WMG centre High Value Manufacturing Catapult

Energy Innovation Centre

Providing Next Generation Solutions to UK Industry

Technology Strategy Board
Driving Innovation

THE UNIVERSITY OF WARWICK
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www.wmghvmcatapult.org.uk
Collaborating with the WMG centre

We work with you, understanding your project goals

Working collaboratively with business simplifies the transfer of cutting-edge university research to industry, strengthening the UK's technology base. By working with WMG’s world-class academics and engineers you will develop critical technologies as well as having access to state-of-the-art facilities. This can be done without the often prohibitive research costs incurred when working alone.

There are a number of ways WMG can work with companies to deliver high impact project outputs.

- Partners can identify projects specifically for their organisation
- WMG and partners can collaborate on bids into other funding sources e.g. Technology Strategy Board, Engineering and Physical Sciences Research Council, etc.
- Partners can leverage research through a project with the International Doctorate Centre by placement of existing staff or WMG can assist in the recruitment of high quality students
- SMEs can start on small, individual projects and then graduate to larger-scale, collaborative projects

We are one of seven centres in the HVM Catapult. Our partner centres are:

- Advanced Forming Research Centre, Strathclyde
- Advanced Manufacturing Research Centre, Sheffield
- The Centre for Process Innovation, Wilton
- Manufacturing Technology Centre, Coventry
- National Composites Centre, Bristol
- Nuclear Advanced Manufacturing Research Centre, Sheffield

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The Energy Innovation Centre

The Energy Innovation Centre at WMG centre HVM Catapult comprises a battery characterisation laboratory plus abuse testing chambers and an electric/hybrid drives test facility.

The Centre will soon include a £13m Battery Chemistry Scale-Up Pilot Line which will be the only one of its kind in the UK. Funding for the scale-up line and early stage projects has been provided by the UK Government's Department of Business Innovation and Skills and the Technology Strategy Board, via the HVM Catapult. See page 18 and 19 for more details.

The combined facilities will provide a one-stop-shop for the development of new battery chemistries from concept to fully proven traction batteries, produced in sufficient quantities for detailed industrial evaluation in target applications.

More Information:

For more information about our research, equipment, facilities and for a virtual tour of our workshops please visit our website: www.wmghvmcatapult.org.uk

Contact us:

If you are interested in working with WMG centre HVM Catapult please contact us. We would be happy to meet you and give you a tour of our facilities.

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centre HVM Catapult
comprises a battery characterisation laboratory plus abuse testing chambers and an electric/hybrid drives test facility.

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Partners

We work with companies on a variety of research projects in Energy Innovation and have links with other universities and established energy research organisations including:

Argonne National Laboratory
OBIC
Bladon Jets
drayson racing technologies
Imperial College London
Jaguar
Land Rover
Johnson Matthey
Purdue University
RML Group
Tata Motors European Technical Centre
University of Oxford

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WMG centre HVM Catapult Energy Research Activities

Our research activities cover the full spectrum of testing and evaluations needed for Battery Characterisation as summarised below:

**Vehicle**
- Hybrid Powertrain Testing
- Simulation and Modelling
- Test Technique Developments
- Hardware-in-the-Loop (HiL)
- Vehicle to Grid

**Energy**
- Battery Technology Evaluation
- Thermal Characterisation
- Ageing
- Abuse and Vibration Testing
- Battery Tear Down and Forensic Analysis

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A hybrid vehicle is a complex system made up of many individually optimised components. To optimise the overall system, it is necessary to fully understand the interaction of the components. This can include the effect of:

- Different hybrid vehicle architectures on efficiency and emissions
- Supervisory control strategies on efficiency and emissions
- Component temperatures on efficiency
- Vehicle usage conditions on battery lifetime
- Motor and inverter design on high voltage bus EMI

“What are the interactions between powertrain components at a system integration level?”

Facilities and Equipment:
Vehicle Energy Facility including emissions measurement equipment and battery cycler plus Thermal Chamber with Dynamometer. Modelling software packages including: WARPSTAR, Matlab Simulink and Dymola

Researcher:
Dr. Andrew McGordon
Battery System Evaluation

“How does battery cell performance match published data over a variety of usage scenarios?”

Electric and hybrid vehicles require several hundred cells to be connected together to create a complete battery pack. Safety, performance and reliability are the three key attributes required of the battery pack in an EV/HEV. Our energy storage research team is undertaking a programme of tests on commercially available battery technologies from cell to pack level. Characterisation testing provides critical data that can assist the selection of the most appropriate cell chemistry for a given application; ageing tests help determine how batteries degrade under a range of usage cases; thermal testing identifies the cooling capacity required for a battery pack and influences the design and development of thermal management systems for a given vehicle; abuse and vibration testing investigate safety and reliability issues. In addition, the team regularly tear down commercial battery packs to identify failure mechanisms which need to addressed in next generation battery pack designs.

Facilities and Equipment:
- Vehicle Energy Facility
- Battery Cell Cyclers
- Battery Module Cyclers
- High Power Pack Level Battery Cyclers
- Abuse Testing Chambers
- Vibration Test Chamber
- Temperature Control Unit
- Hydraulic Crash Rig
- Thermal Imaging Camera

Researcher:
Dr. Yue Guo

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Simulation and Modelling

“How can computer models be used to better understand the performance of batteries?”

Accurately predicting the performance of batteries is difficult since they are governed by statistical electrochemical interactions. It is possible to test batteries to determine their behaviour but this is expensive and time consuming and only allows predictions within the tested limits. Our validated suite of models allows prediction of battery performance across a wide range of conditions and applications.

The models range from high level 1st order models through equivalent electrical circuits and thermal models to electrochemical models. They are intended for use at vehicle level through to component level to gain an understanding of basic electrochemical phenomena affecting ageing.

Resources:
Data derived from cell cyclers and thermal chambers.

Researcher:
Dr. Andrew McGordon

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“What is the best approach to testing batteries for automotive powertrain applications?”

Battery technology is being rapidly developed with new advances announced every few months. Improvements are being made in the areas of battery electrolytes, electrodes, separators, tab welding and cell cooling. In step with these advances, there is a need for testing procedures to evolve and in particular for the tests to reflect real-world usage.

Our researchers are experienced in the test and characterisation of battery cells, modules and full battery packs and we are using our experience to develop next generation test strategies. While our primary focus is on vehicle propulsion applications, we are equipped to handle battery testing for other sectors including static power storage, consumer goods and aerospace.

Researcher:
Anup Barai

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Hardware-in-the-Loop Simulation (HILS) has been adopted by manufacturing organisations as an efficient means of protoyping designs and early-stage verification of complex systems. Within the context of Energy Storage Systems (ESS), HILS facilitates the transition from cell design to system design. HILS supports a fundamental understanding of the impact of realistic load cycles, cell manufacturing uncertainties, cell-to-cell interactions and thermal variations on the performance and degradation of the complete ESS. HILS provides a safe and cost effective means of verifying the performance of a proposed ESS in the following ways:

**Energy**
- There are significant challenges when scaling-up individual cell prototypes to a complete integrated system to deliver a target energy density, weight and cost. Through HILS it is possible to obtain performance data from a single prototype cell as if it were operating within a complete integrated system.

**Software and Controls**
- The design and verification of control algorithms that determine or control state of charge (SOC), state of health (SOH), cell balancing, diagnostics and prognostics present significant challenges which can be addressed by the appropriate use of HILS. Designs are often based on simplified models that inherently assume homogeneity and ignore further aspects of the system e.g. ancillary devices.

**Systems Integrators**
- Researchers working at technology readiness levels (TRL) 5-9 often evaluate new system designs within the context of their final application, but at the initial stages of development they are often hampered by a lack of cell availability. Furthermore, the commercial, engineering and safety implications associated with physical testing and design prototyping will be prohibitive. HILS provide an effective means of evaluating such systems.

"How can HiLS testing accelerate the understanding of battery technology?"

**Researcher:**
Dr. James Marco

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### Thermal Characterisation

“How much cooling is required for a battery? How does a battery behave at different temperatures?”

A critical factor in the long term performance, robustness and reliability of any battery system is the thermal management of the battery cells. Current Lithium-ion battery technologies have a relatively small operational temperature range that a battery pack’s cooling system must constrain the battery cells within.

Understanding the thermal behaviour of a cell, module and complete vehicle battery pack over a variety of operating conditions, including real world drive cycles, is key to the design and development of successful cooling systems.

Our capability ranges from the thermal characterisation of a single cell through to the evaluation and optimisation of different vehicle pack cooling technologies.

### Facilities and Equipment:
- **Battery Cell, Module and Pack level cyclers**
- **Climatic Chambers (EUCAR Hazard level 6)**
- **Thermal room**
- **Multiple temperature controlled cooling circuits**
- **Thermal Imaging cameras**
- **Thermocouple temperature logging systems**
- **Isothermal Calorimeter**
- **Clamp-on (Doppler) flow meters**

**Researcher:**
Mark Amor-Segan

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[Graph showing temperature over time for different cells and currents.]
Vehicle to Grid

“Is there a benefit from using electric vehicles as grid level energy storage devices?”

The Vehicle to Grid (V2G) concept uses parked electric vehicles to supply short-term power requirements to the electric grid. This is expected to become increasingly important as a growing number of uncontrolled renewable energy sources, such as wind turbines, are connected across the grid. It is also important for peak shaving applications and grid ancillary services.

Previously studies have focussed on the situation where there are many electric vehicles connected so that there is always sufficient electrical storage to stabilise the grid beneficially. We have developed a Vehicle to Home (V2H) model which considers the interaction of individual vehicles and homes; this is more appropriate for the current low population of electric vehicles connected across the grid.

Researcher:
Dr Andrew McGordon

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Battery Ageing

“How will the performance of a given battery technology degrade over a range of different usage cases?”

The useful lifespan of a battery pack is dependent on a wide range of environmental and usage factors that exist during its working life. Many of these factors are linked with complex dependencies and interactions.

Understanding how and why a lithium-ion cell ages is critical to achieving the safe and reliable operation of a battery pack over its intended lifespan.

Battery ageing research is helping to build our knowledge of different ageing factors, develop better models of cell ageing and create battery management strategies for long term reliable battery performance.

Facilities and Equipment:
- Battery Cell level cyclers
- Climatic Chambers (EUCAR Hazard level 6)
- Temperature controlled storage chambers
- Electrical Impedance Spectroscopy
- AC ripple test system
- Mechanical and Vibration test equipment

Researcher:
Dr Yue Guo
Abuse and Vibration Testing

“What will happen to a battery in an extreme event?”
“How does a battery and high voltage powertrain system behave under different vibration duty cycles?”

Safety is a key concern in battery energy storage systems. The problems in early 2013 with lithium-ion batteries on board Boeing 787 airliners brought this to the public’s attention. During use batteries can face a variety of situations that take a battery outside its normal operating boundaries. These include short circuits, over-charging, unduly low temperatures, excessively high temperatures, physical damage to the pouch cells including the entry of foreign objects, and long term vibration.

Before selecting a battery for use in an application it is essential to test it over a full range of operating conditions. Our facilities include a comprehensive abuse testing facility which comprise two independent battery test chambers and a large shaker table for vibration testing of full size vehicle battery packs.

Facilities and Equipment:
- Abuse testing chambers (2)
- Extreme temperature control unit
- Hydraulic crush rig
- Overcharge rig
- Shaker table in containment building

Researcher:
Anup Barai

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Battery Tear Down and Forensic Analysis

“How can battery failure mechanisms be determined?”

While enormous efforts are being made to develop high reliability battery packs there are still many failure mechanisms that cause premature ageing or unpredicted total failure. There is great interest going forward in identifying failure mechanisms and determining the root causes and ways to prevent these. Battery tear down and forensic analysis are the techniques we use to identify failure mechanisms.

High voltage battery packs can be disassembled to module or cell level. Detailed examinations can then be made of the constituent components including pouch cells, battery management systems, bus-bars and cooling plates etc.

Facilities and Equipment:
Abuse chambers (2)
CT Scanner
Battery Cell Cycler
Battery Module Cycler
Electrical Impedance Spectroscopy (EIS)
High Voltage Personal Protection Equipment
Temperature controlled storage chamber

Researcher:
Anup Barai

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Previously, electrochemist researchers have only been able to create very small “coin” cells using laboratory glove boxes (sealed units that allow researchers to manipulate materials in a contained environment). When promising new cell chemistries were identified, researchers had to use the facilities of battery manufacturers for the production of full-size prototype pouch cells. Often the manufacturers required large quantities of the prototype cells to be ordered, which the research projects could not afford.

The specifications of this new, climate-controlled facility will allow the manufacture of large pouch cells (typically 45 cm in size) that are relevant to the needs for high density energy storage in electric and hybrid vehicle applications. Pouch cells consist of electrodes, separators and electrolyte contained in flexible, heat-sealable foil and they can be made to specific shapes and sizes. The facility will cater for other application requirements including static power storage, aerospace, portable power and consumer products.

Researchers from WMG and partner organisations will work collaboratively to produce prototype pouch cells for detailed evaluation and characterisation. The new facility will also create high reliability battery electrodes.

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According to Dr Rohit Bhagat, an electrochemist at WMG, “having the capability to make prototypes will allow WMG along with its industrial and academic collaborators to evaluate novel battery chemistries created in our research projects in a more affordable and timely manner. After fabrication, the prototype cells will be evaluated for performance, battery life and safety in WMG’s comprehensive battery testing facilities.”
WMG’s academic and research staff come from a wide range of disciplines and have industrial business experience which provides considerable added value to research programmes.

Professor Paul Jennings
Head of Energy and Electrical Systems
Manages a number of staff working on projects in the catapult including the scale up of novel battery chemistries from laboratory to production line. He has been involved in research with the automotive industry for over 20 years. He leads work in Experiential Engineering and also on hybrid and electric vehicle technologies looking at the factors affecting their successful introduction.

Mark Amor-Segan
Principal Engineer
Over 25 years experience in the development and validation of fault-tolerant embedded processing platforms. Areas of expertise include complex electronic and software based systems, telecommunications and diagnostics.

Anup Barai
Research Assistant
Experience in energy storage systems testing and validation, and development of next generation testing strategies for future energy storage systems.

Dr Stewart Birrell
Senior Research Fellow
Expertise in automotive ergonomics and human factors, from the design and evaluation of in-vehicle HMI to understanding how users interact with vehicle systems.

Nigel Curtis
Instrumentation Technician
Over 30 years experience as electronics designer in automotive, EV and energy storage systems.

Gunwant Dhadyalla
Principal Engineer
Over 20 years experience in the automotive electronics industry. Managing technical research in the areas of embedded systems and high voltage architectures modelling.

Dr Yue Guo
Research Fellow
Experience and expertise in modelling of automotive electronic systems, automated model based testing, battery modelling and characterisation using new and existing techniques.

Dr John Low
Assistant Professor, Energy for Low Carbon Vehicles
Expertise in the design, build, test, characterisation and post-mortem analysis of electrochemical energy storage devices.

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Dr James Marco
Associate Professor, Vehicle Electrification and Energy Storage
A Chartered Engineer with over 15 years industry/academic experience of low carbon technologies for the transport and energy storage sectors. Specific areas of research include: systems engineering, real-time control, systems modelling, design optimisation and the design of energy management control systems.

Dr Andrew McGordon
Senior Research Fellow
A physicist with industrial experience of modelling in the steel industry, applying modelling to hybrid vehicles and components, specifically battery technologies and energy management. Supervising the installation of test facilities for hybrid vehicles and electrical energy storage.

Andrew Moore
Lead Engineer
Experienced in industrial electronics design/research/development, he has provided electronic designs and expertise in industrial areas, ranging from Automotive, Aerospace and Rail ATE systems; to product designs for RADAR, LASERS, MIG Welders, Robotics and Microbiology.

Sina Shojaei
Research Assistant
Experienced in modelling, and evaluation of electro-mechanical hybrid powertrains, control strategy development and powertrain optimisation.

Dr Ravichandra Tangirala
Research Fellow
Experienced in electrical and electrochemical study, characterisation, testing and development of batteries.

Adrian Taylor
VEF Precision Engineering Technician
Over 40 years experience in both mechanical and electrical engineering, covering precision tool room, aerospace and polymer manufacture fields.

Dr James Taylor
Research Fellow
Data mining and predictive analytics expert: experienced in working with large-volume, information-rich data sets from automotive and other industries for the development of diagnostic and prognostic systems.

Terrence Timms
VEF and Battery Characterisation Facilities Officer
Technical expertise in mechanical and electrical engineering also proven automotive and engine CAD design.

Dr Kotub Uddin
Senior Research Fellow
Theoretical physicist by training with industrial experience specialising in applied mathematical modelling and scientific computing.

Dr Widanalage Dhammika Widanage
Senior Research Fellow
Research interests are in the areas of lithium-ion battery modelling, electric vehicles and mechatronics. Specifically interested in developing modelling techniques for battery dynamics and mechatronic systems.

Dr Chek Pin Yang
Research Fellow
System modelling and performance analysis of high voltage architectures including powertrain and motor control using Simulink, Dymola, COMSOL and PSPICE; wireless charging systems for HEVs.

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The scheme allows employees to mix and match a variety of Master’s level modules according to their needs within their employer’s businesses, as well as their individual and professional development needs. A number of qualifications, ranging from a Postgraduate Award to a Master’s degree can be acquired.

WMG offers a number of modules which are directly relevant to the research being conducted in the Energy Innovation Centre.

- **Hybrid Vehicles: Hybrid System Technologies**
  The course aims to develop a detailed understanding of the principles of Hybrid Vehicle Systems Technologies.

- **Hybrid Vehicles: Practical Component Testing**
  The course aims to develop a detailed theoretical and practical understanding of the real world behaviour of Electric Vehicle (EV) components.

- **System Modelling and Simulation**
  The course aims to develop a detailed theoretical and practical understanding of the principles of 1-D systems modelling and simulation.

- **Robust Automotive Electronics**
  The course aims to develop a detailed theoretical and practical understanding of the principles and application of electronic components and circuits in automotive applications.

- **Advanced Test Techniques for Electrical Systems and Software**
  The course aims to develop a detailed theoretical and practical understanding of the principles and application of key approaches to the testing of automotive electrical and electronic systems.

- **Robust Automotive Software**
  The course aims to develop a detailed theoretical and practical understanding of the principles of and processes for software design, development and implementation in automotive applications.