ADVANCED PROPULSION CENTRE UK

Building the Propulsion Nation

The UK's Innovation Ecosystem

Ruth Dixon

Portfolio Manager

"Turning low carbon propulsion technology into products developed in the UK"

UK Automotive Industry

- £64bn turnover,
- £26bn exports
- Exporting to over 100 markets
- 1.5m vehicles produced
- 2.4m engines produced
- 162,000 jobs*
- 2,049 automotive suppliers
- Home to eight F1 teams

A Positive Industrial Environment

Collaboration

⬇

Targeted Investment

⬇

Productivity

⬇

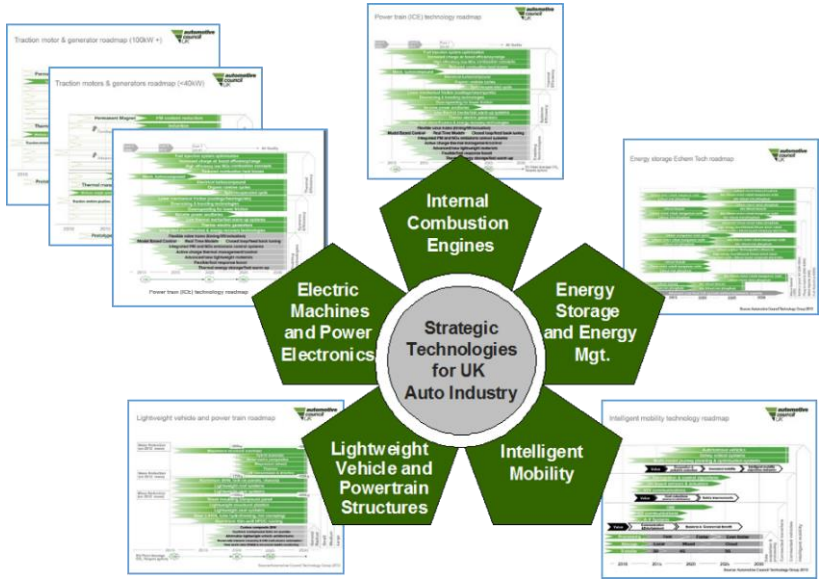
Growth

Acting together to achieve a common goal

automotive council UK

Partnership between Industry and Government
A Single Voice

Technology Direction

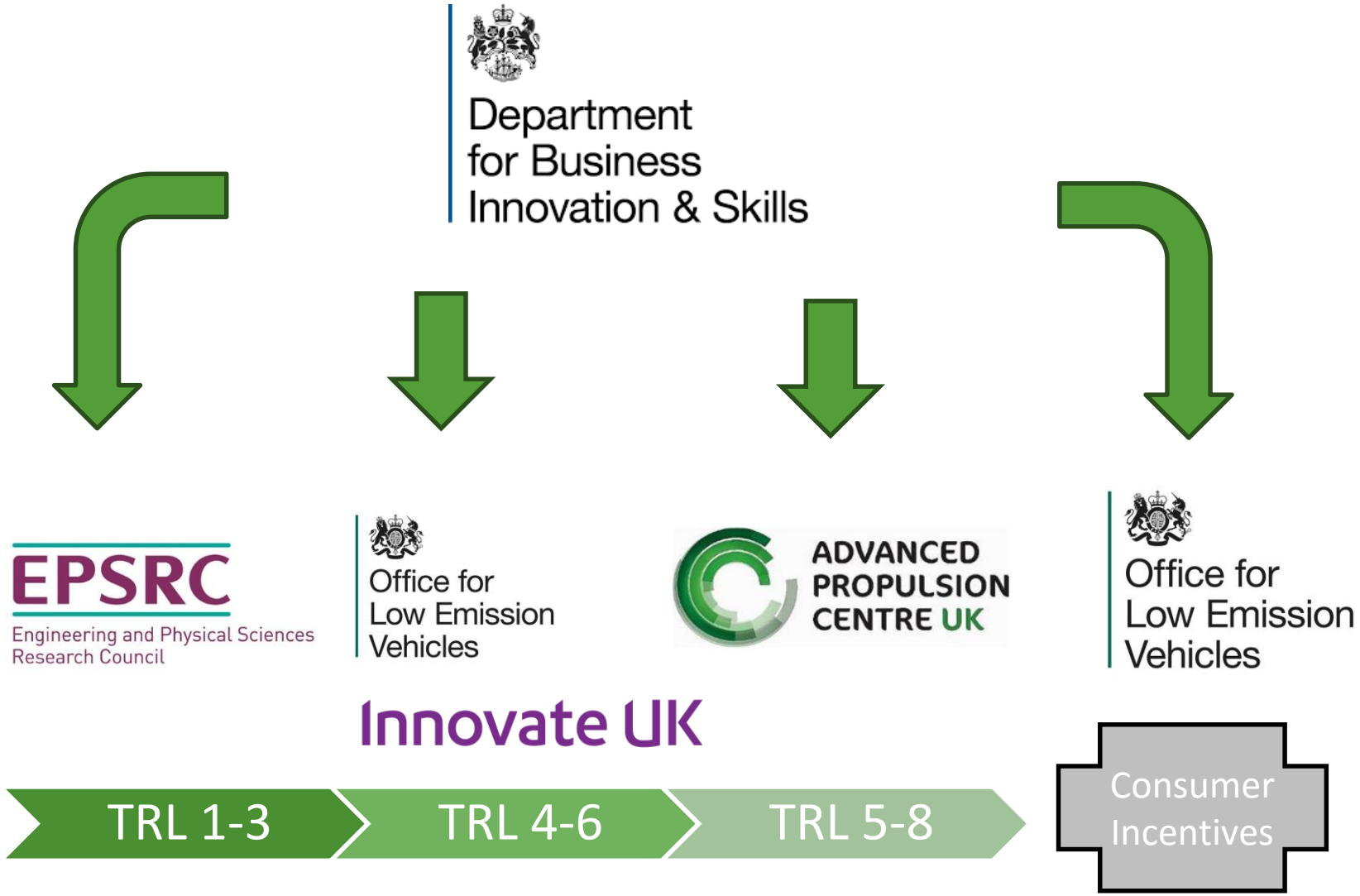


Strategic Direction

Key areas of focus:

1) Innovation & Technology
2) Supply chain enhancement
3) Investing in people & Skills
4) Business Environment

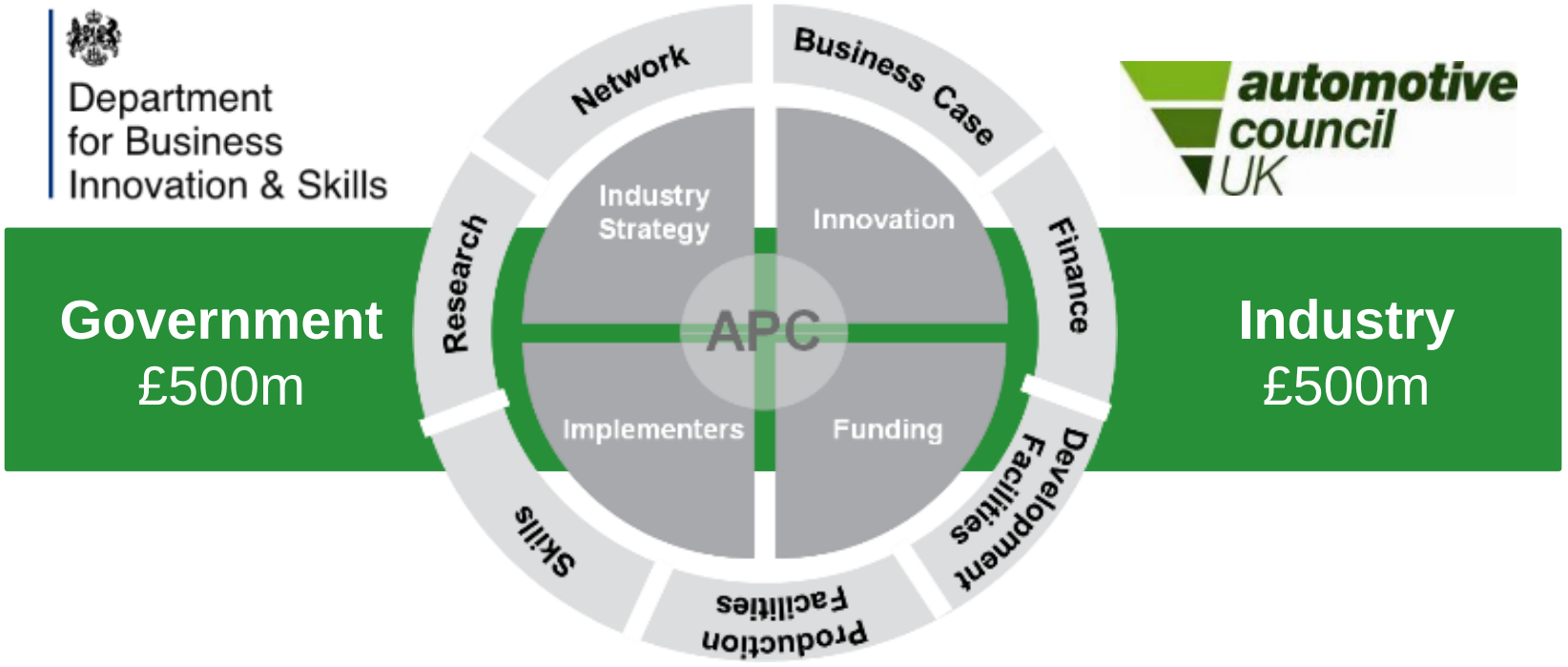
UK Support for the Automotive Industry



The Advanced Propulsion Centre is a 10 year co-investment partnership between government and industry

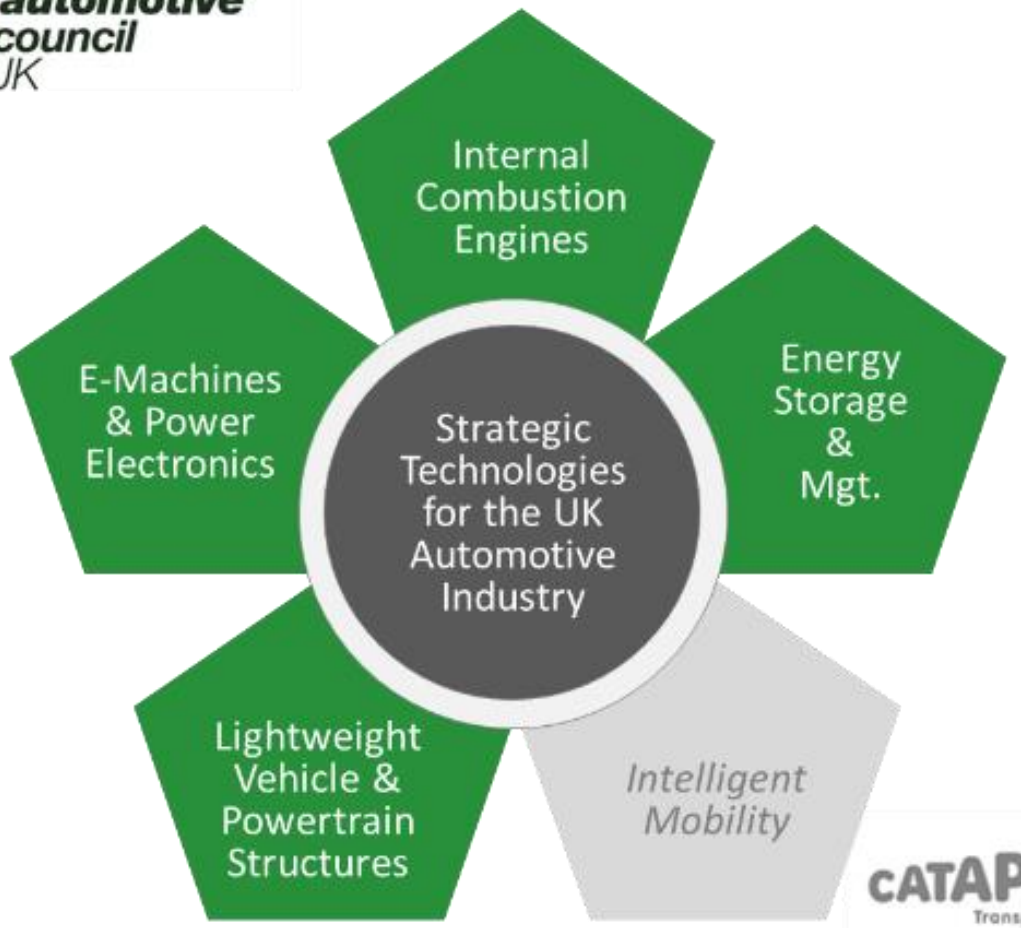
Department for Business Innovation & Skills

automotive council UK



Building capability through the research, development and industrialisation of Low Carbon Propulsion Technologies

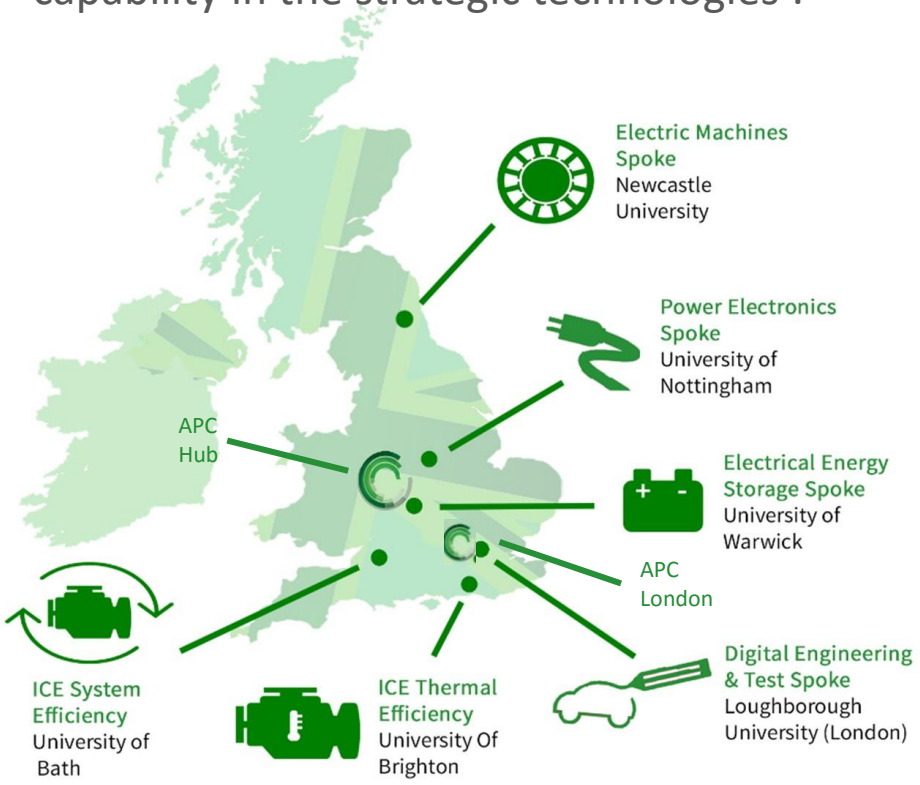
Our Scope



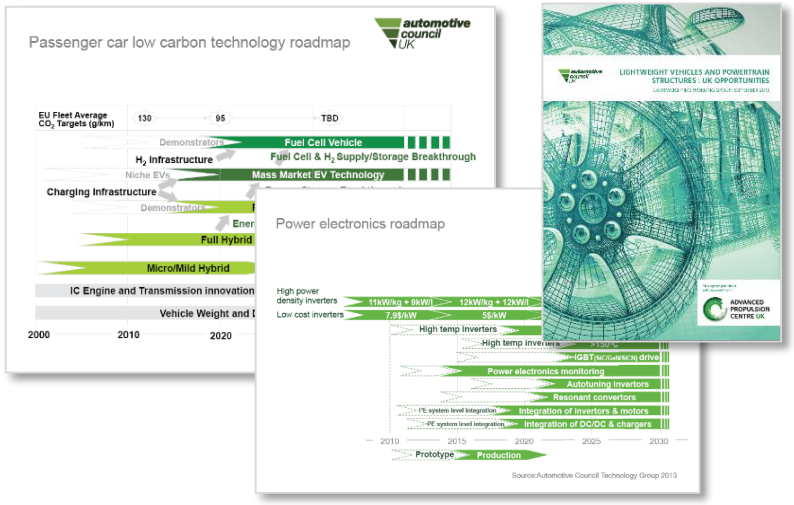
The Advanced Propulsion Centre is able to support projects aligned with the Automotive Council's strategic technologies

UK Wide Capability

The APC Spoke network are industrial and academic communities with world class capability in the strategic technologies :



The APC deliver a regular review of UK wide capability and the development of the industries product and technology roadmaps:



Funded Projects

- Twice-yearly competitions
- Up to £50 million of matched funding available annually
- Projects must
  - Deliver significant reductions in vehicle CO_2 or other emissions
  - Align with the four Strategic Technologies
  - Develop the UK's supply chain in the field of low carbon vehicle propulsion technology

APC 1-4 Projects

ADVANCED PROPULSION CENTRE UK

Advanced Combustion Turbocharged Inline Variable Valvetrain Engine

Ford + Partners

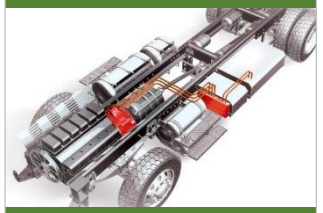
High Fuel Efficiency Hydraulic Transmission for Earthmoving Equipment

JCB + Partners

GYRODRIVE Original Equipment Development

GKN + Partners

FIRS3T Frequent IntegRated Soft Stop Start Technology



Cummins + Partners

HVEMS-UK High Volume E-Machine Supply from the UK

Jaguar Land Rover + Partners

ALIVE 6 New Technologies for the Ingenium Engine Family

Jaguar Land Rover + Partners

Zero Emission Range Extended Powertrain for Electric Vehicles

Intelligent Energy + Partners

Modular Architecture for Low Emissions Buses

WRIGHTBUS
UNIVERSITY OF CAMBRIDGE
MAGTEC HYBRID & ELECTRIC VEHICLE DRIVES
chargemaster - charging the future

Wrightbus + Partners

CO2 Divided by 2

MORGAN
MORGAN MOTOR COMPANY
POTENZA TECHNOLOGY

Morgan + Partners

HEBD High Energy Density Battery

NISSAN Innovation that excites
HYPERDRIVE
ZERO CARBON FUTURES
WMG THE UNIVERSITY OF WARWICK
Newcastle University

Nissan + Partners

Advanced Transmission and e-drive for High Value Hybrid Drive Vehicles

Hofer powertrain
McLaren AUTOMOTIVE
WMG THE UNIVERSITY OF WARWICK
YASA MOTORS

Hofer + Partners

Low CO2 Technologies for Accelerated Next Generation Caterpillar 4-7l Engines

Perkins
Imperial College London
cmcl innovations
Loughborough University

Perkins + Partners

APC 5 Projects currently under review

IAN FOLEY
GKN HYBRID POWER

GKN Hybrid Power

Company History

Automotive Hybrid Power

WILLIAMS HYBRID POWER

Innovate UK
Technology Strategy Board

Go-Ahead

GKN

ADVANCED PROPULSION CENTRE UK





2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

F1 Systems — Porsche GT3R — Audi e-tron — Gyro-drive Project / Alstom — DSTL contracts — HGV

mk1 mk2 mk3 mk4A mk5/A mk6/e mk4B mk8A mk8B mk10

What is a GKN Hybrid Power Flywheel ?

The Mechanical Battery

- The flywheel is an electric motor
- Stores energy mechanically
- Unique MLC Rotor
- Spins at up to 36,000 rpm
- Peak Power 120kW

Benefits

- Very high power density
- Wide operating temperature range
- Very high cycle life with no loss of performance
- Cost effective in volume

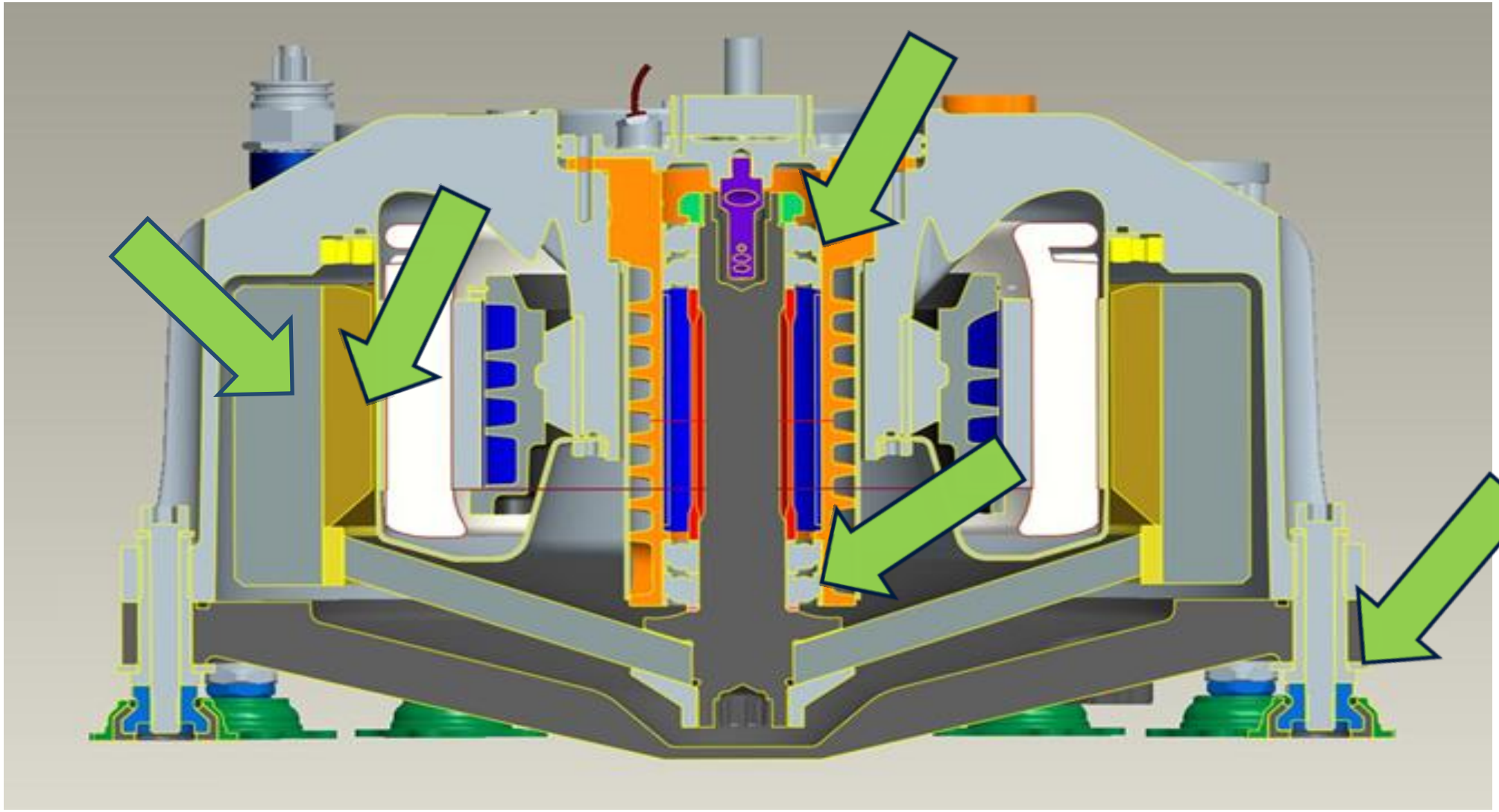
Filament Wound Carbon Fibre Outer Rotor

MLC

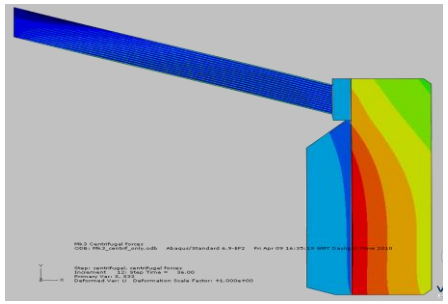
The inner ring of the flywheel is made of glass fibre mixed with magnetic particles. This provides the magnetic flux for the motor

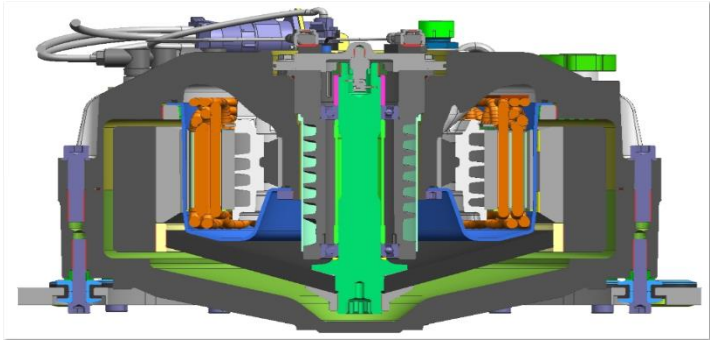
Magnetically Loaded Composite

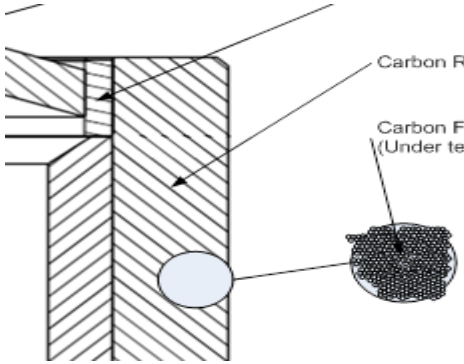
Flywheel Operation

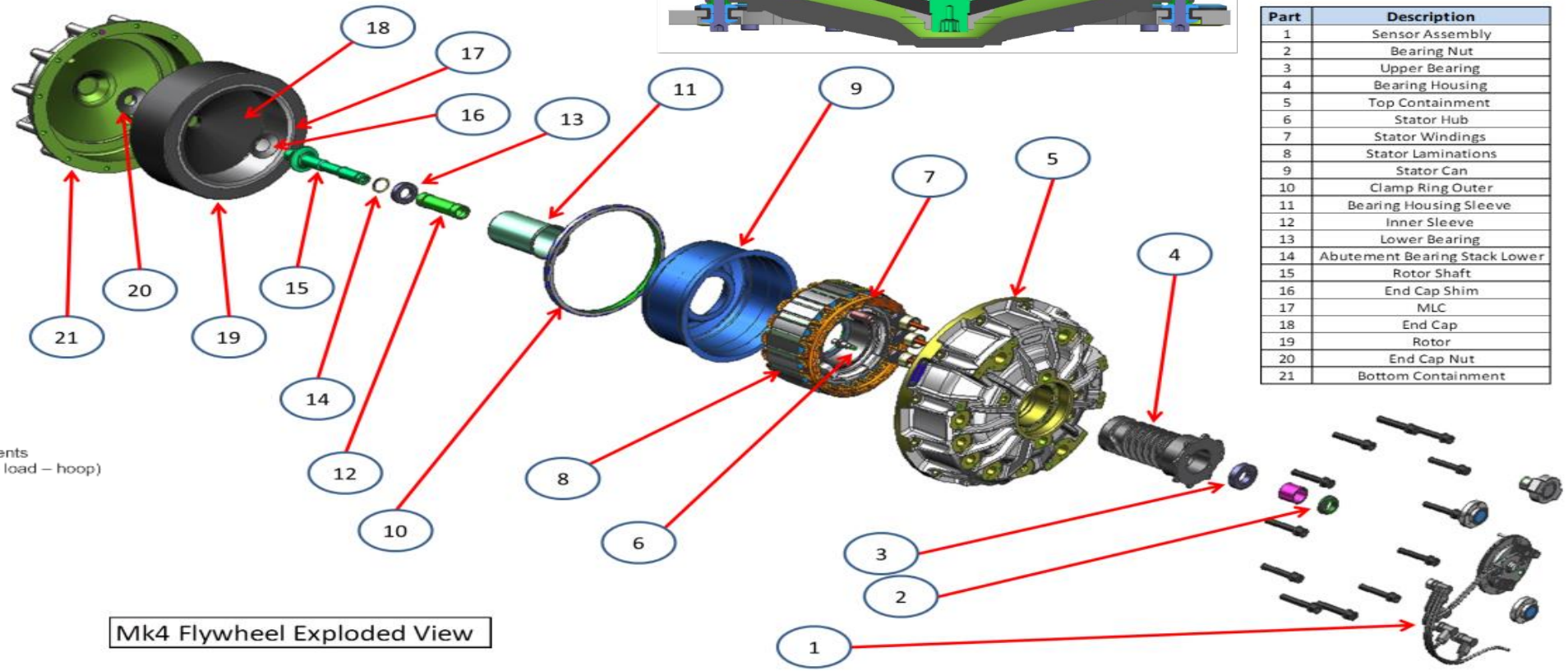


Technology Overview – Mk4 Flywheel Exploded View







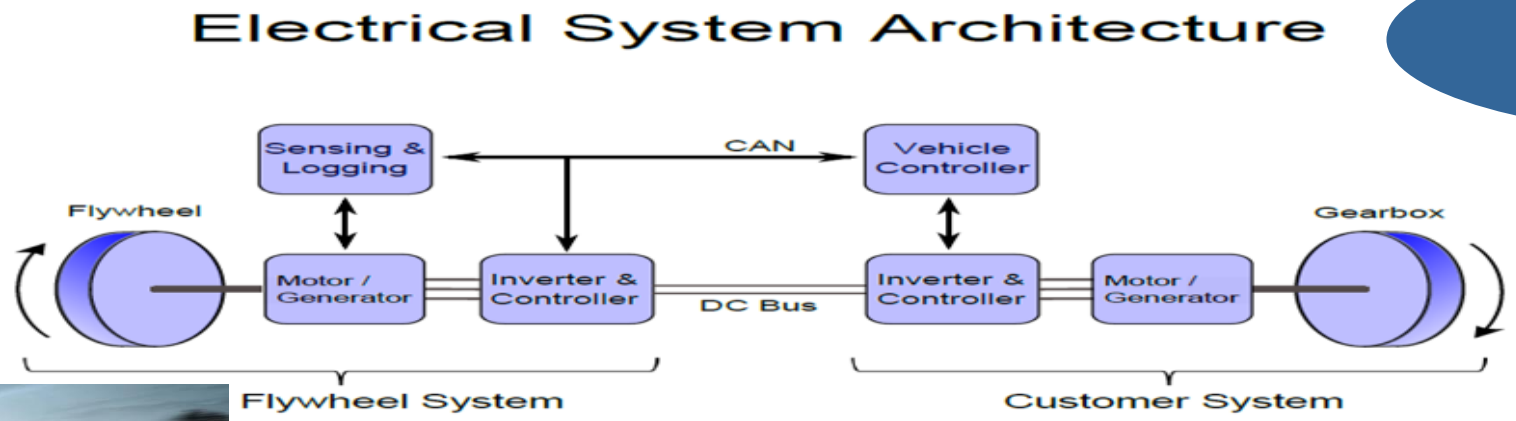


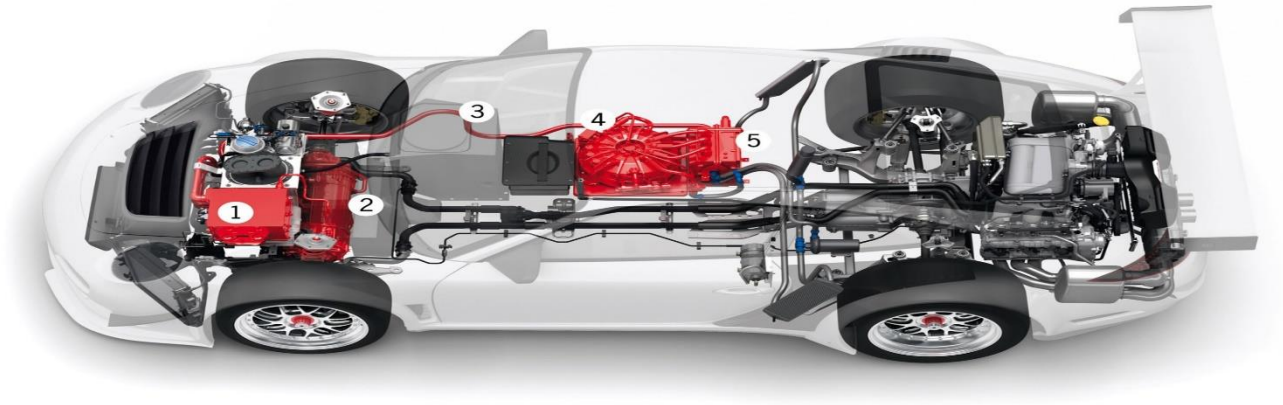
Part	Description
1	Sensor Assembly
2	Bearing Nut
3	Upper Bearing
4	Bearing Housing
5	Top Containment
6	Stator Hub
7	Stator Windings
8	Stator Laminations
9	Stator Can
10	Clamp Ring Outer
11	Bearing Housing Sleeve
12	Inner Sleeve
13	Lower Bearing
14	Abutement Bearing Stack Lower
15	Rotor Shaft
16	End Cap Shim
17	MLC
18	End Cap
19	Rotor
20	End Cap Nut
21	Bottom Containment

Mk4 Flywheel Exploded View

Flywheel Hybrid System - Principle of Operation

FESS = Flywheel Energy Storage System





1-Power Inverter

2-Motor Gearbox

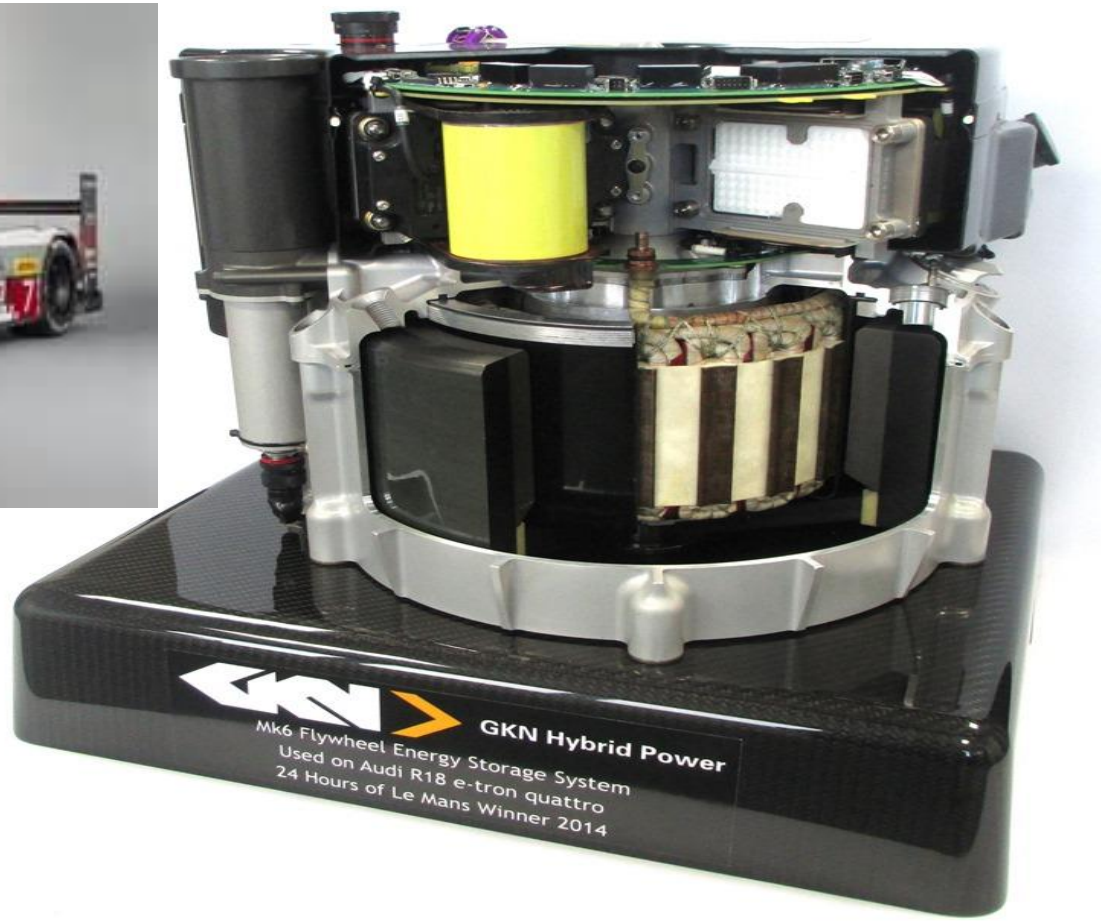
3-HV Bus

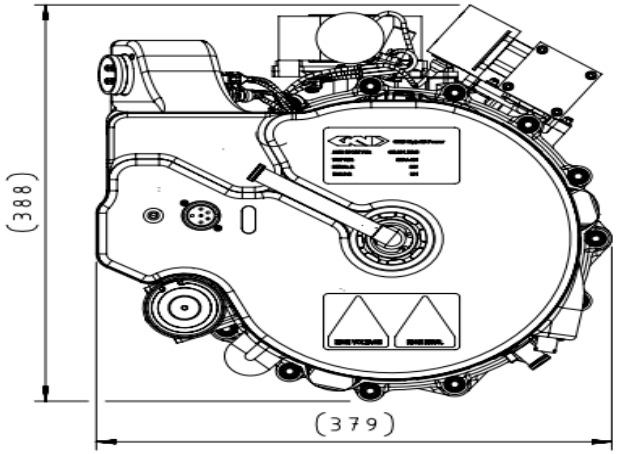
4/5-FESS

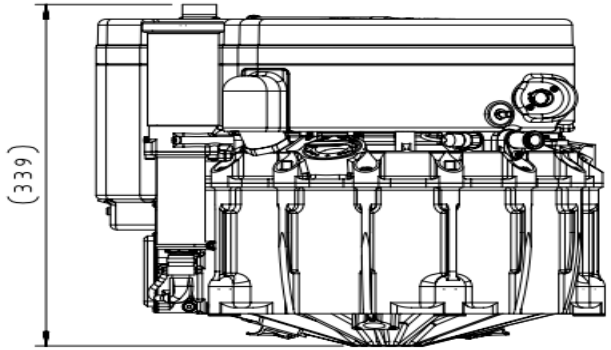
Mk6e Motorsport FESS

Energy storage for Audi R18 e-tron quattro

- Fully integrated system
- “Mechanical battery”
- External connections:
  - High Voltage DC bus
  - 12V supply
  - CAN communication
  - Water cooling in/out



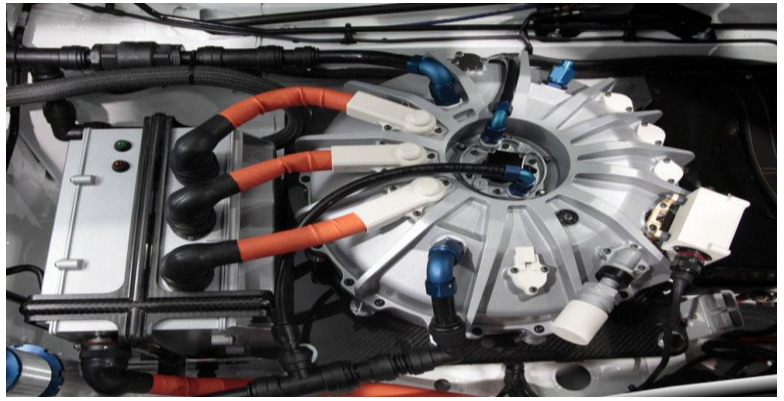




Mk6e Motorsport FESS

Specifications

Mk3 raced in Porsche 911 GT3R Hybrid (2010)



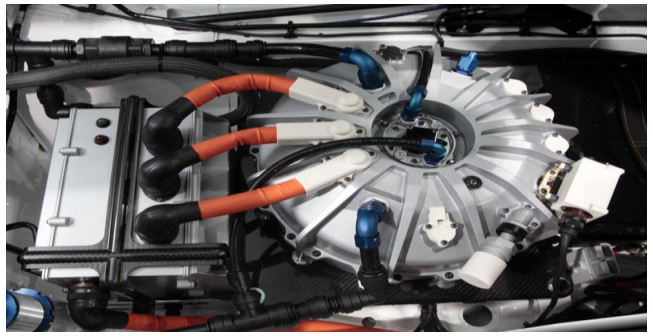
Mk6e raced in Audi R18 e-tron quattro (2015)

Parameter	Mk3 (2010)	Mk6e (2015)
Useable Kinetic Energy	880 kJ	780 kJ
Peak Power	120 kW	200 kW
Average Power (racing duty cycle)	48 kW	60kW
Voltage	400 Vdc	700 Vdc
Maximum Rotor Speed	36000rpm	45000 rpm
Total mass (FW, inverter, ancillaries)	58.5 kg	39.1 kg

Mk6e Motorsport FESS

Specifications

Energy density improvement of 33%



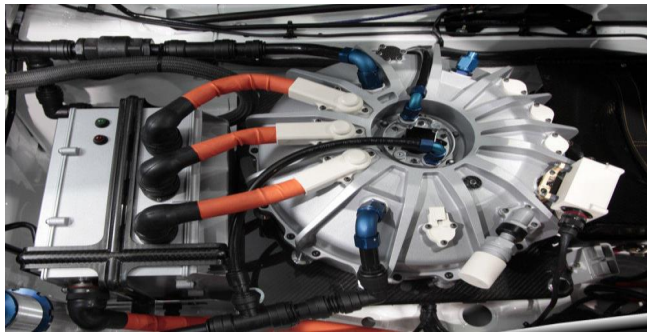
Parameter	Mk3 (2010)	Mk6e (2015)
Useable Kinetic Energy	880 kJ	780 kJ
Maximum Rotor Speed	36000rpm	45000 rpm
Total mass (FW, inverter, ancillaries)	58.5 kg	39.1 kg
Energy Density	15.04 kJ/kg	19.95 kJ/kg

+33%

Mk6e Motorsport FESS

Specifications

Power density improvement of 150% peak and 87% on average power

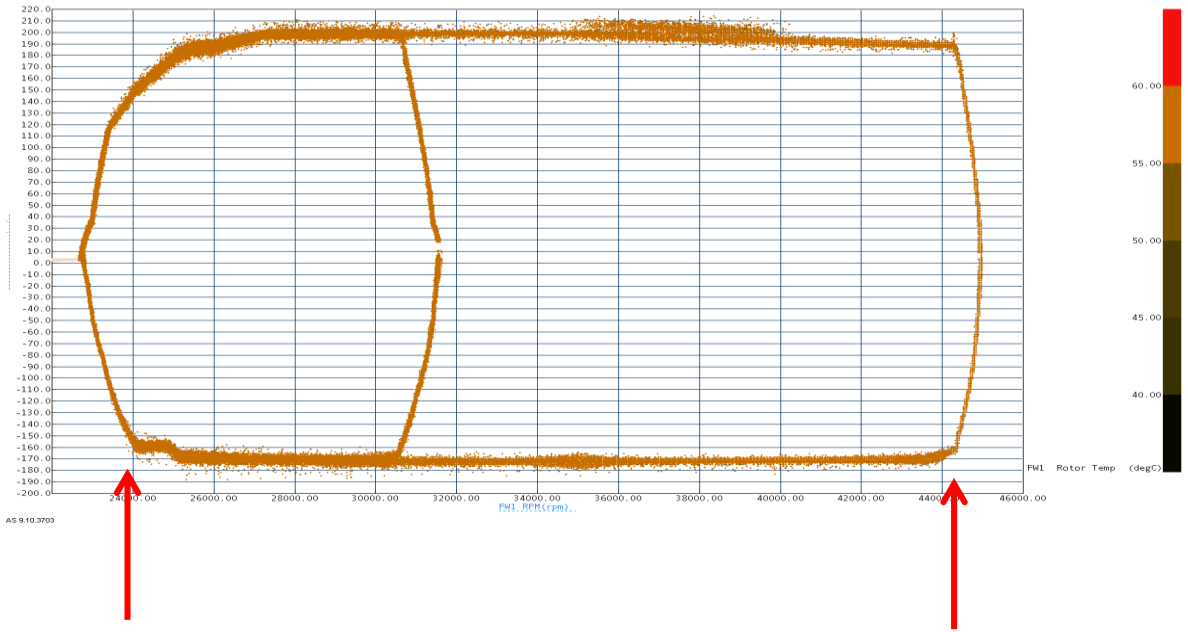


Parameter	Mk3 (2010)	Mk6e (2015)
Peak Power	120 kW	200 kW
Average Power (racing duty cycle)	48 kW	60kW
Total mass (FW, inverter, ancillaries)	58.5 kg	39.1 kg
Peak Power Density	2.05 kW/kg	5.12 kW/kg
Average Power Density	0.82 kW/kg	1.53 kW/kg

+150%

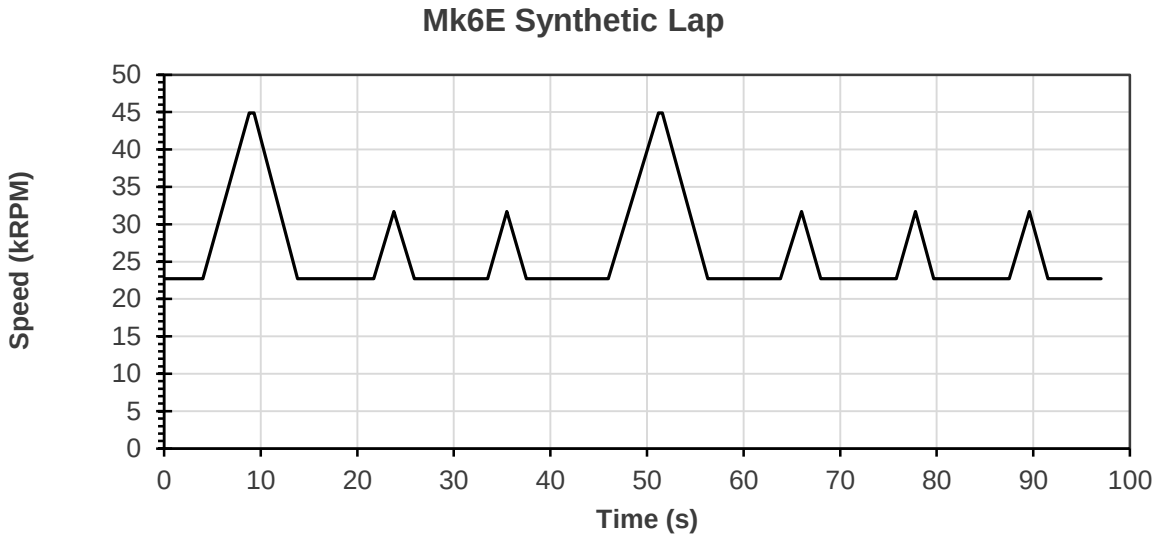
+87%

Mk6e Motorsport FESS



Min operating speed

Max operating speed



Duty Cycle

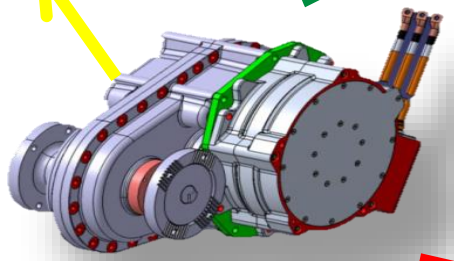
- **60 kW absolute continuous electrical power @ 40°C water inlet temp and 8l/min**
- **50 kW absolute continuous electrical power @ 60°C water inlet temp and 8l/min**

Safety Case

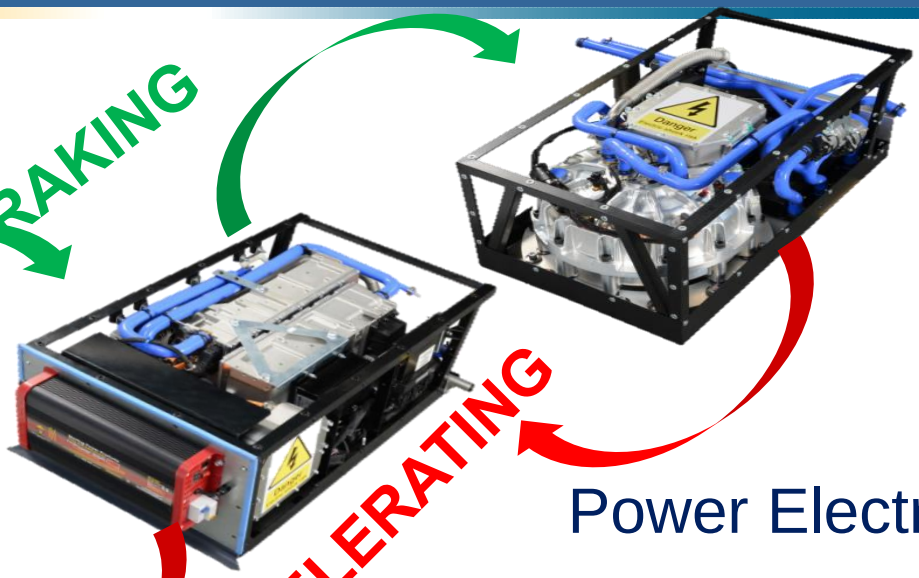
Audi R18 e-tron Quattro crashed heavily in practice for 2014 Le Mans 24 hour race

The flywheel is mounted next to the driver. The flywheel remained intact and the driver escaped unhurt

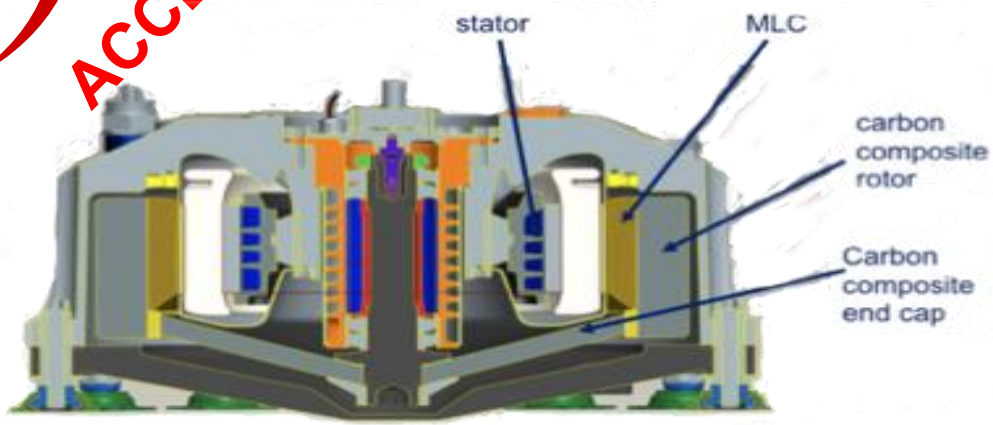
Gyrodrive Hybrid System Operation



GKN Motor / Gearbox



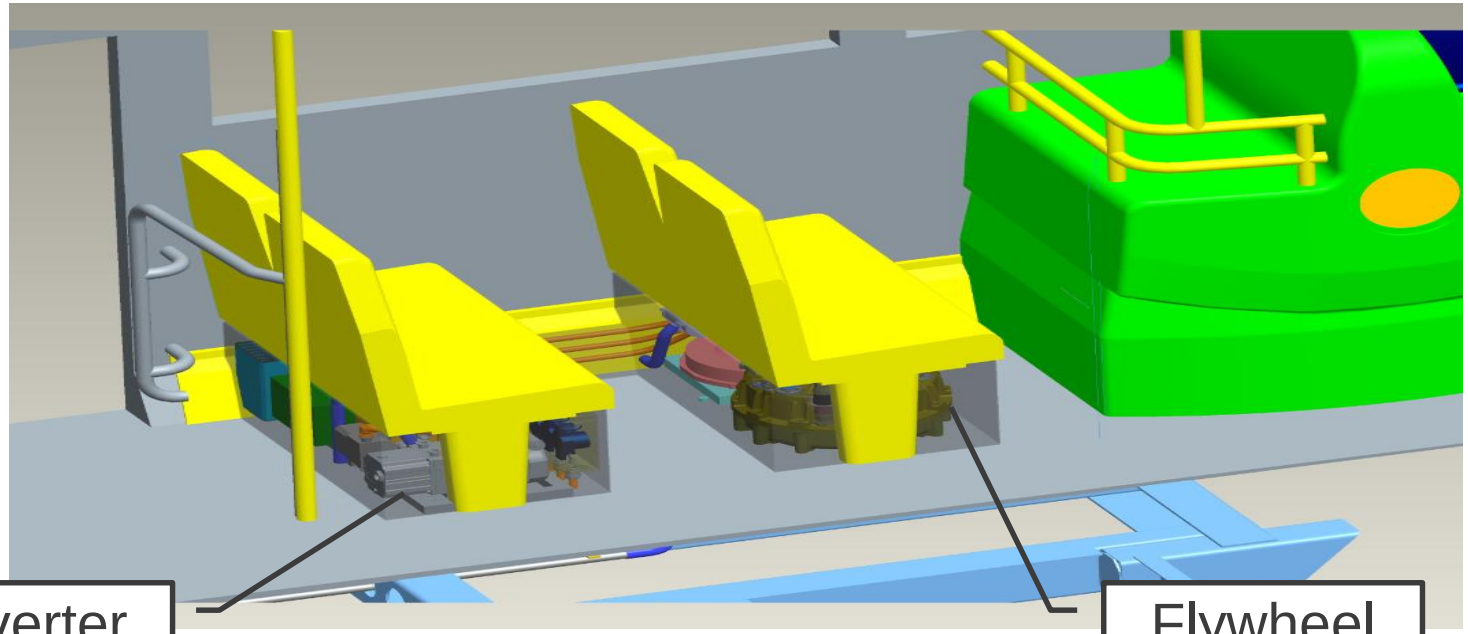
Power Electronics



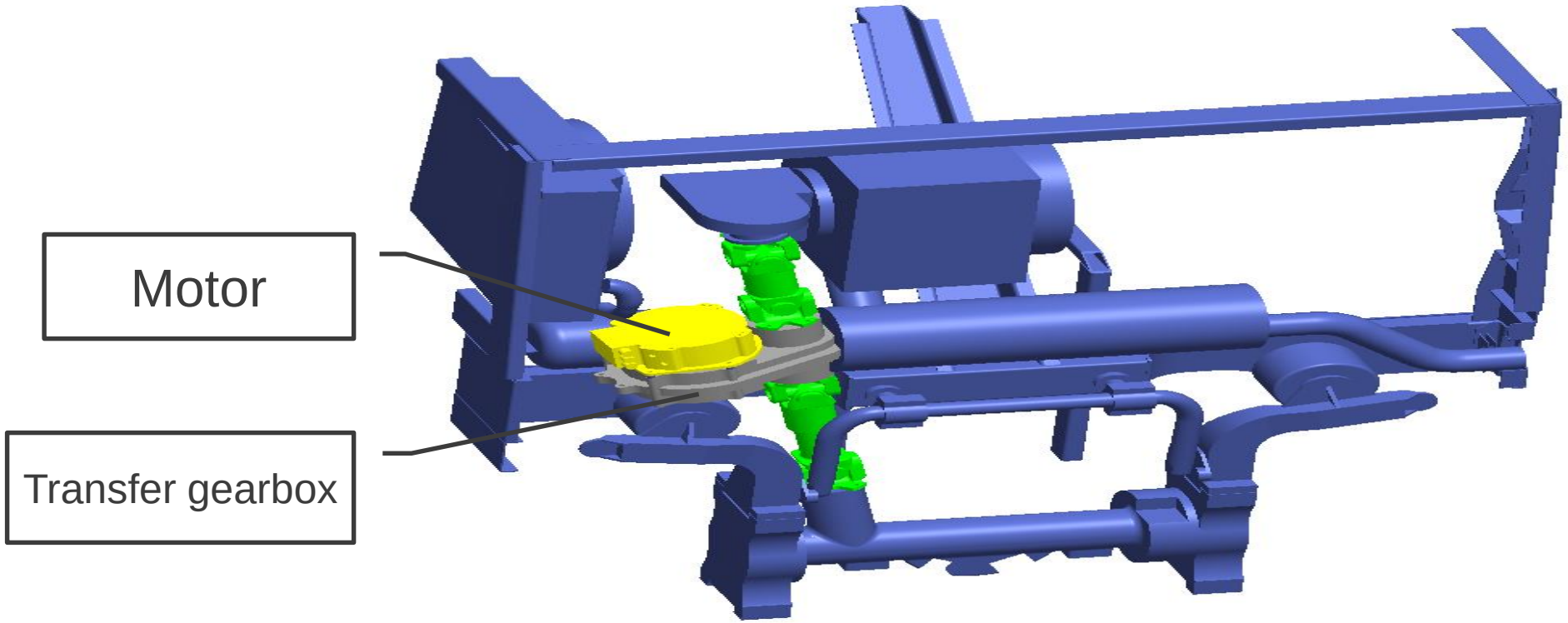
Through the motor / generator in the driveline the Gyrodrive flywheel captures the kinetic energy during braking and reuses it to help accelerate the bus.

Gyrodrive Hybrid System Installation

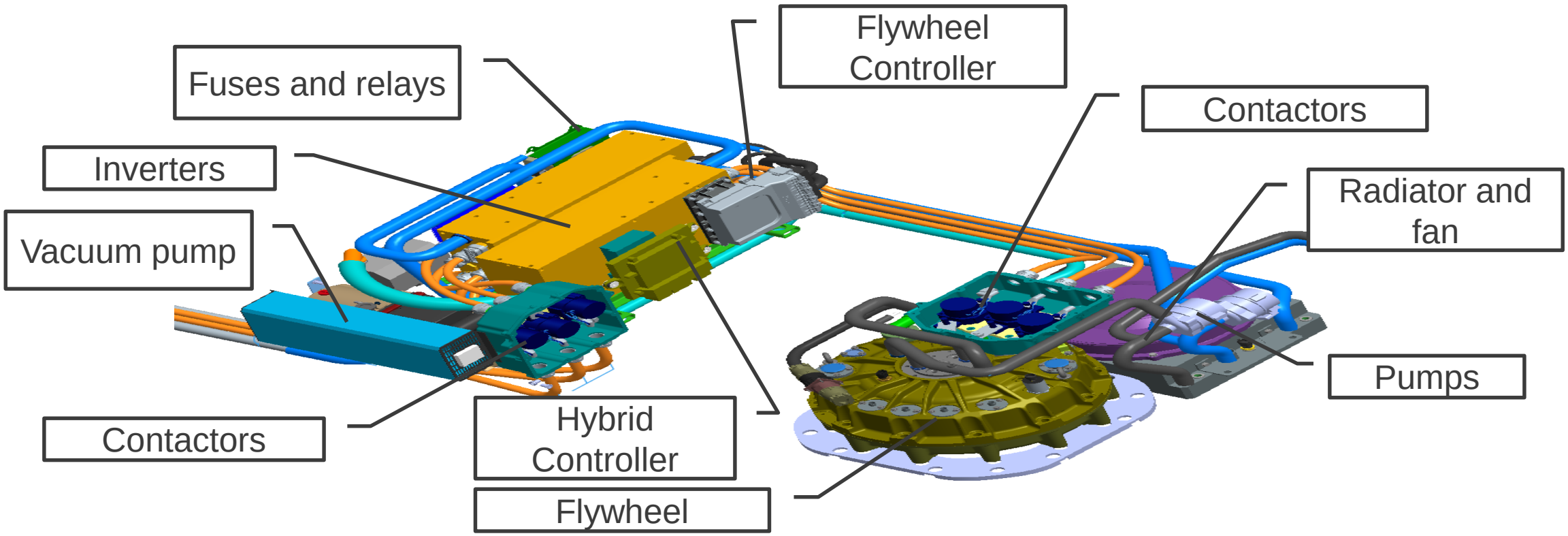
LONDON DOUBLE DECK (ADL AND B9TL)



Gyrodrive Hybrid System Installation



Gyrodrive Hybrid System Components

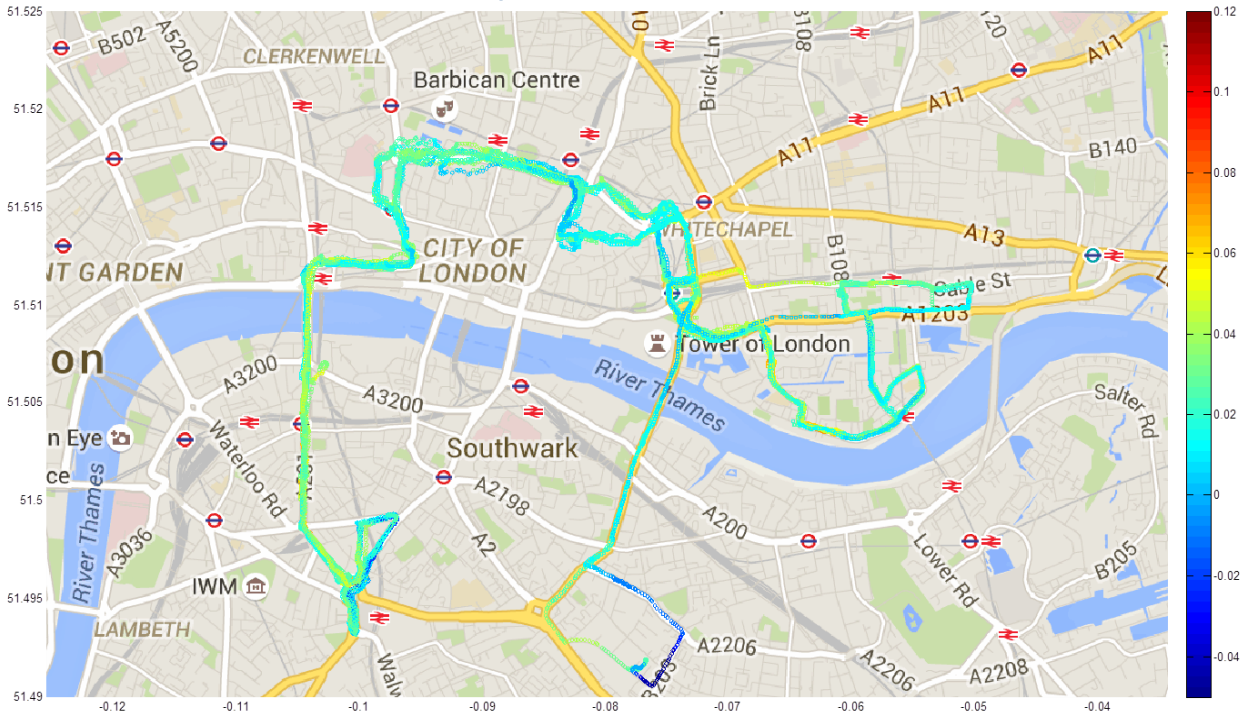


Gyrodrive installation in lower saloon

Gyrodrive installation in lower saloon

Fuel Analysis - Heat maps

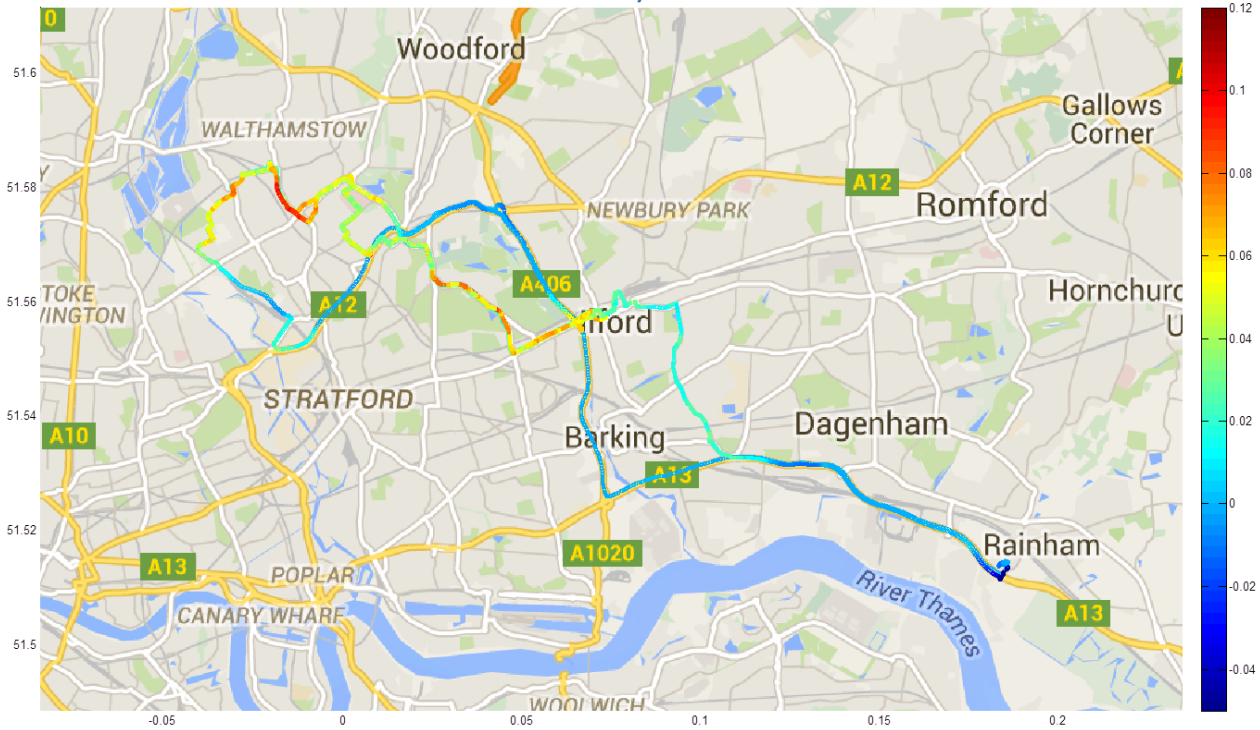
Route 100, ADL E200 E6



- Standard fleet average = 7.46mpg = 0.38 l/km

- Typical map, E200 running
- Green = 0.04 l/km = +11%
- Light blue = 0.02 l/km = +5%

Route W19, ADL E200 E6

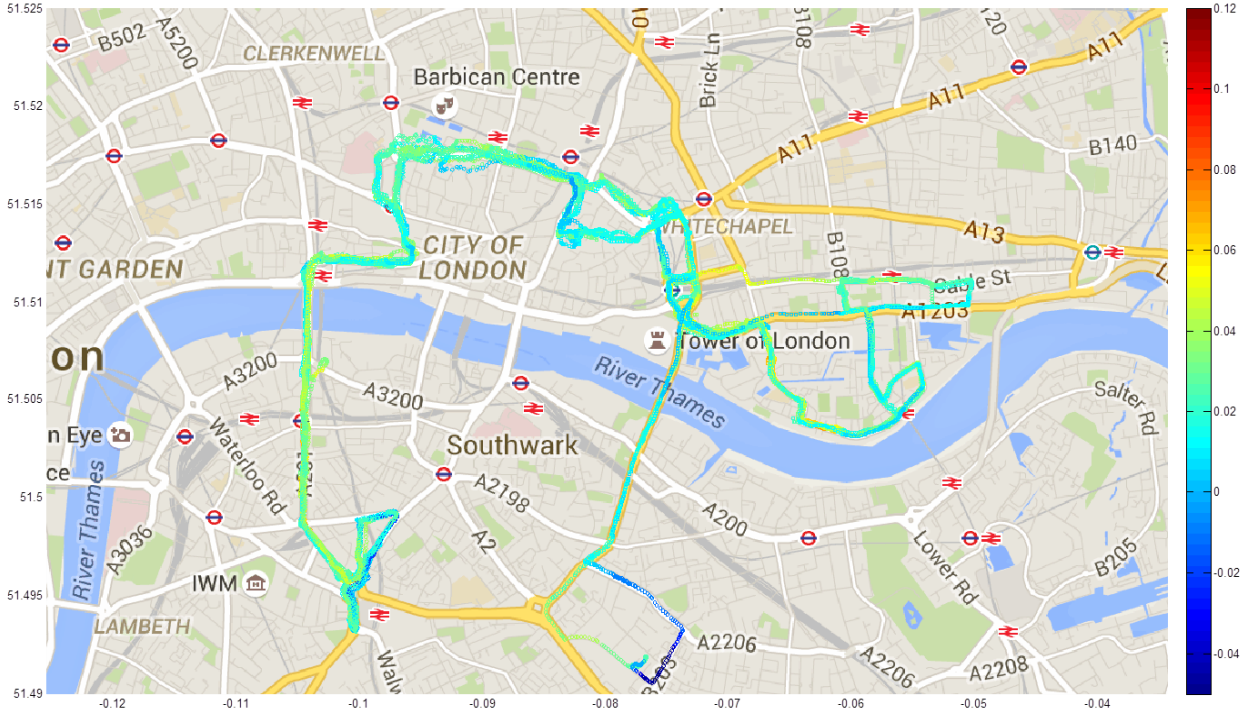


- Standard bus fleet average of 7.46mpg = 0.38 l/km

- Red = 0.1 l/km = +26%
- Yellow = 0.055 l/km = +14%
- Green = 0.04 l/km = +10%
- Light blue = 0.02 l/km = +5%

Fuel Analysis - Heat maps

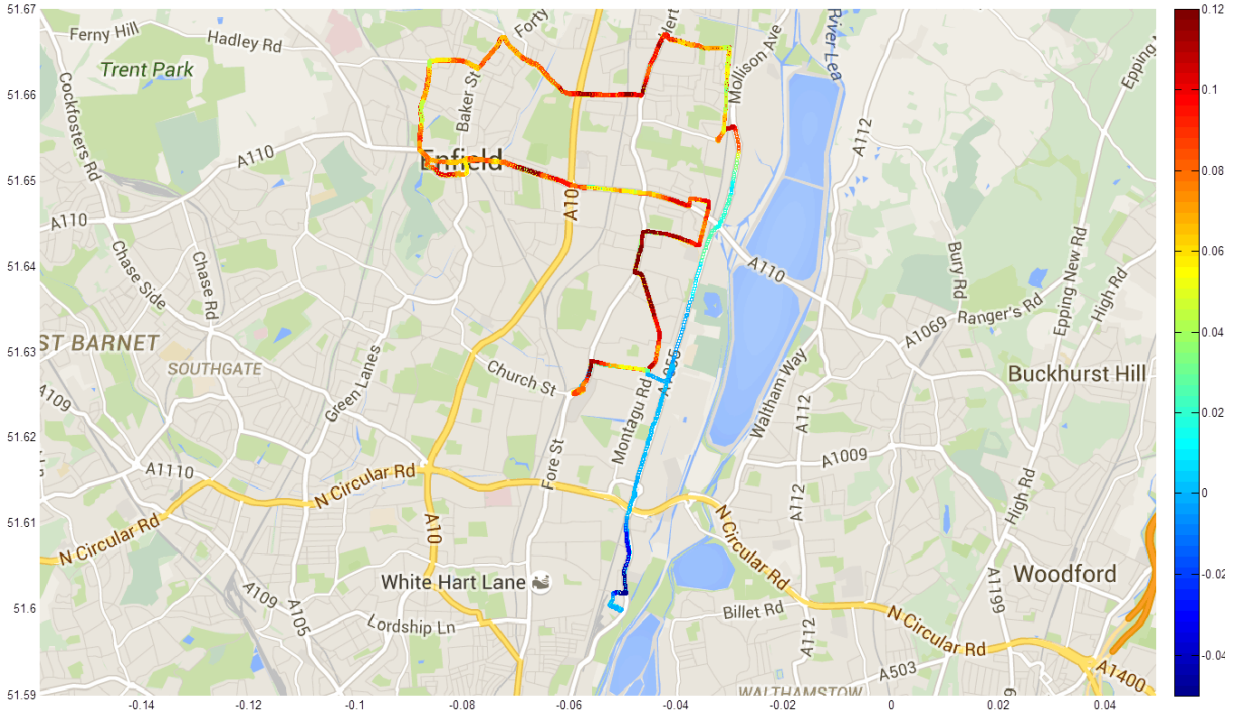
Route 100, ADL E200 E6



- Standard fleet average = 7.46mpg = 0.38 l/km

- Typical map, E200 running Route 100, 19/1/2016
- Green = 0.04 l/km = +10%
- Light blue = 0.02 l/km = +5%

Route 191, Volvo B9 E5



- Standard bus fleet average of 5.05mpg = 0.56 l/km

- Brown = 0.12 l/km = +21%
- Red = 0.1 l/km = +18%
- Orange = 0.08 l/km = +14%
- Yellow = 0.06 l/km = +10%

Application to HGV

- EU CO2 regs for HGV – 2020 – 2022
- OEM's developing integrated Gearbox MGU
- GKN HP Mechanical battery offers cost effective solution

OEM Gearbox with integrated MGU

Low cost GKN "Mechanical Battery" 120kW / 3MJ

Summary

- Flywheel technology proven in Le Mans
- Low Volume production rollout begun in City bus
- Mass production system under development
- High Volume application in HGV