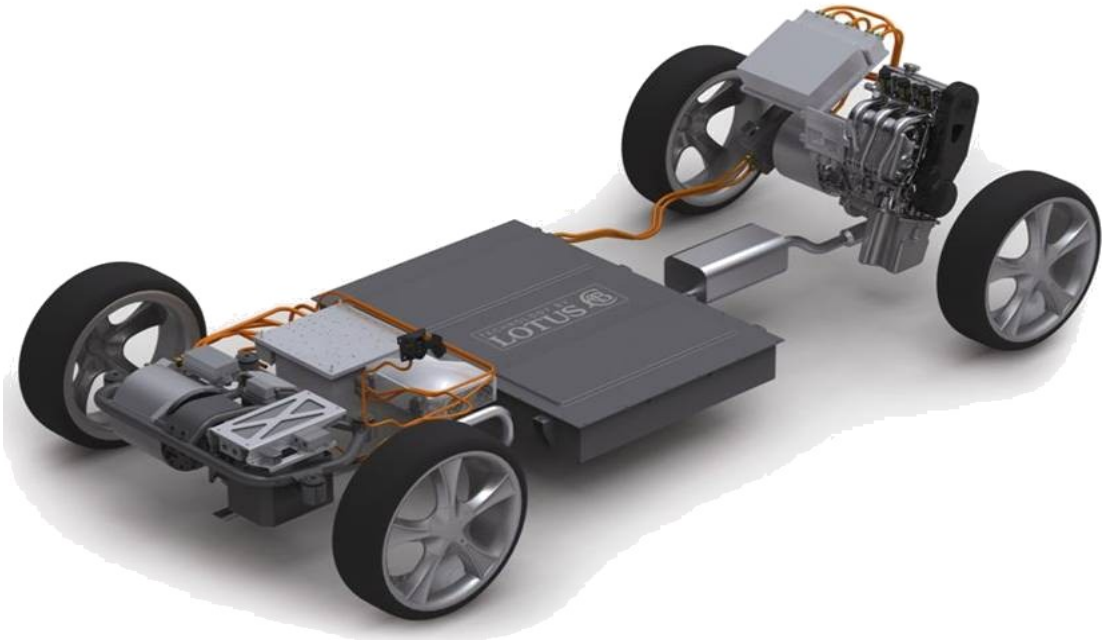


EXTENDED RANGE ELECTRIC VEHICLE – WHY?

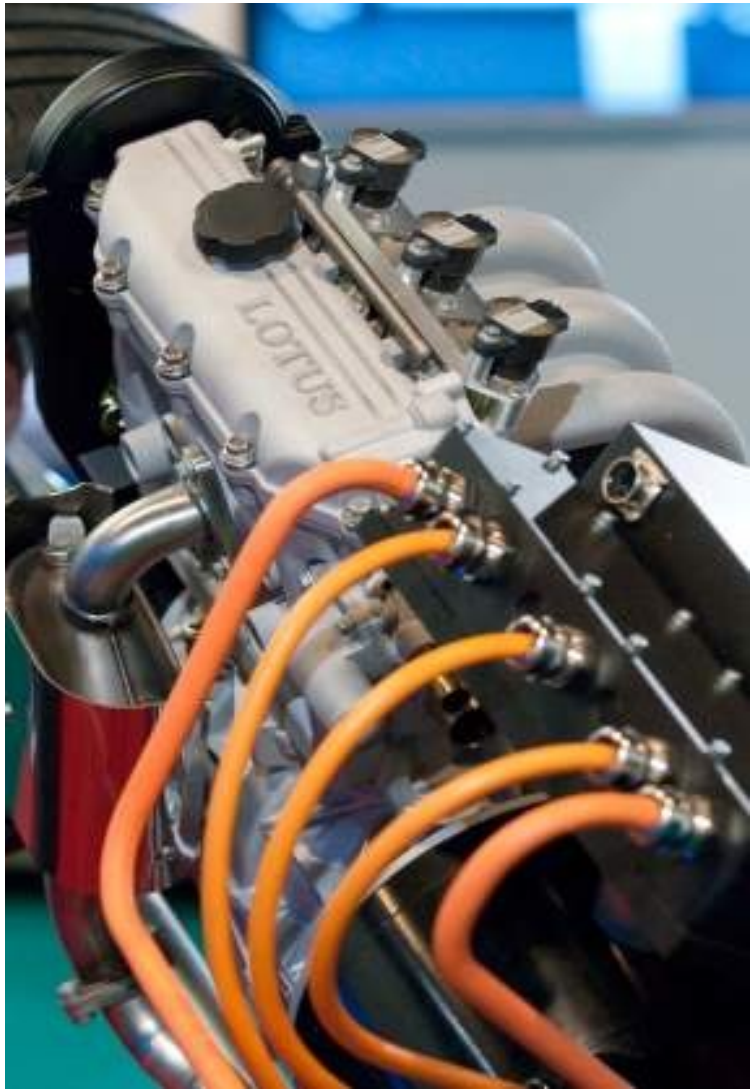
ENGINEERING

- Optimum solution for drivers who typically use their vehicles for short distances but still require longer range capability
- ‘Range Anxiety’ issue of electric vehicles resolved
- Reduced dependence on an electric charging infrastructure
- In EV mode provides Zero Vehicle Emissions Capability
- Supports Low CO2 Strategies





SPECIFICATION – RANGE EXTENDER



Range Extender Engine (Generation 1)

- 1.2 litre, 35 kW, 3 cylinder engine
- Tri fuel - methanol, ethanol or gasoline.
- Aluminium mono block, integrating cylinder block, head & exhaust manifold.
- Close coupled Catalyst

Range Extender Generator

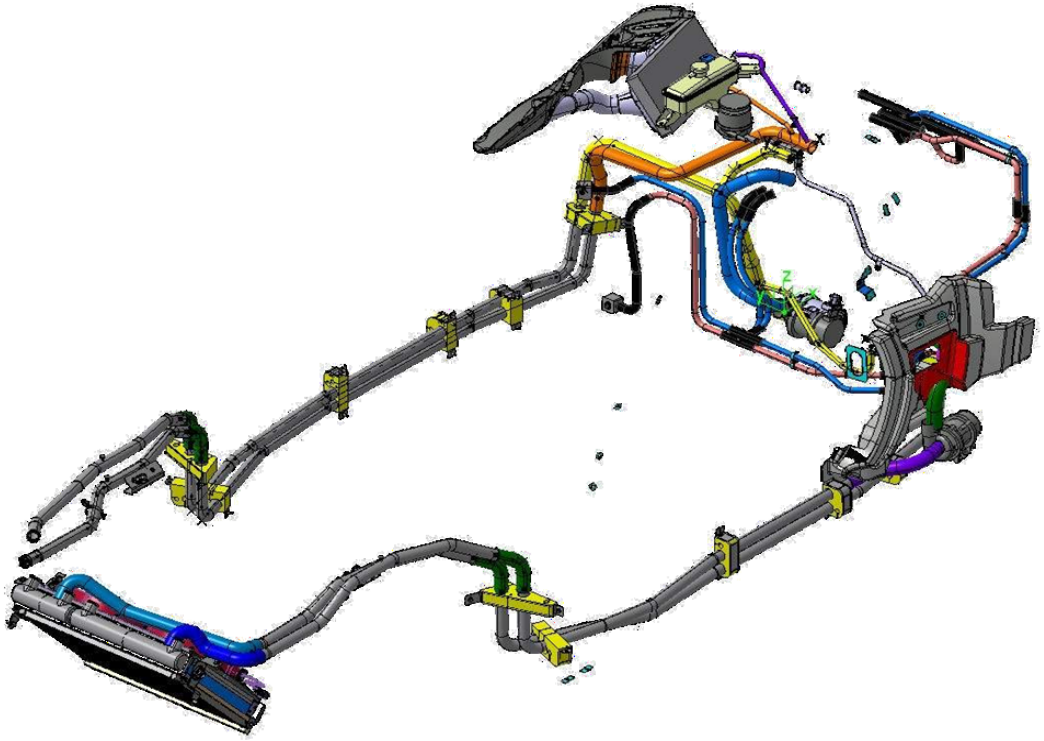
- Axial flux synchronous motor / generator
- 162 kW peak, 54 kW continuous
- 120 Nm nominal torque (240 Nm peak)
- Engine flywheel integrated into generator rotor
- Generator rotor directly mounted to the crankshaft

SPECIFICATION - COOLING SYSTEMS

ENGINEERING

This car requires 4 temperature management systems for

- The IC engine cooling (90°C)
- The High Voltage systems cooling (60°C)
  - 2 x Motor Invertors
  - 2 x Drive motors
  - 1 x Generator
  - 1 x DC Converter
- HV Battery pack heating and cooling (40°C)
- Cabin HVAC (20°C)
- Each system has a dedicated water pump and ra
  to ensure vehicle operation between -5°C and +3



DRIVER INTERFACE AND SOUND SYNTHESIS

ENGINEERING

Infotainment System

- Typical systems interface (music, video, sat nav etc)
- Hybrid system status, and Halo Sonic Sound Synthesis System set up.

HALOsonic Sound Synthesis

- External sound synthesis for Pedestrian safety
- Internal sound synthesis system providing active feedback and linked to the virtual Gear shift.

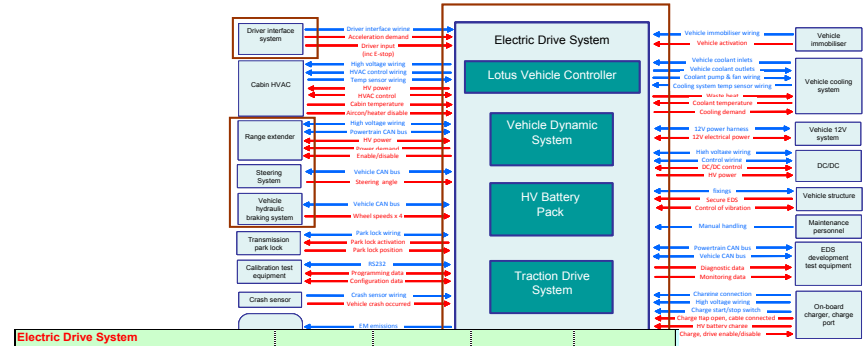
Virtual Gear Shift

- Simulated 7 speed paddle shift linked to HALOsonic Internal & External Electronic Sound Synthesis
- Power interrupt / regenerative braking function to simulate gear change

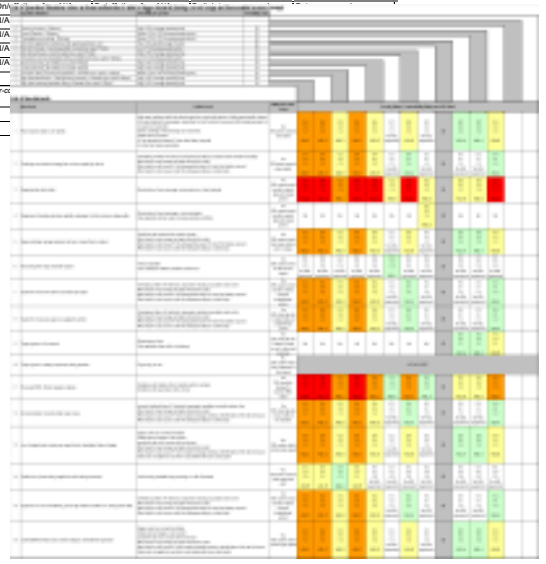
EVORA 414E HYBRID - SAFETY ANALYSIS

ENGINEERING

- Lotus are developing the application of ISO 26262 (functional safety of road vehicles) to a hybrid vehicle, on the 414E project.
- Having set safety goals the drive system has been defined in physical and functional terms outlining the key interfaces between systems.
- A hazard analysis conducted using these interfaces to understand the risks associated with potential failures.
- Based on operational situations, hazards have been identified, which have resulted in preliminary ASIL for the vehicle systems (Automotive Safety Integrity Level)
- Similar to a DFMEA, the hazard assessment and risk analysis has been guiding systems design.



Electric Drive System		No function	Reduced function	Over Function	Intermittent function	Unintended function
Driver interface system		*The driver interface system relays driver inputs to the appropriate system in the vehicle, via hard wiring*				
Driver interface wiring	P					
Torque demand	F	Zero torque demand	Car slow	Car too fast	Car dangerous/ uncontrollable	N/A
E-stop	F	Emergency shut-down not possible	On/off, therefore N/A	On/off, therefore N/A	E-stop latches, theerefore N/A	False e-stop
Sport/Eco switch	F	No mode change	On/off, therefore N/A	On/off, therefore N/A	Switch to wrong mode	Get wrong mode
Drive mode signal P	F	Car won't go into park	On/off, therefore N/A	On/off, therefore N/A	Switch to wrong mode	Get wrong mode
Drive mode signal R	F	Car won't go into reverse	On/off, therefore N/A	On/off, therefore N/A	Switch to wrong mode	Get wrong mode
Drive mode signal N	F	Car wont go into neutral	On/off, therefore N/A	On/off, therefore N/A	Switch to wrong mode	Get wrong mode
Drive mode signal D	F	Car won't go into drive	On/			
Ignition barrel - key in	F	N/A	N/A			
Ignition barrel - accessories	F	Can't progress to ignition	N/A			
Ignition barrel - ignition	F		N/A			
Ignition barrel - crank	F	HV system not activated	N/A			
HMI	F					
Cabin HVAC		*Cabin heating, ventilation and air-c circuit.*				
High Voltage wiring	P					
HVAC control wiring	P					



EVORA 414E HYBRID - CONTROLS SYSTEMS

ENGINEERING

Concept: Control Systems separated into three interdependent Controllers:

Vehicle Controller

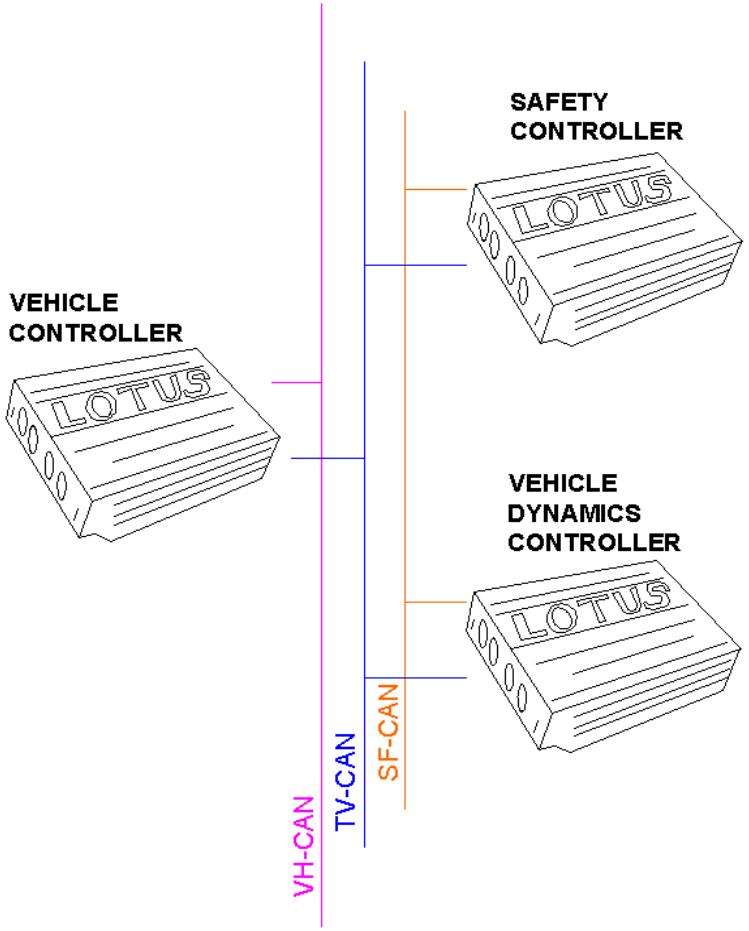
- Energy, Power and Torque Management
- Driver & Vehicle Interfaces

Vehicle Dynamics Controller

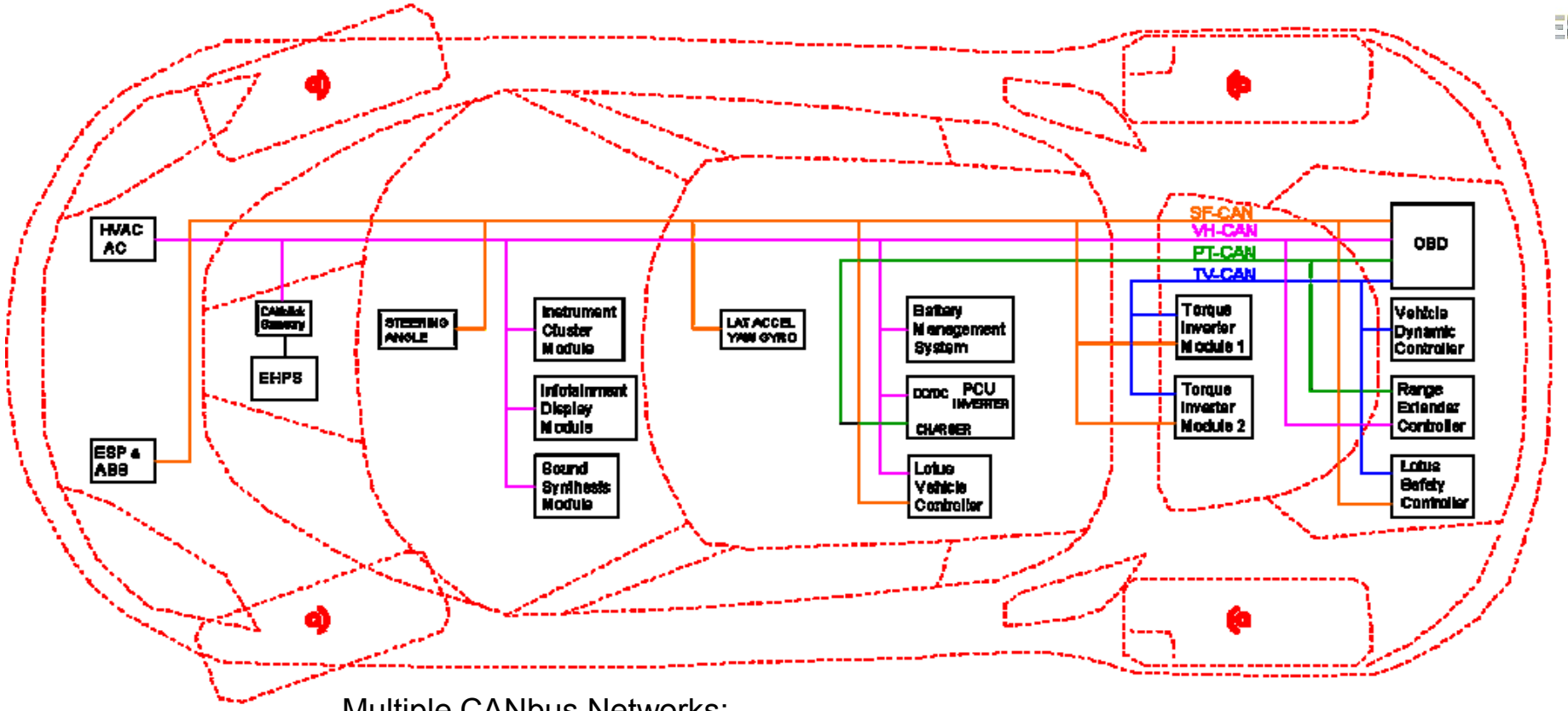
- Control Torque Split modes
- Dedicated Private CANbus

Safety Controller

- Functional Safety monitoring
- Parameter Error and Validation checking



EVORA 414E HYBRID - CANBUS ARCHITECTURE



Multiple CANbus Networks:

- **TV-CANbus:** Dynamic Control Signals to Power Inverters
- **SF-CANbus:** Monitoring Dynamic controller & ESP sensors
- **VH-CANbus:** HV Systems, Comfort, Info & Steering
- **PT-CANbus:** Range Extender & Generator

EVORA 414E HYBRID - SOFTWARE

ENGINEERING

Modular Vehicle & Dynamic Control Software

The software is split into modular functions which are implemented in Simulink Models and application C code.

Simulation Software (Lotus RAVEN and IPG CarMaker) is used for:

- Vehicle Dynamic response to simulated Motor Faults
- Develop Algorithms for Electronic Differential modes

Independent Safety Control Software

- Alternative Implementation of Strategy for functional safety monitoring
- Focused on verifying Current output signal, Wheel Lock and Torque Feedback.
- Monitoring the CANbus (Watchdogs, Checksum and Rolling Counters)

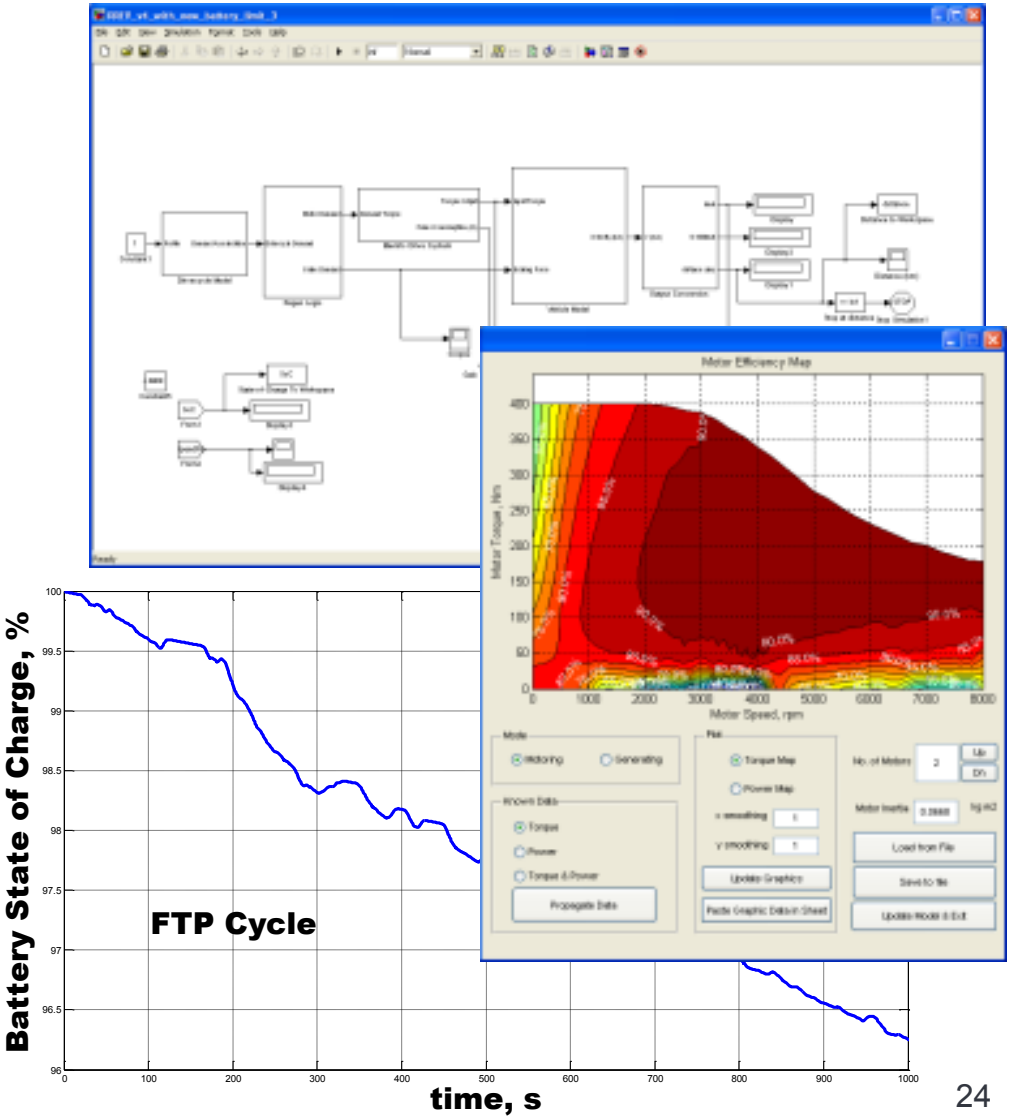
The software modules are validated

- Separately
- As part of Software in the Loop (SIL)
- As part of Hardware in the Loop (HIL) test rigs or in the Vehicle

Lotus Vehicle Simulation - LVS

ENGINEERING

- EV and Series hybrid modelling and simulation
- Model based design of Vehicle applications and electric architecture built within a Simulink environment
- Energy management concepts defined early
- Concept EV/HEV electrical device sizing and confirmation of programme targets at the concept stage
  - EV range
  - EV launch acceleration times
  - Vehicle maximum speeds
  - Energy used over wide range of drive-cycles
  - Drive-cycle CO2 predictions for HEVs
  - Battery SoC investigations
  - HEV control strategies for economy or performance



EVORA 414E HYBRID - PERFORMANCE

ENGINEERING

- Predicted Vehicle Performance
  - 0-60 mph <4 Secs
  - Electric only range 35 miles (Total hybrid range 300 Miles)
  - EV max speed: 130mph (Charge sustaining 60mph)
  - CO_2 emission 60g/km (ECE-R101 test schedule)

EVORA 414E HYBRID

ENGINEERING

- A Platform for Whole Vehicle Integration Development

Chassis/Body Structure
Re-engineer for EV components
Structural
Crashworthiness

Range Extender
Required power at wheels
Charge depleting / sustaining
Drive cycle
'Range' definition

NVH
Motor
Engine
Exterior

Battery
Cell Technology
Characteristics
'Quick-release' pack

Cooling Systems
Motor
Power electronics
Battery
IC Engine

Driving Dynamics
Ride & Handling
Performance tuning

UltraCapacitors
Torque assist
Peak current buffer

Battery charging
Charge rates
Domestic charging
Infrastructure charging

Vehicle Systems
Brakes
Balancing friction brakes with regenerative braking
Power steering
HVAC
In-car display

Battery Management (BMS)
Battery pack conditioning
Battery pack charging
Usually supplier recommended

Controls
HEV controller sits above other controllers:
Motor
Engine
Transmission
HVAC
Stop/start
Etc…etc…

Motor Technologies
AC / DC
Brush / brushless
Inboard
Wheel motor
Generator
Regenerative braking

Summary: Benefits of Series Hybrid compared with pure EV

ENGINEERING

- Total range of 300 miles would need more than 127kWh of battery capacity
  - Not possible to package in vehicle
  - Battery weight in the region of 1300kg (same as base vehicle)
    - For reference range extender weight is 58kg
  - Cost prohibitive: $76k based on $600/kWh

Conclusion:

- Series hybrid technology will be a useful ‘stepping stone’ until a breakthrough in battery technology will allow comparative range

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THANK YOU

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