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Energy Efficient Transport for Tomorrow

Professor Hongming Xu
Dr Stuart Hillmansen

Introduction

- Research in land transport at Birmingham:
  - Vehicle and Engine Technology Research
    - Mechanical Engineering
    - Chemical Engineering
  - Birmingham Centre for Railway Research and Education
    - Electronic, Electrical and Computer Engineering
    - Civil Engineering
    - Metallurgy and Materials
    - Mechanical Engineering

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Acknowledgement

- Both groups have been successful in gaining funding from the Science City Energy Efficiency initiative and also the University investment (total over £6m in the last 6 years)
- Support from industrial partners, and funding from TSB and EPSRC
- Contributions from colleagues within the 2 groups

EPSRC

Technology Strategy Board
Driving Innovation

SCIENCE CITY RESEARCH ALLIANCE
UNIVERSITY OF BIRMINGHAM
THE UNIVERSITY OF WARWICK
Birmingham Science City
ideasforlife
investing in **your** future
European Regional Development Fund
European Union
Advantage West Midlands
www.advantagewm.co.uk

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Vehicle and Engine Technology Research Centre

Prof Hongming Xu
Chair in Energy & Automotive Engineering
Head Vehicle and Engine Technology Research

Prof Miroslaw Wyszynski
Chair in Novel Vehicle Technology

Dr Athanasios Tsolakis
Senior Lecturer in Automotive Engineering

Dr Karl Dearn
Lecturer in Mechanical Engineering

Dr Oluremi Olatunbosun
Senior Lecturer in Mechanical Engineering

Dr Andrew M Tobias
Senior Lecturer in Railway Systems Engineering

Prof Farhang Bakhtar

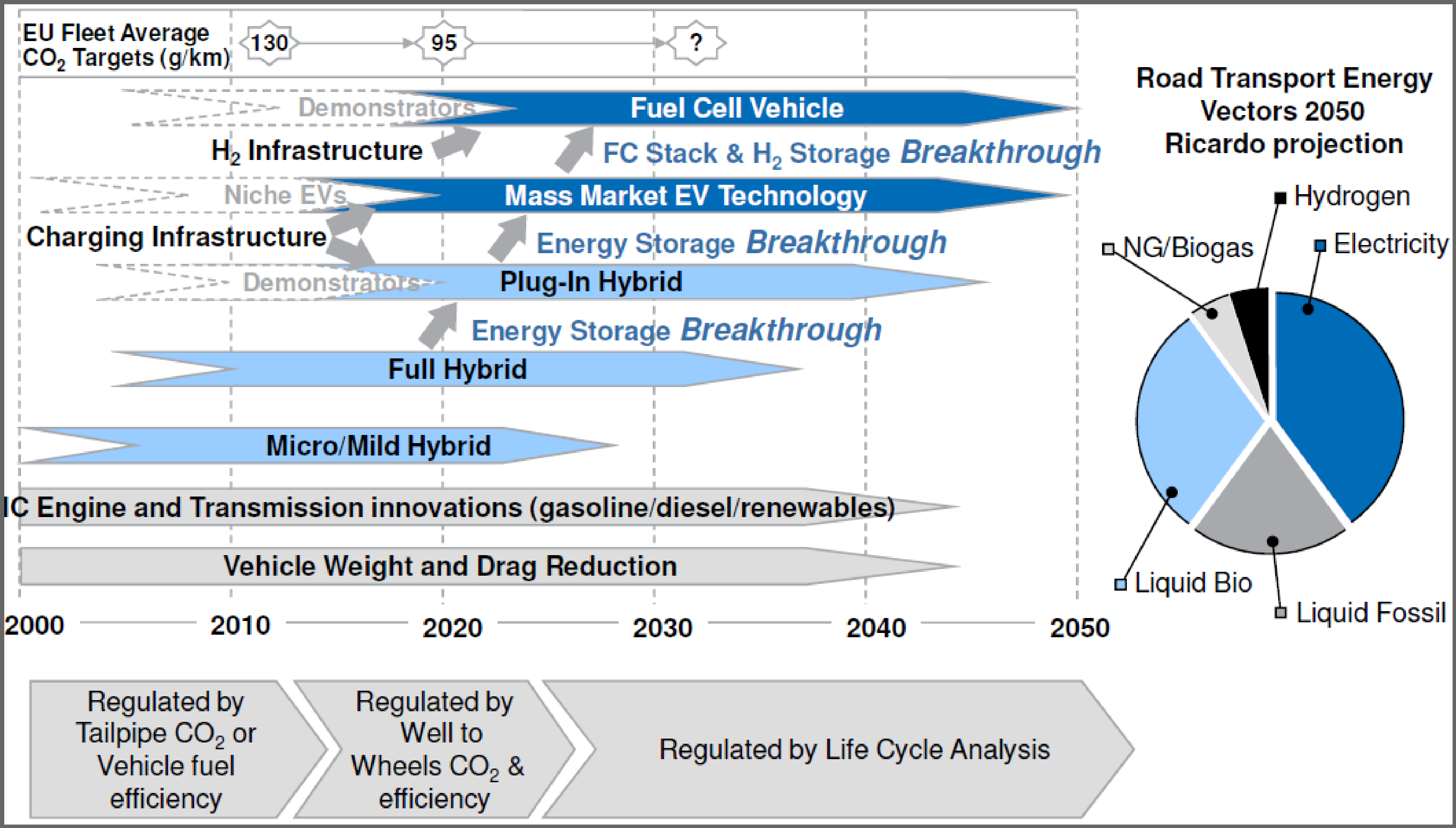
Prof (Hon) Steve Richardson (Jaguar)
Prof (Hon) Roger Cracknell (Shell)
Dr Jun Qiao (ETI)

Major research activities

- Fuels pretreatment and mixture preparation for engines
- Flow and combustion diagnostics in engines
- New and bio-fuels and their combustion and emissions
- Exhaust gas aftertreatment systems
- Tribology in vehicles
- Tyres dynamics
- Vehicle ride and handling dynamics
- Noise vibration and harshness (NVH)
- Railway systems and management

- 3-5 pre-doctoral Research Assistants
- 30-40 PhD research students
- 5 -10 academic visitors (Senior Research Fellow)

Ultra Low Carbon Vehicles Roadmap



Source: Ultra Low Carbon Vehicles in the UK – BERR/DfT; Ricardo roadmaps and technology planning; Shell Energy Scenarios to 2050 (2008)

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Future Engines and Fuels Lab Refurb. - £1.5 m

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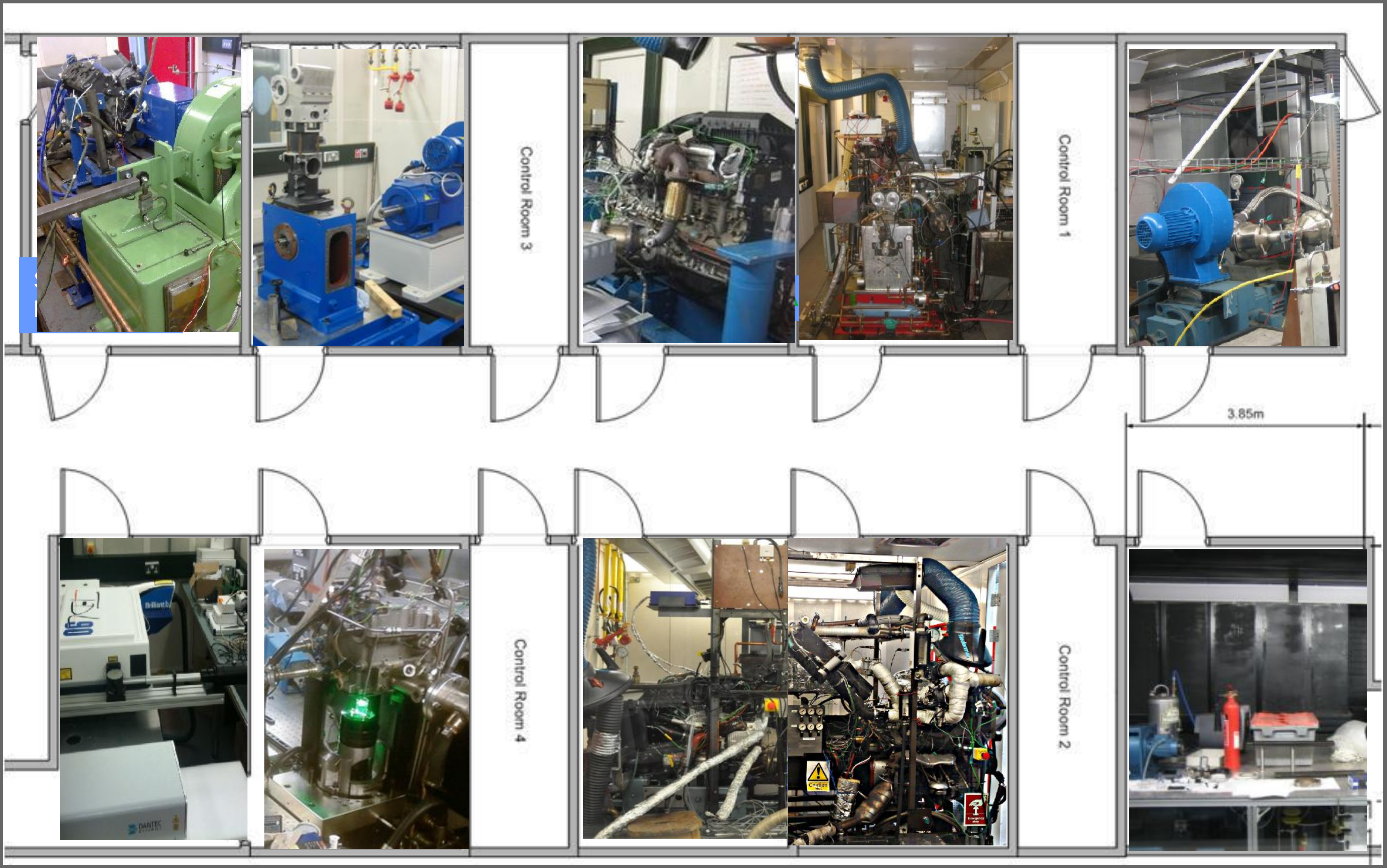
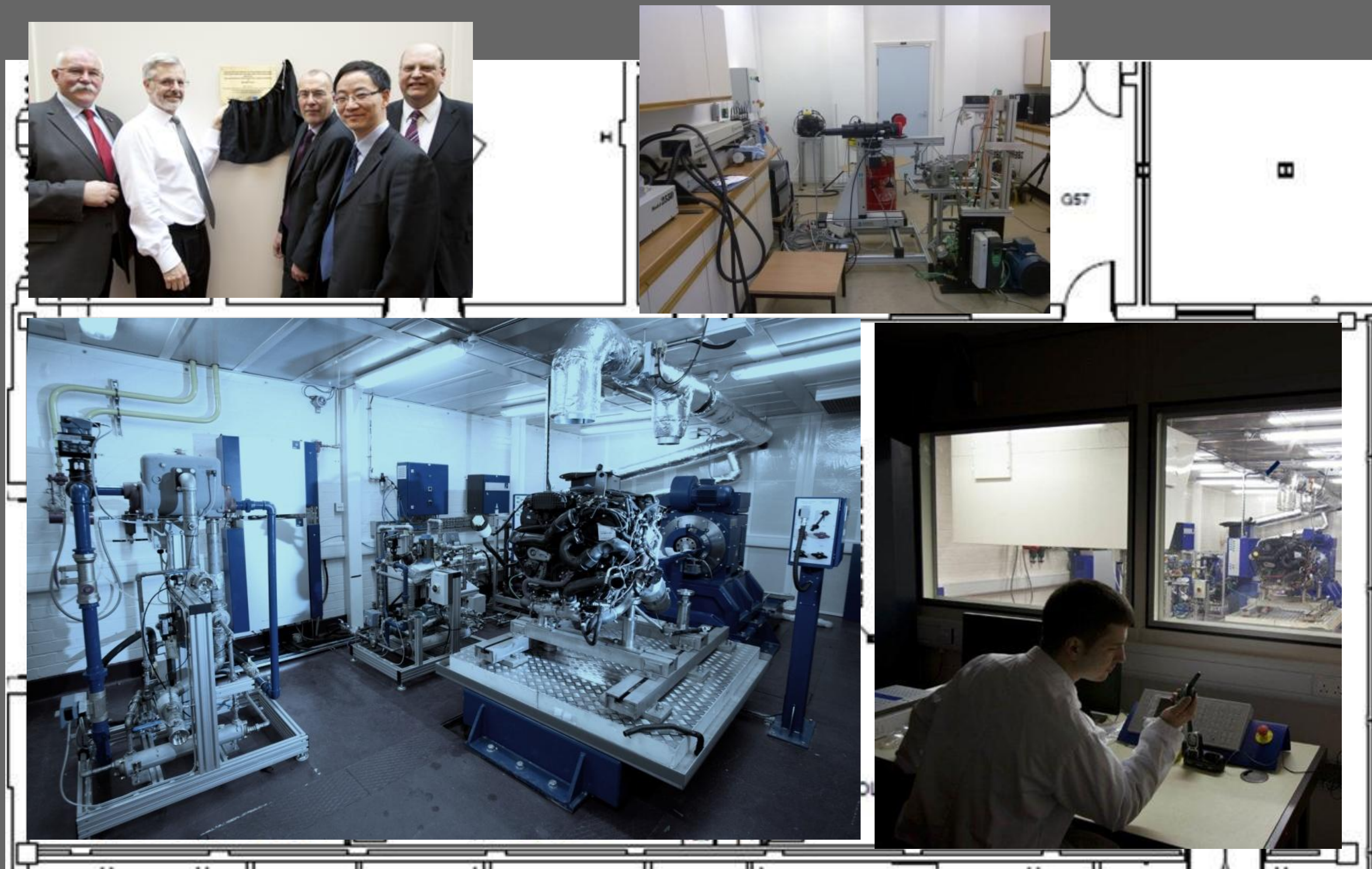
Future Engines and Fuels Lab 2009 (G48)



New facilities



New transient engine cell for cold start (-20^{o}C) with fuel testing facilities

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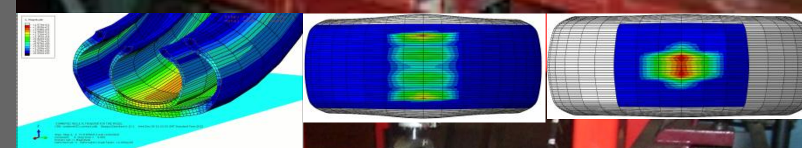
Tyre and vehicle ride and handling dynamics

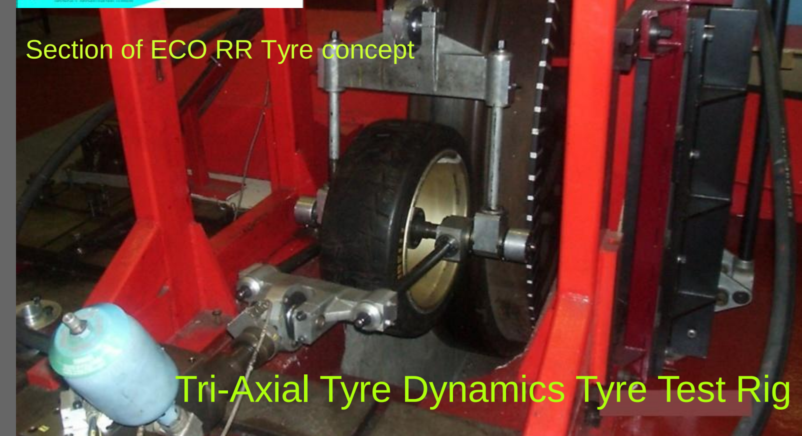
Vehicle Dynamics Lab: Suspension Test Rig

Four-Post Vehicle Dynamics Rig



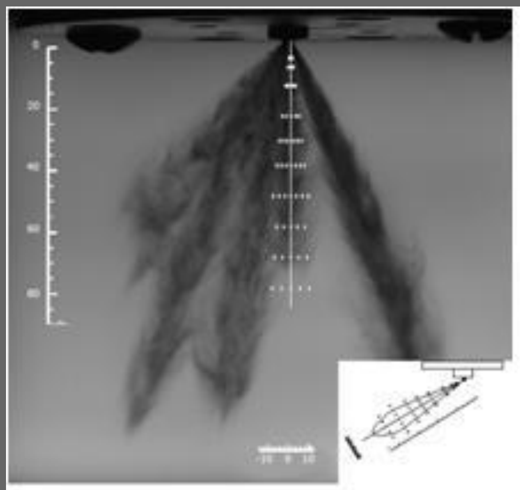
Section of ECO RR Tyre concept

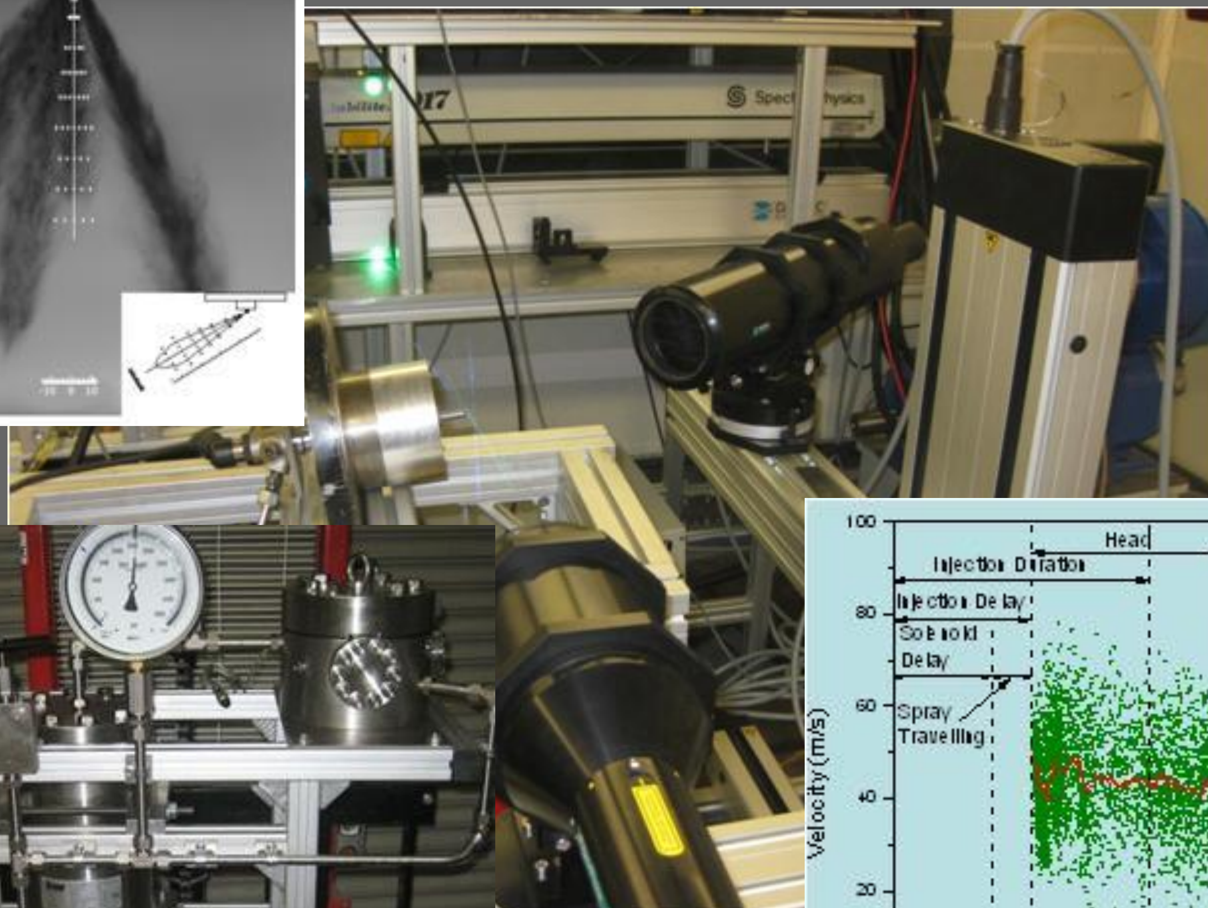
Vehicle Structural Dynamics Analysis Facility

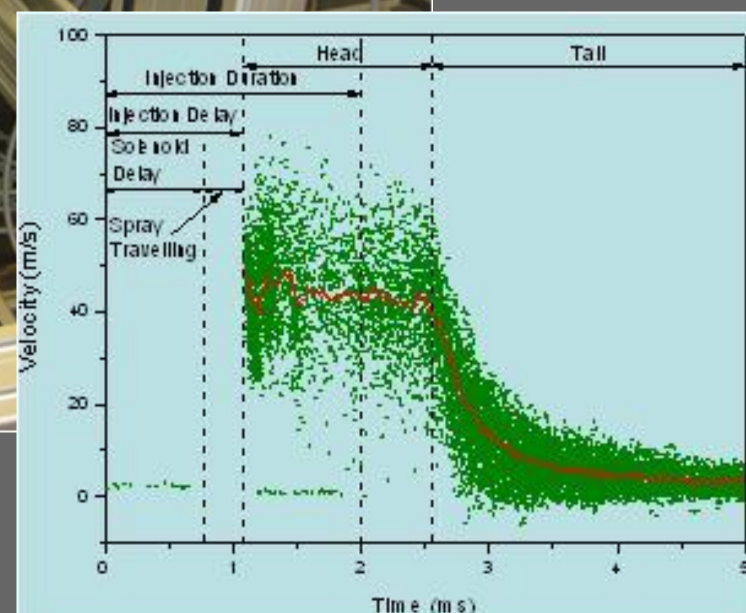


Tri-Axial Tyre Dynamics Tyre Test Rig

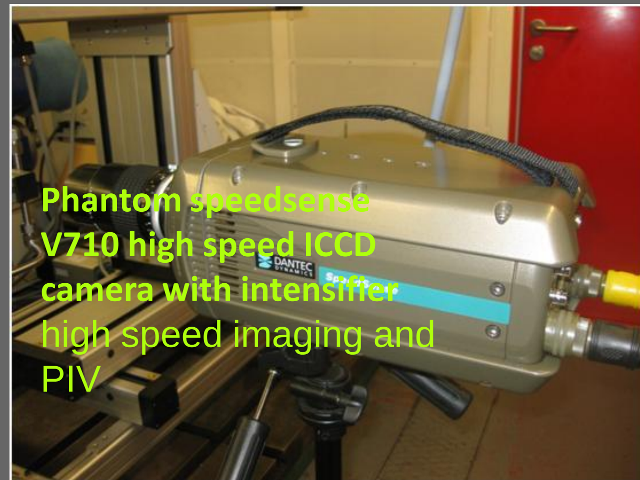
Spray characteristics (3-D PDPA)

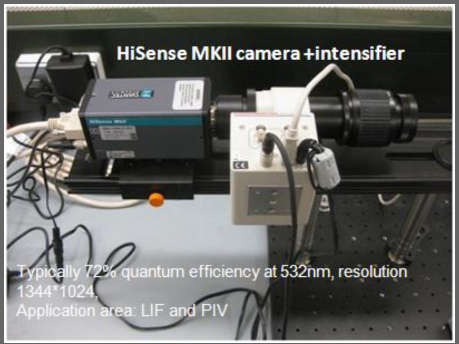


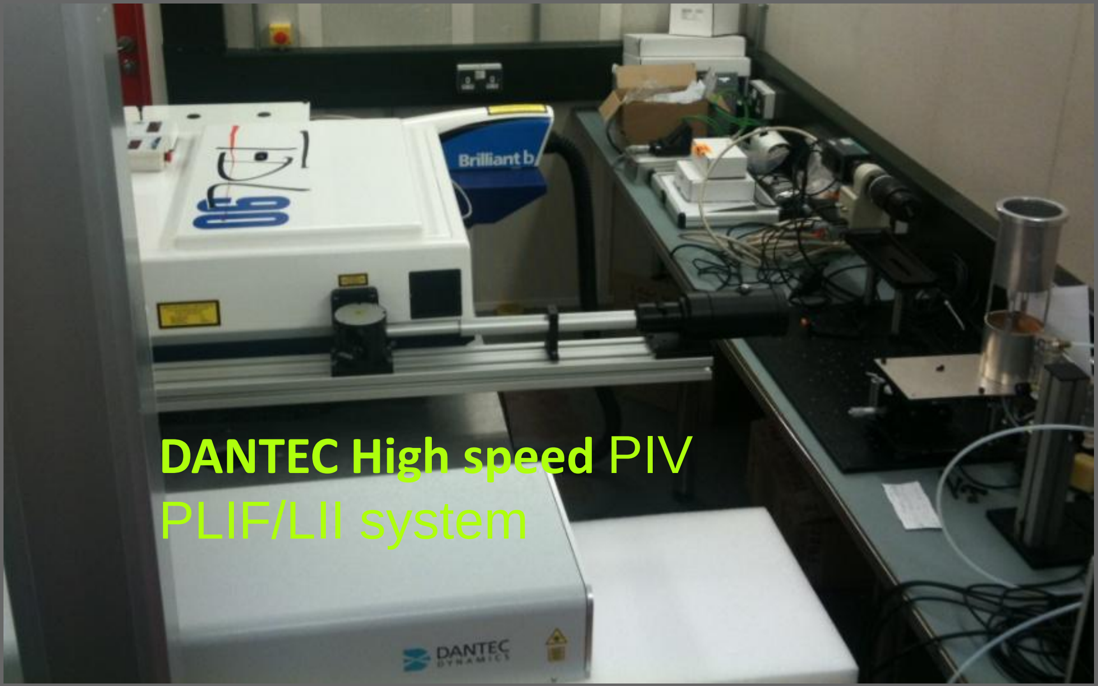




Advanced Laser Diagnostic (PIV, 2D PLIF/LII) studies







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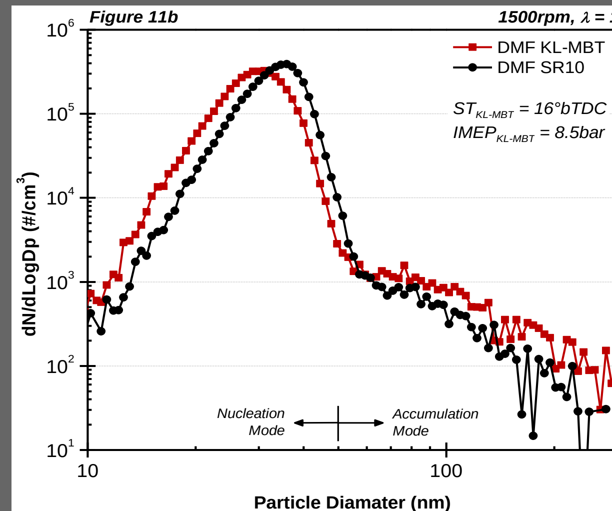
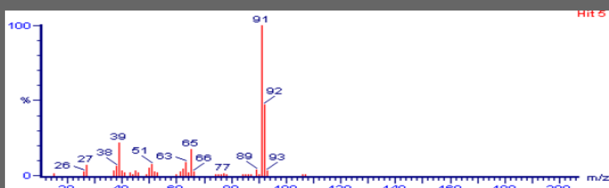
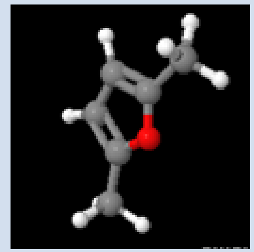
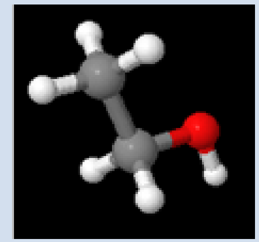
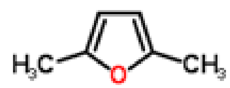
Gaseous and particle emission studies





New biofuels and alternative fuels

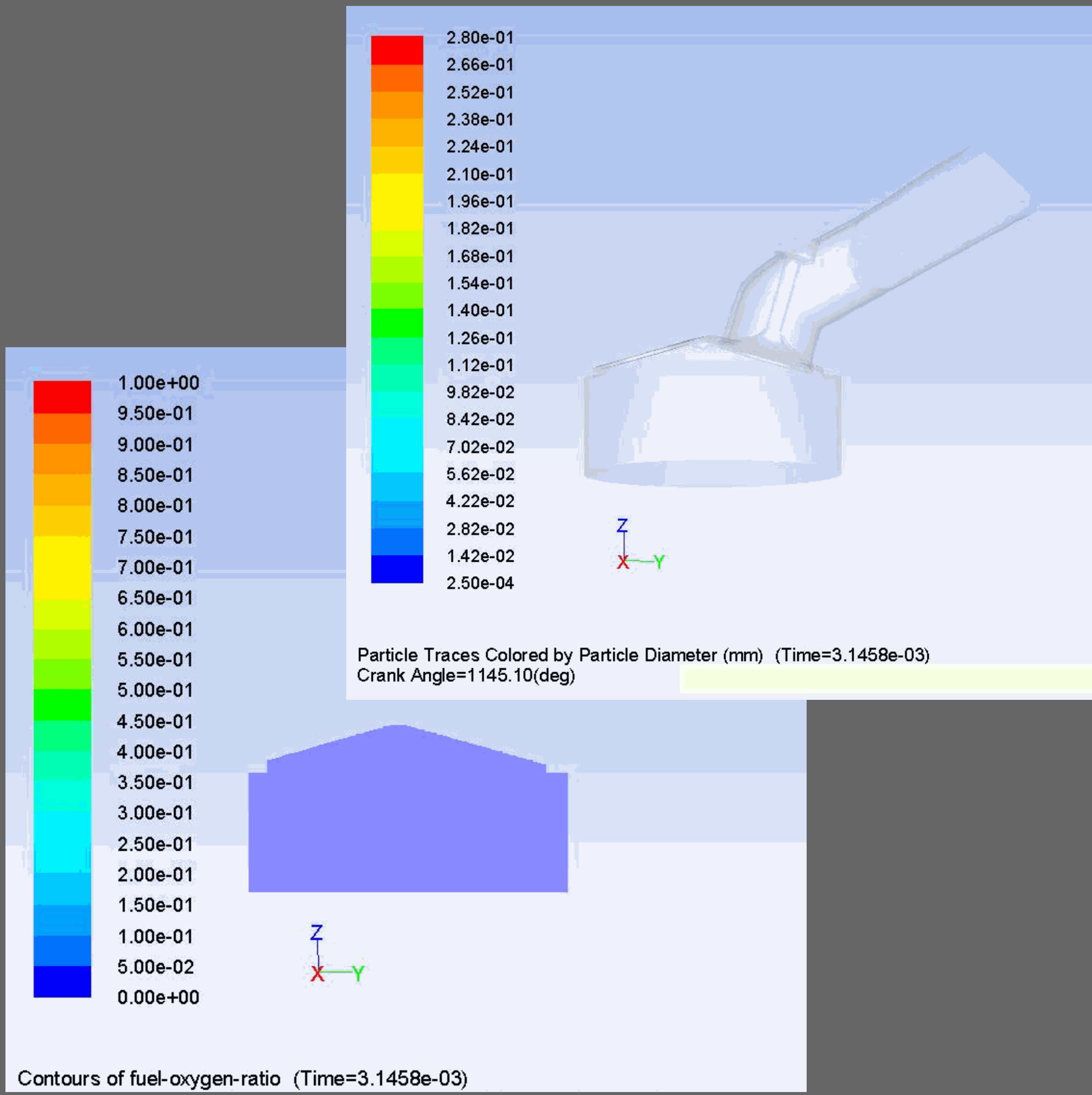
Name(s)[i,ii]	2,5 Dimethylfuran	Ethanol	Gasoline
Linear Structure Formula[i]	$(CH_3)_2C_4H_2O$	CH_3OCH_3	Variable
Molecular Formula[i]	C_6H_8O	C_2H_6O	C_2 to C_{14}
Molecule 3D View[iv]			Variable
Molecule Schematic[iv]			Variable
BP, Boiling Point (1atm)[i]	93.0°C	77.3°C	
Enthalpy of Vaporization[iv] (20°C)	$31.91 kJmol^{-1}$	$43.2496 kJmol^{-1}$	
Enthalpy of Combustion[iii]	$42.0 kJmol^{-1}$	$26.9 kJmol^{-1}$	$43.4 kJmol^{-1}$
ρ, Density of Liquid [i]	$0.8954 kgm^{-3}$ @20°C	$0.79363 kgm^{-3}$ @15°C	
Research Octane Number (RON)[v]	119	110[vii]	95[iv]
Auto Ignition Temperature[vii]	285.85°C	423°C	257°C

Productio

liquid fuel

carbohydrates. ***Nature***, 2007. 447: p. 982-986.

Biofuel engine modeling and validation



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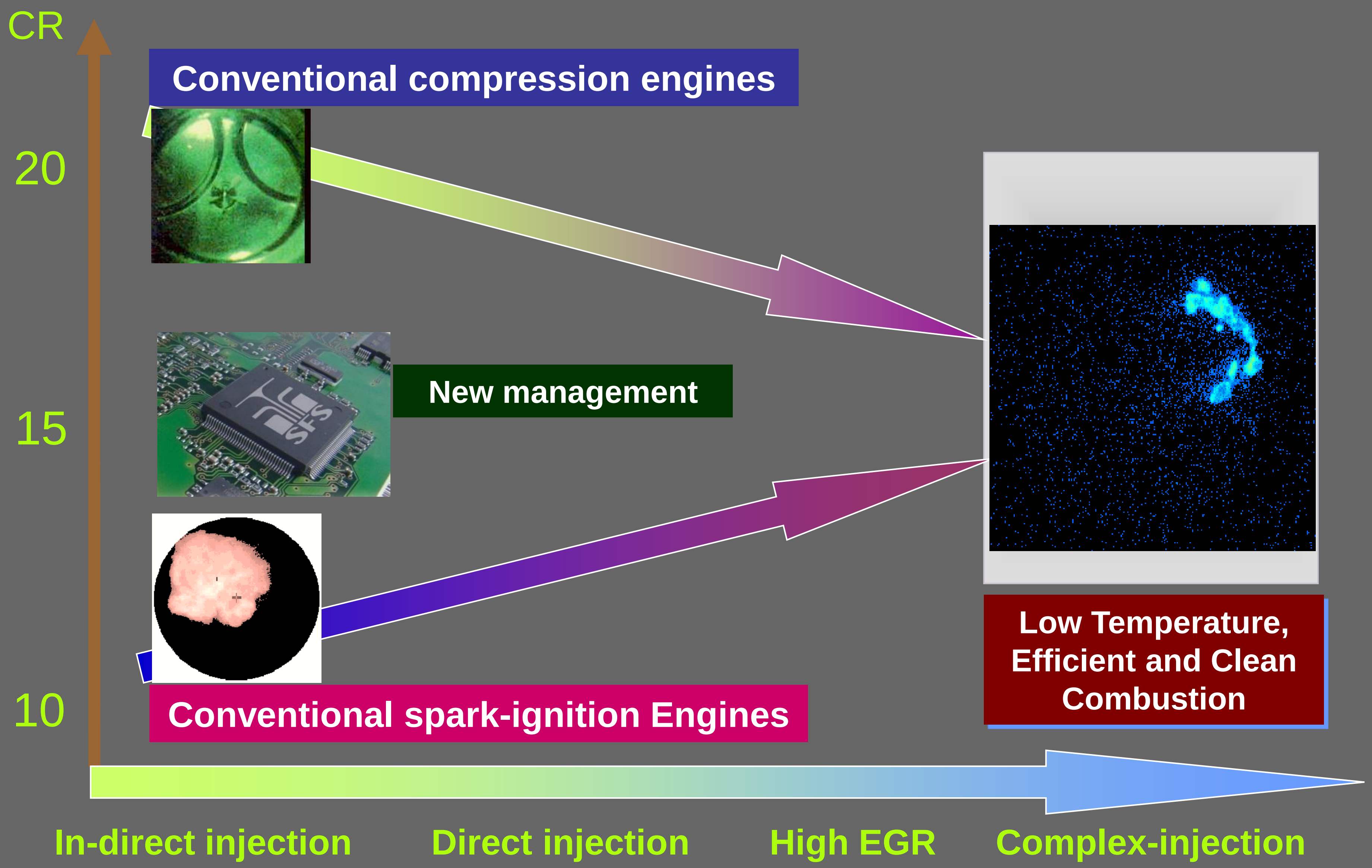
New combustion systems

to merge gasoline and diesel engine technologies



UK FORESIGHT projects on HCCI

Foresight Vehicle

CHARGE (**C**ontrolled **H**omogeneous **A**uto-ignition **R**eformed **G**as **E**ngine),

2 yrs DTI /EPSRC sponsored, total funding = **£840K**

- Facilitate **natural gas** HCCI using fuel reforming

CHASE (**C**ontrolled **H**omogeneous **A**uto-ignition **S**upercharged **E**ngine)

3 yrs DTI/EPSRC sponsored, total funding = **£1,539K**)

- Expand **gasoline** HCCI window

2002 2004 2007 - 2008

partners: **Jaguar Cars,** Birmingham University
Johnson Matthey, MassSpec UK
National Engineering Laboratory Race Technology

JAGUAR THE UNIVERSITY OF BIRMINGHAM JM MS UK

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Current Biodiesel project sponsored by TSB

SERVE (Flex-diesel Engines with Sustainable Bio-fuels for Clean and Efficient On- and Off-Road Vehicle Engines)

3 years TSB(DTI) sponsored, total funding £2,124K (UoB £593k)

Dec 2007

Sept 2011

1) to identify the changes required by the engine system (including aftertreatment) to run on blends containing up to 30% of a variety of both generations bio-diesel fuels
2) to develop novel ‘Flex-diesel’ technologies involving onboard pre- and after-treatment to maintain optimized engine performance and emissions with increasing percentages of fully sustainable bio-fuels

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Ongoing project, sponsored by TSB

CREO - CO_2 Reduction through Emission Optimisation (3 years, total funding £8m, UoB £400k)

Oct 2010 Sept 2013

to investigate on-board fuel pre-treatment technologies (e.g. catalytic fuel reforming) that, when integrated within the engine system (i.e. combustion or aftertreatment) will primarily improve the fuel economy and CO_2 emissions. In addition, benefits in engine and aftertreatment catalyst operability and emissions (including regulated and unregulated) will be assessed.

Collaborative Research Sponsored by EPSRC

Impact of DMF on Engine Performance and Emissions as a New Generation of Sustainable Biofuel, £509k

Feb 2009 — August 2012

EPSRC Engineering and Physical Sciences Research Council EP/F061692/1.

Research Councils UK Energy For a Low Carbon Future

To study the characteristics of combustion and emissions of a newly proposed generation of Biofuel for gasoline (SI) engines with bench-marking to ethanol, involving modelling and experimental study of fuel spray, direct injection mixture preparation, combustion and emissions (regulated and unregulated)

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partners

JAGUAR · LAND ROVER · Shell · innospec · green fuels

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Railway Power and Energy Research at Birmingham

- Energy accounts on average for around 15% of the operational costs for railway companies, and it is growing ~ £500 million PA
- Research in railway traction at Birmingham dates back to the early 1970s
- Nowadays the main focuses of our research are:
  - **Monitoring**
  - **Simulation and testing**
  - **Optimisation**
- Collaborative working with key industry players in UK, EU, Singapore, China, Australia, Hong Kong

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Current Projects (2009-2011) in Power and Energy

- Department for Transport – Calculation of energy consumption
  - Phase 2 - DMU (Class 150 and Pacer replacement)
- Department for Transport / DeltaRail – Discontinuous electrification
- Department for Transport / TRL – Evaluation of novel train propulsion systems
- Department for Transport / MerseyRail / Network Rail – Evaluation of losses and energy saving strategies in DC railways
- Atkins – Multi-Train Simulator development
- KTP / Atkins – AC railway power network simulator
- Singapore Land Transit Authority – Bespoke train simulator
- Kuala Lumpur Metro – Power system analysis
- Chinese Government – Energy usage assessment for high speed rail
- General Electric – Hybrid commuter train analysis
- ATOC – Strategic distribution of energy meters
- PhD Student – Hydrogen trains
- PhD Student – Optimised Supervisory Control for Hybrid Rail Vehicles

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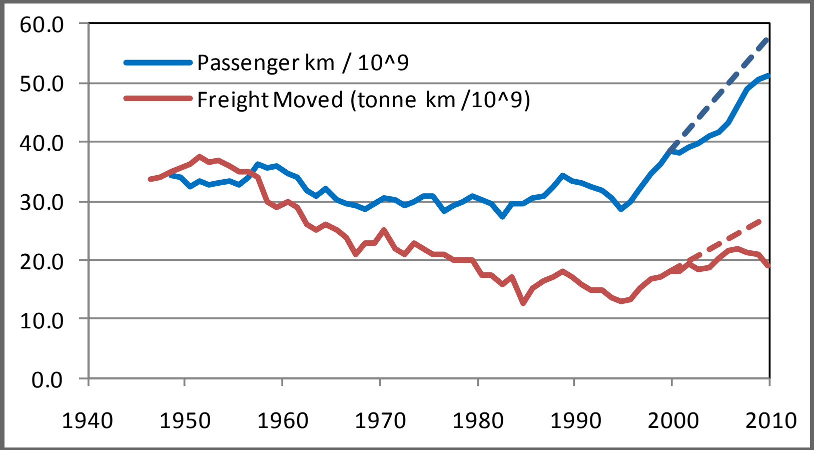
MerseyRail monitoring



Train based:

- Traction and auxiliary currents and voltage
- Cam shaft position
- Driver's handle position
- Position on track
- Inertial measurement
- Temperature

Sub-station based:

- Voltage and currents

Department for Transport

Merseyrail More than just a journey

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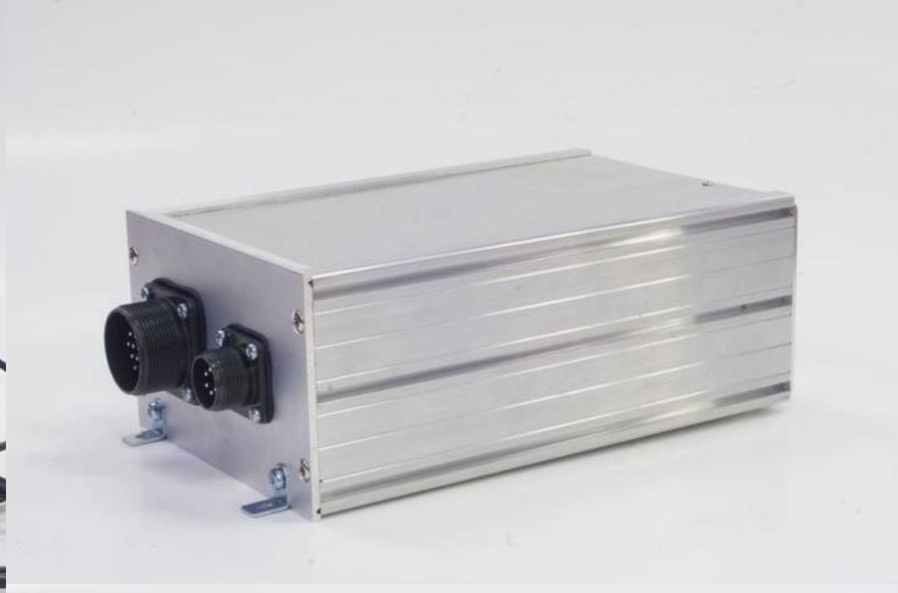
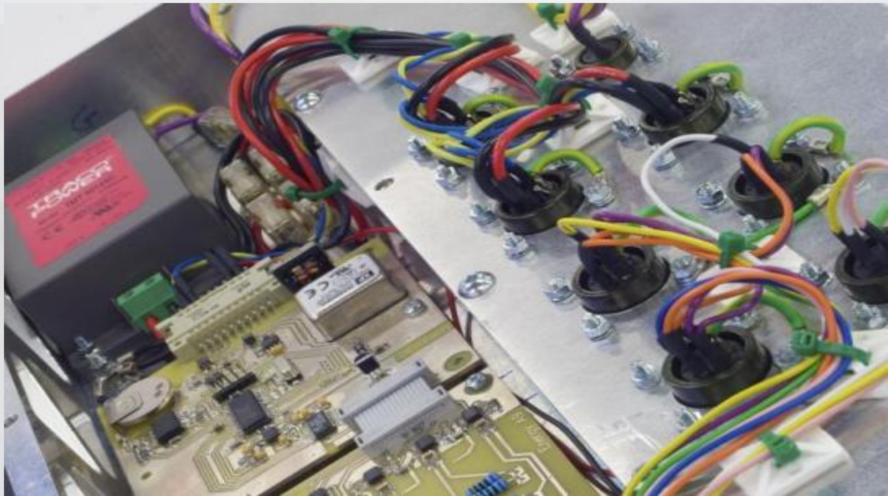
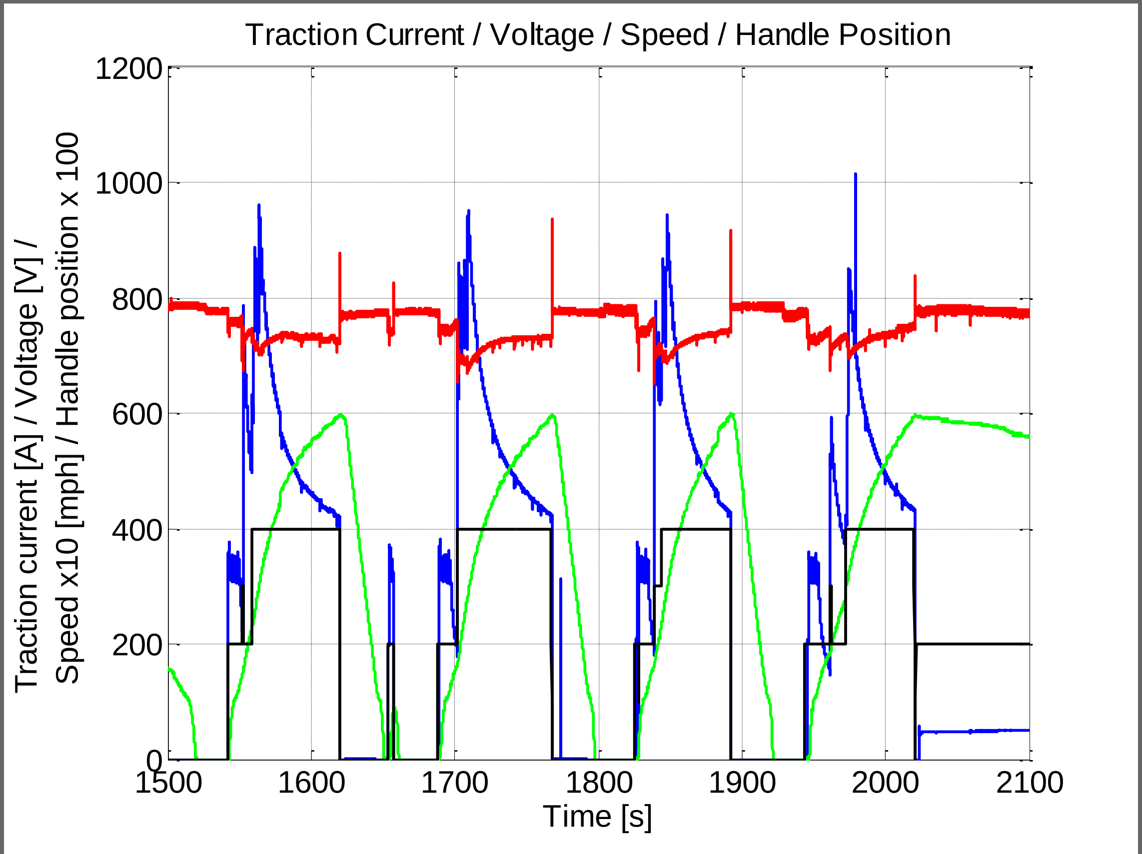


Detailed analysis



- Traction current
  - Half Train
- Line voltage
- Speed
- Handle position
- Brake tests

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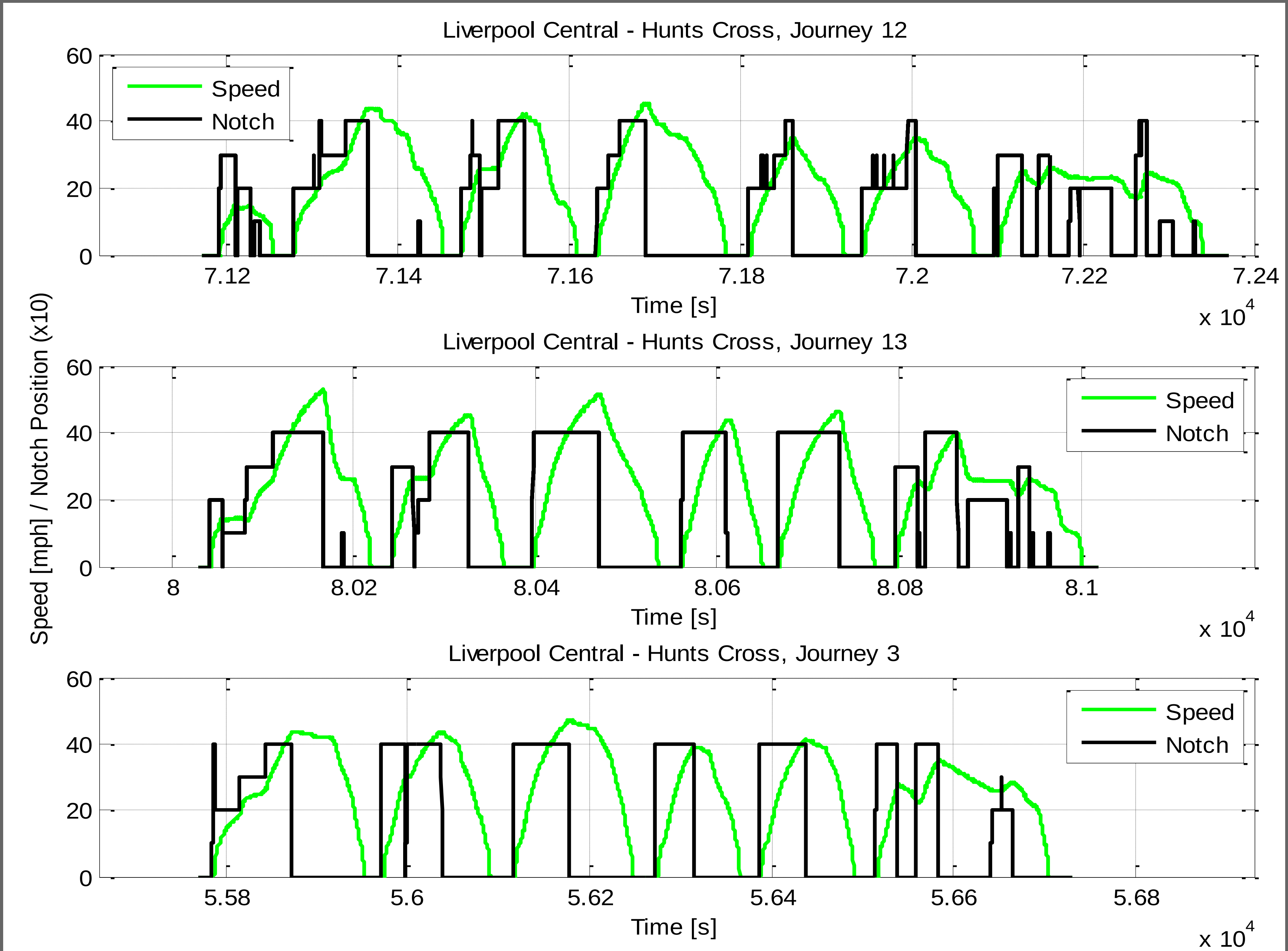
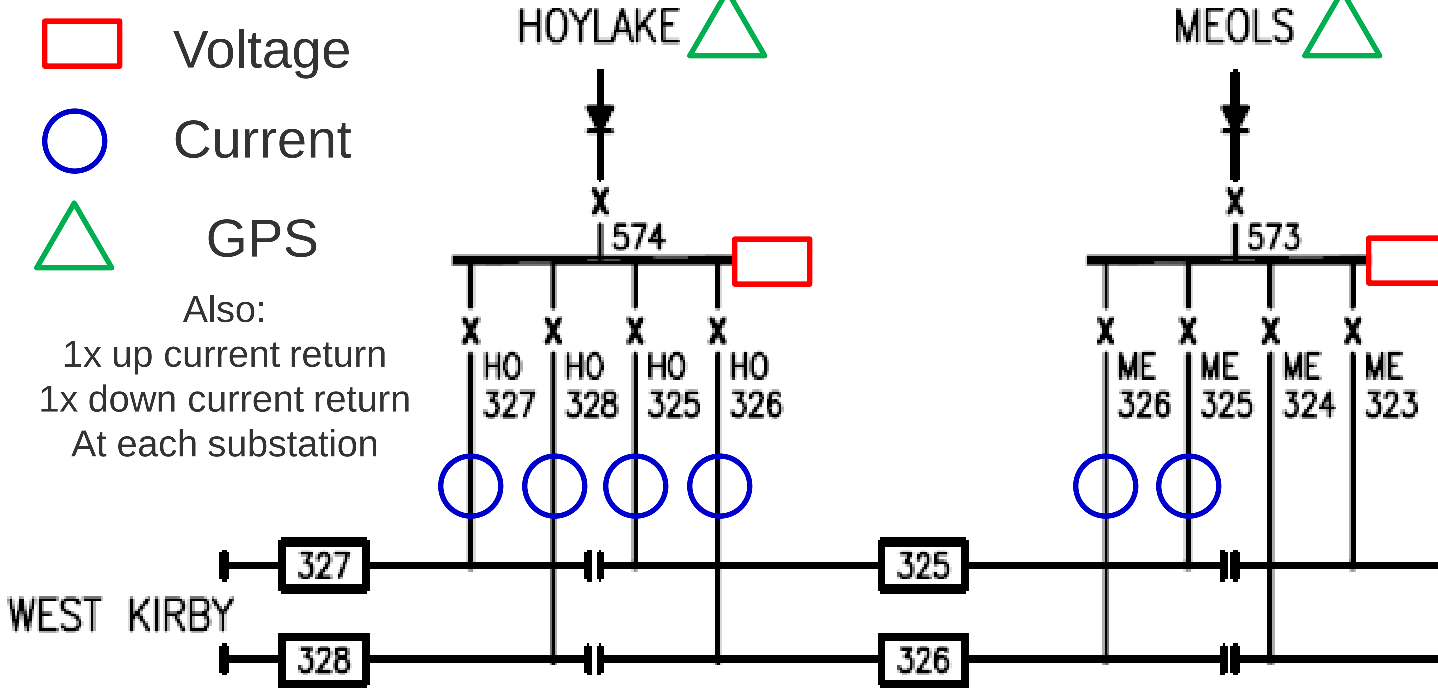
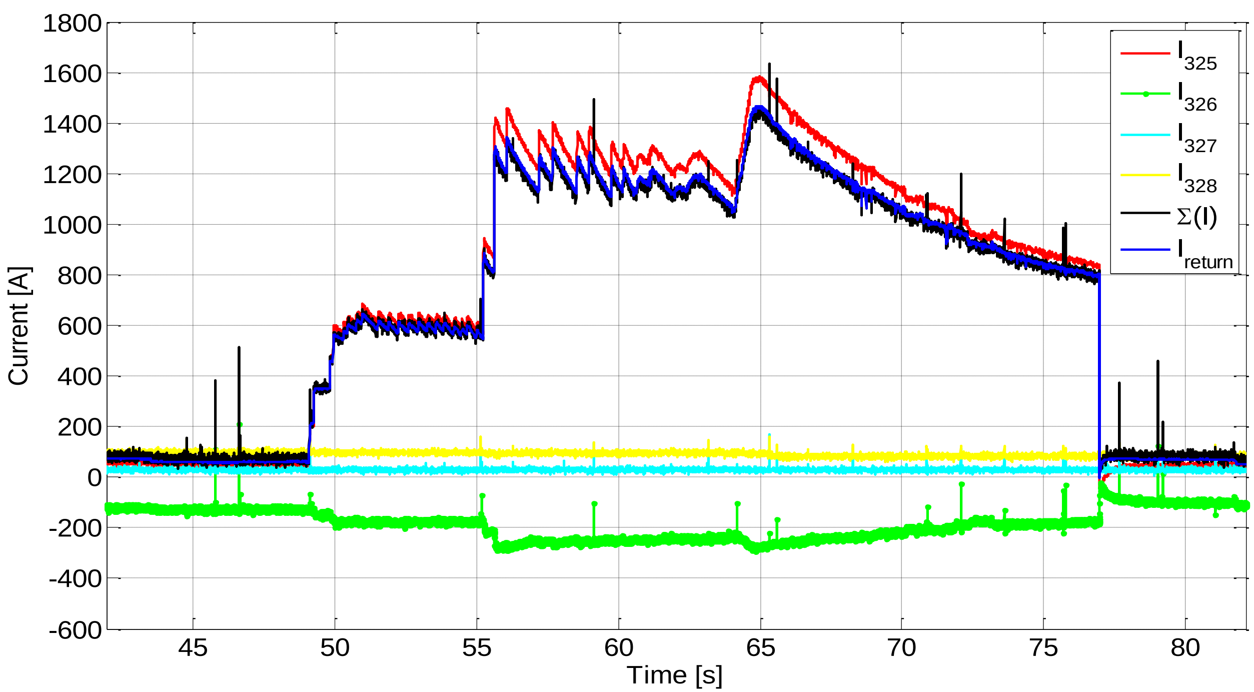
Department for Transport

Merseyrail

More than just a journey


Liverpool Central - Hunts Cross, Journey 12
Speed
Notch
60
40
20
0
7.12
7.14
7.16
7.18
7.2
7.22
7.24
Time [s]
x 10^4
Speed [mph] / Notch Position (x10)
Liverpool Central - Hunts Cross, Journey 13
Speed
Notch
8
8.02
8.04
8.06
8.08
8.1
Time [s]
x 10^4
Liverpool Central - Hunts Cross, Journey 3
Speed
Notch
5.58
5.6
5.62
5.64
5.66
5.68
Time [s]
x 10^4


Voltage
Current
GPS
Also:
1x up current return
1x down current return
At each substation
HOYLAKE
MEOLS
574
573
HO 327
HO 328
HO 325
HO 326
ME 326
ME 325
ME 324
ME 323
327
328
325
326
WEST KIRBY


Current [A]
Time [s]
I_{325}
I_{326}
I_{327}
I_{328}
$\Sigma(I)$
I_{return}


507007

University of Birmingham Railway Energy Simulators

- University of Birmingham STS
  - MATLAB based
  - Simple to configure
  - Quick simulation time for optimisation processes
  - Extremely modular and able to deal with a range of traction systems
  - Used by UK Department for Transport, Singapore Metro, RSSB

Atkins / University of Birmingham MTS
  - Full power system simulation
  - Multi-train operation
  - Configurable to specific applications/outputs
  - Used by Hong Kong Metro, London Underground, Singapore LTA, Docklands Light Railway

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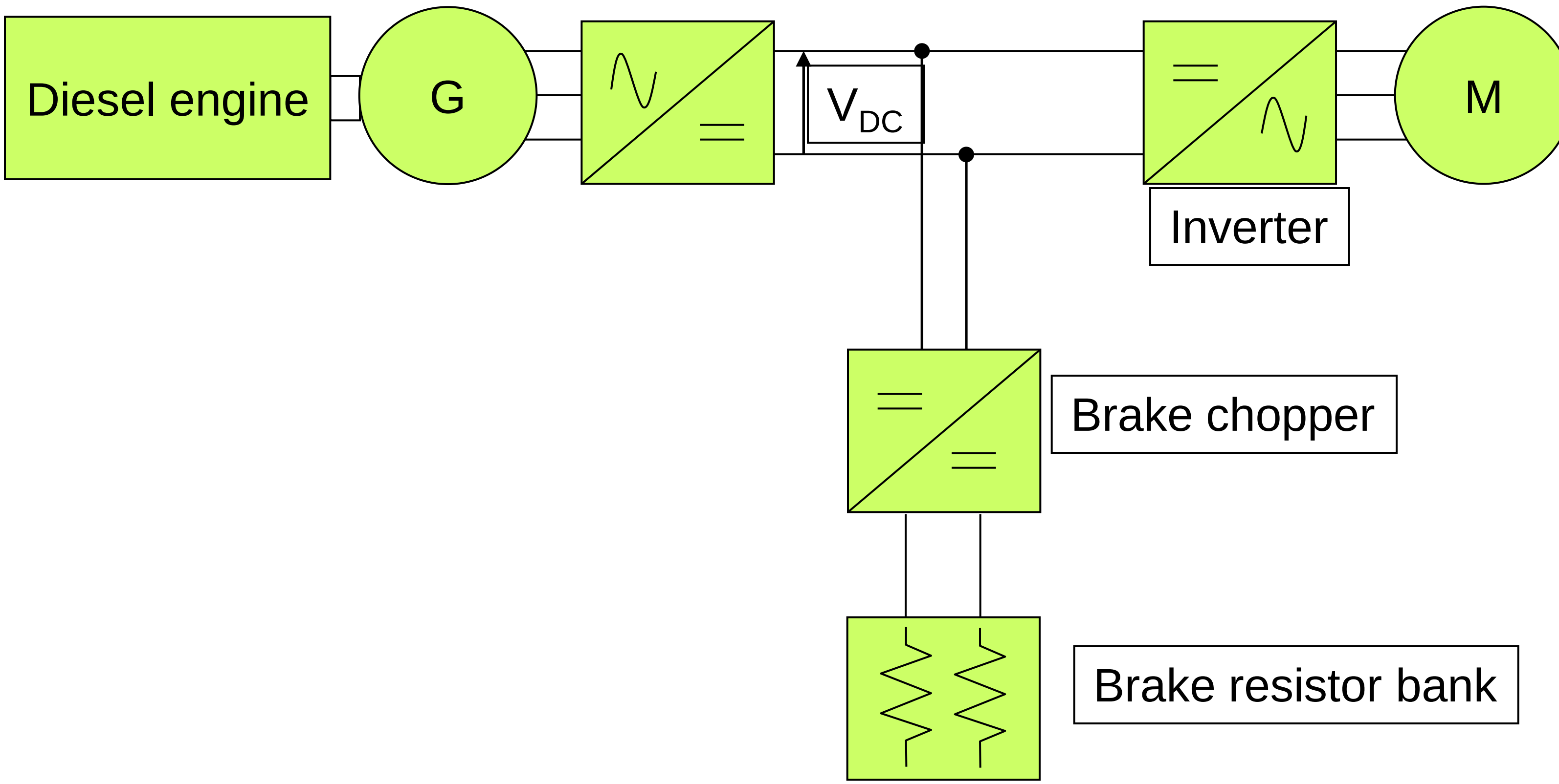
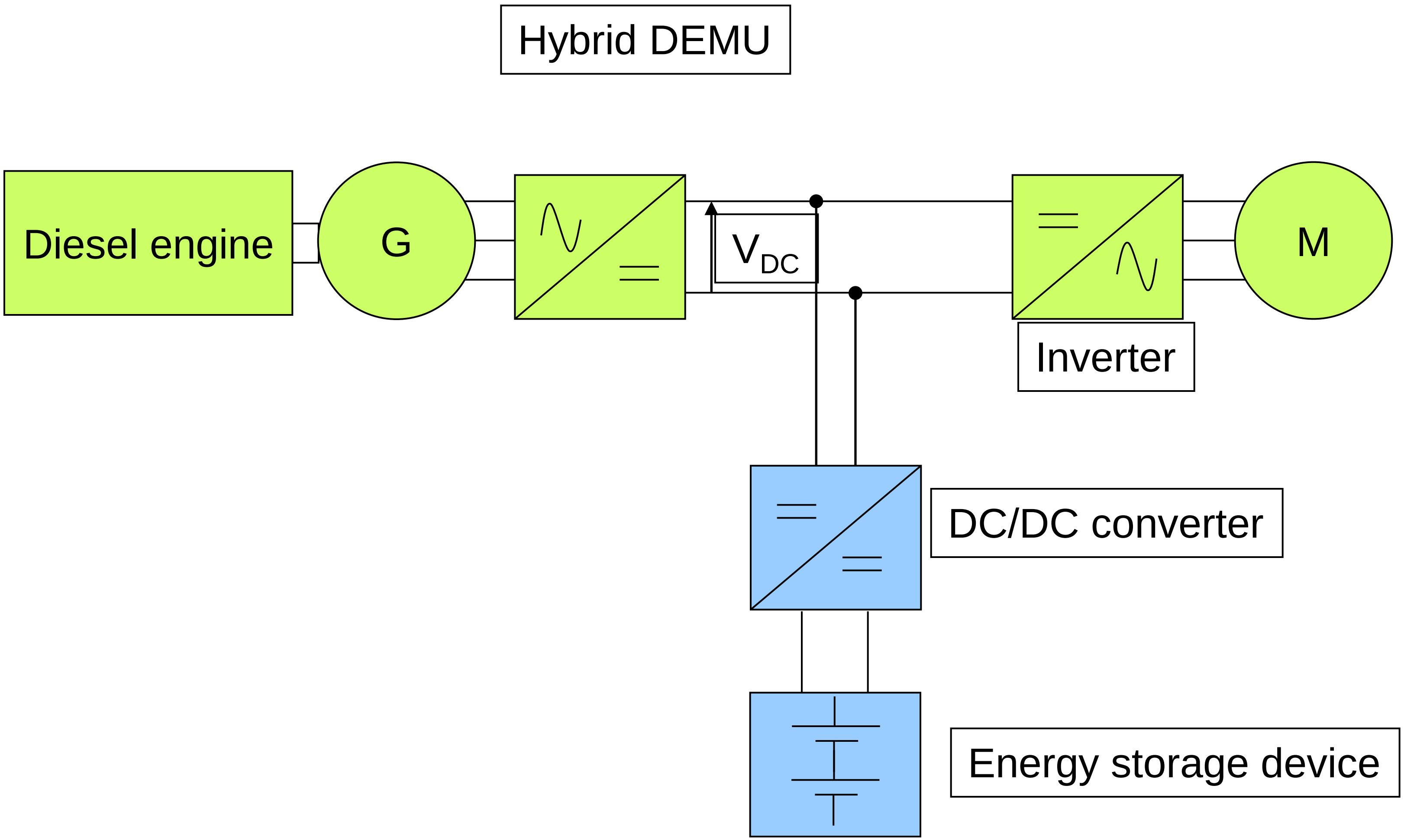
Alternative Power System and Hybrid Traction System Simulation and Test

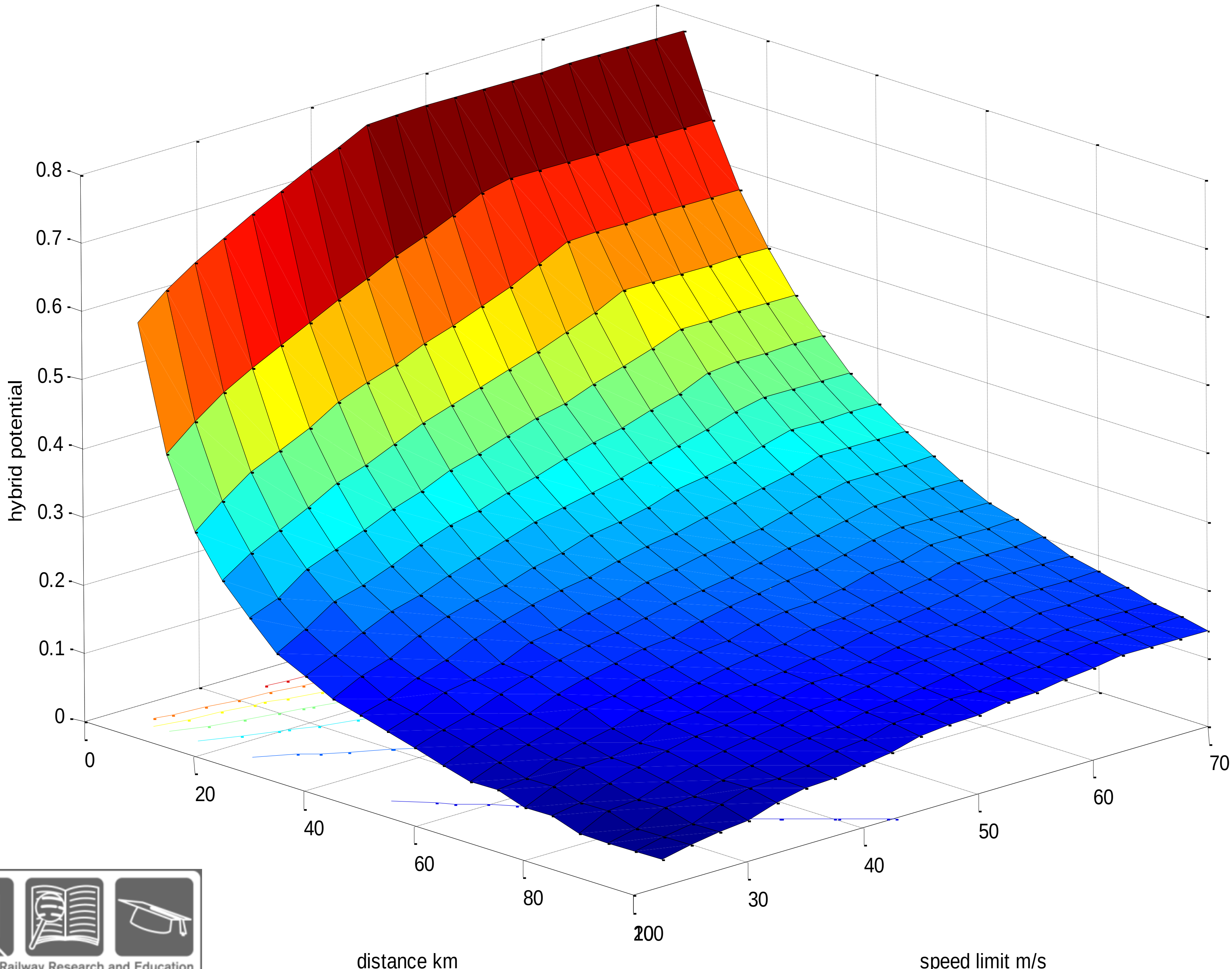
- 1. Capture and reuse of braking energy
- 2. Able to operate prime mover at optimum efficiency

- Hybridisation degree is dependent on the type of duty cycle
  - High speed – no downsizing but energy saving
  - Sub-urban – moderate downsizing possible
  - Shunting loco – significant downsizing possible

Conventional DEMU




Hybrid DEMU
Diesel engine
G
V_{DC}
M
Inverter
DC/DC converter
Energy storage device



Centre for Railway Research and Education

Alternative Power System and Hybrid Traction System Simulation and Test

Power Cycler

- Electrical device evaluation
  - Energy storage
  - Power converters
- Dynamic load cycling
- Specifications (max)
  - 170 kW sink
  - 125 kW source
  - <100ms out response timing

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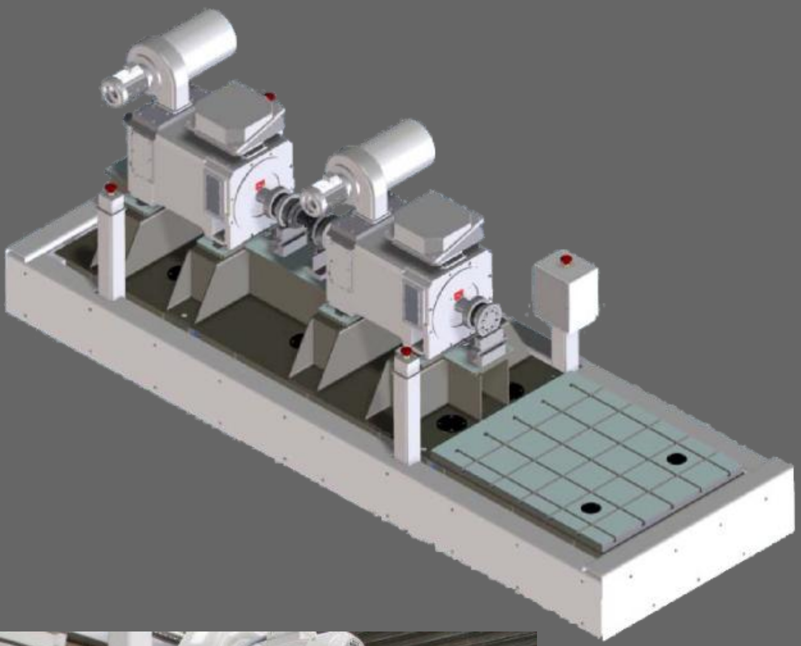
Alternative Power System and Hybrid Traction System Simulation and Test



Machine Rig and Dynamometer

- Drivetrain evaluation
  - Electric
  - Hybrid (Parallel & Serial)
- ESD Evaluation
  - Kinetic (Flywheels)
  - Electric (Batteries)
- Specifications (max)
  - 700 Nm Torque
  - 100 kW Power
  - 3000 rpm base speed

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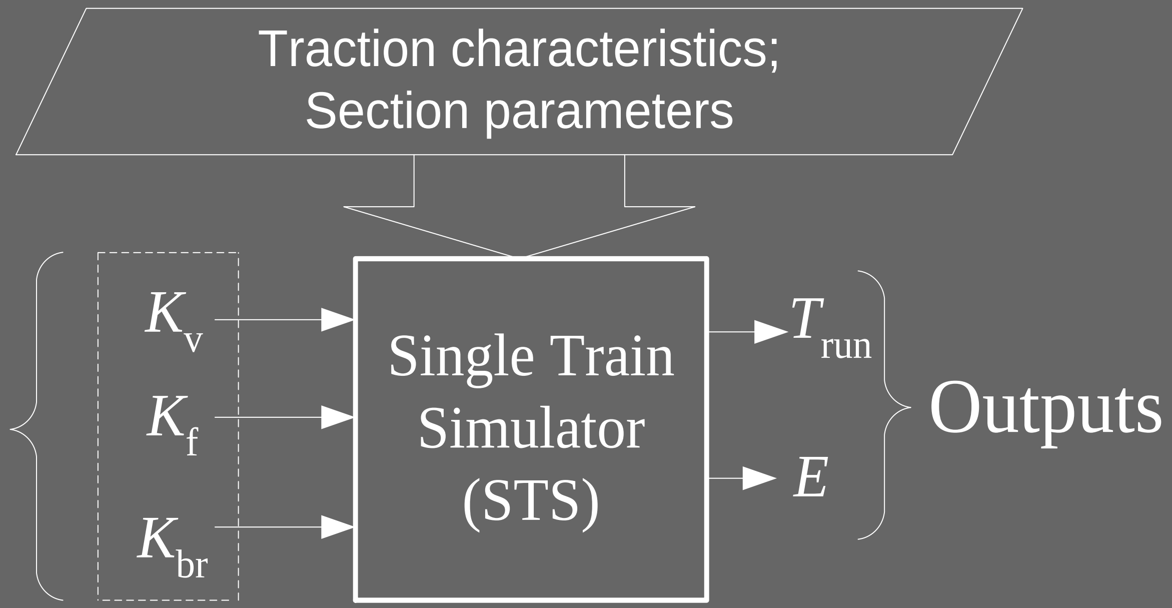
Optimisation using Single Train Simulation



- Input
  - Coasting rate, K_v
  - Motoring rate, K_f
  - Braking rate, K_{br}
- Output
  - Journey time, T_{run}
  - Energy consumption, E
  - Train trajectory

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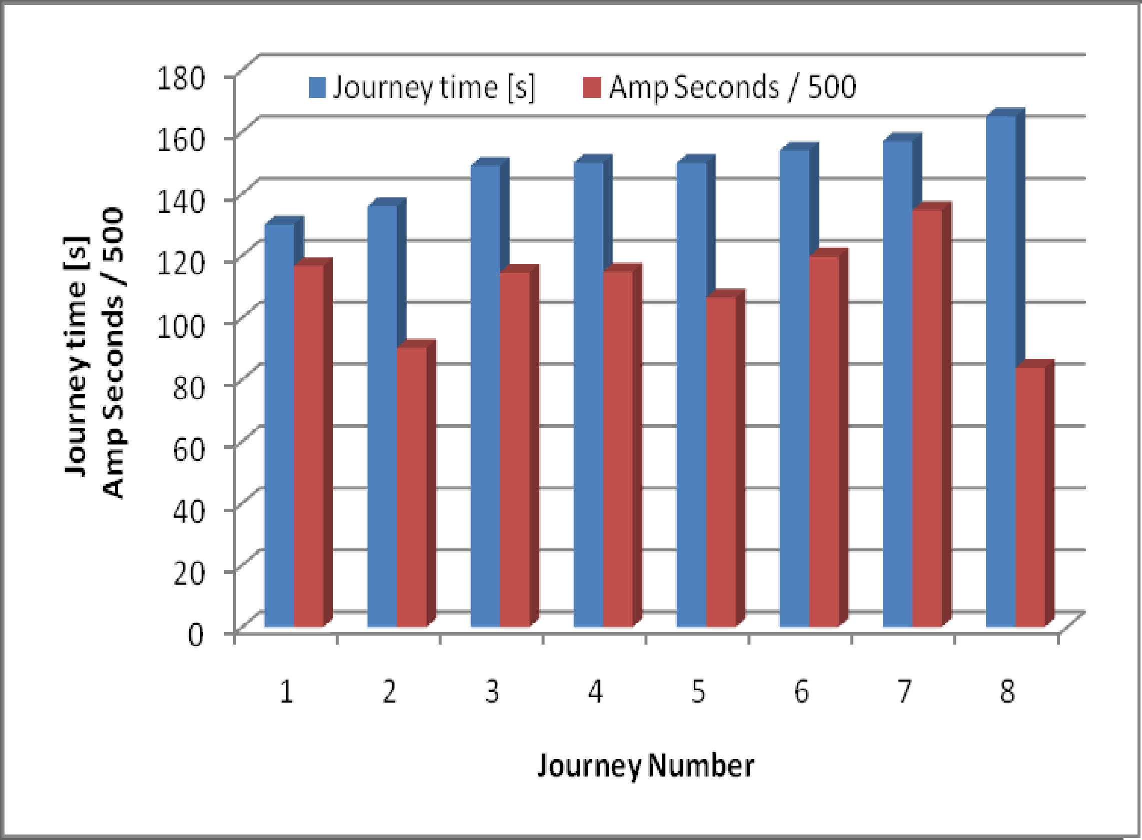
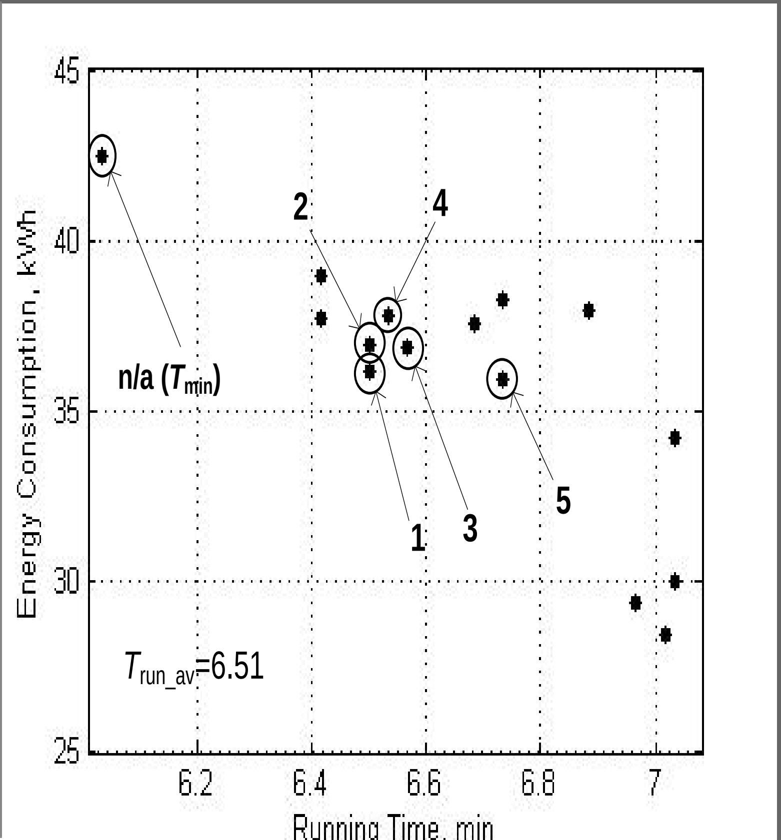
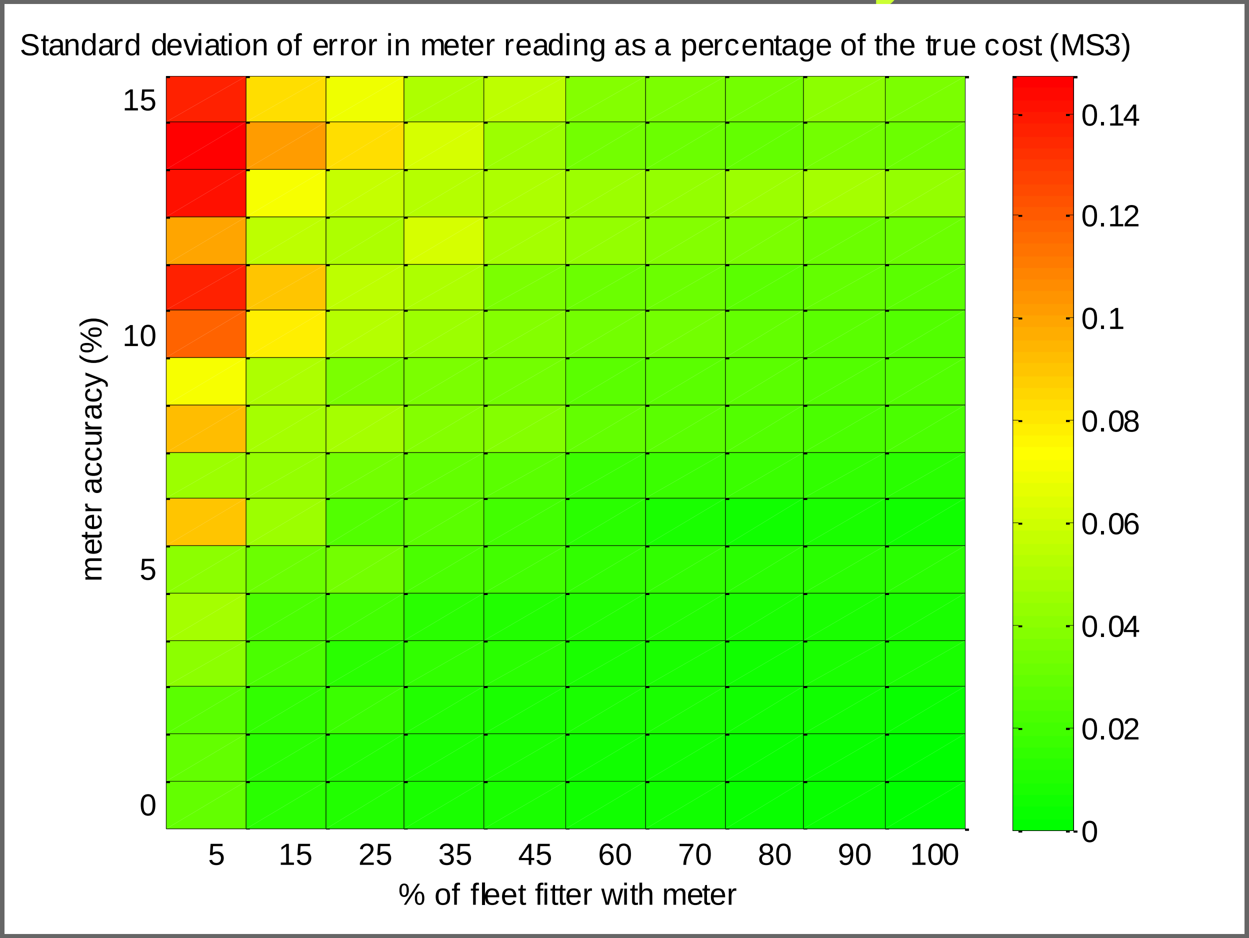
Optimised Train Control

- The optimal solution depends on the cost function (speed vs. time)





Effect of partial fleet fitment of energy meters on the DC railway fleet



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Collaborative Future directions

- Novel traction technologies (Hybrid, hydrogen, entirely battery power, carbon capture)
  - Optimal control (energy, state-of-health)
- High speed rail (power scales with speed cubed)
- Local energy storage and improved infrastructure systems
- Pavement (rail and road) based on energy
- Optimal driving strategies

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Centre for Railway Research and Education

Railway Energy and Train Simulation at Birmingham

Dr Stuart Hillmansen

Centre for Railway Research and Education

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Vehicle and Engine Technology Research Centre

Professor Hongming Xu
Vehicle and Engine Technology Research Centre