UNIVERSITY OF BIRMINGHAM | BIRMINGHAM ENERGY INSTITUTE

# BIRMINGHAM CENTRE FOR ENERGY STORAGE

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# BIRMINGHAM CENTRE FOR ENERGY STORAGE

Established in 2013, the Birmingham Centre for Energy Storage brings together research expertise from across the University to drive innovation from the laboratory to market. The Centre received two strands of funding: £12m for cryogenic energy storage and £1m for thermal energy storage, as part of a £15m initiative led by Imperial College, under the Eight Great Technologies Capital Programme.

The Centre consists of two components: the Birmingham Centre for Thermal Energy Storage and the Birmingham Centre for Cryogenic Energy Storage; both of which draw on the capability in materials, thermodynamic processes, application development, smart grid and policy economics.

We recognise how energy storage, particularly thermal and cryogenic based technologies, coupled with appropriate policy, could play an important role in delivering an integrated energy system. The service that could be provided range from enhancing power quality and reliability, transmission network stability and frequency regulation, to dealing with intermittency of renewable and improving infrastructure utilisation, along with effective and efficient utilisation of industrial waste energy.

Energy systems will need to become more flexible and resilient to respond to greater variability in supply and demand. Our researchers are providing flexibility and robustness by developing new low carbon technologies that allow us to shift energy from one place or time to another – to turn highly fluctuating energy sources to stable ones.

**‘NEW STORAGE TECHNOLOGIES COULD TRANSFORM HOW ENERGY IS SUPPLIED AND USED, HELPING TO MAKE FUTURE ENERGY SYSTEMS MORE EFFICIENT AND RELIABLE, LOWER CARBON AND MORE AFFORDABLE. HOWEVER, INNOVATION IN TECHNOLOGY AND POLICY IS NEEDED TO RELEASE ITS VALUE. THE CENTRE INTEGRATES THE FULL RESEARCH AGENDA TO ACCELERATE THE DEVELOPMENT AND DEPLOYMENT OF THE ENERGY STORAGE TECHNOLOGIES.’**

PROFESSOR YULONG DING, DIRECTOR OF THE BIRMINGHAM CENTRE FOR ENERGY STORAGE



# ABOUT THE BIRMINGHAM ENERGY INSTITUTE

The Birmingham Energy Institute is a focal point for the University and its national and international partners to create change in the way we deliver, consume and think about energy. The Institute harnesses expertise from the fundamental sciences and engineering through to business and economics to deliver co-ordinated research, education and the development of global partnerships.

More than 140 academics across the University are engaged in energy and energy related research and development, with over £75 million external research investment. The Birmingham Energy Institute’s strength comes, not only from the concentration of expertise in specialised centres, but also the breadth of knowledge and facilities that it can draw upon through interdepartmental and interdisciplinary working across the University.

## THERMAL ENERGY RESEARCH ACCELERATOR (T-ERA)

**AS PART OF THE MIDLANDS INNOVATION GROUP OF HIGHER EDUCATION INSTITUTIONS, THE ENERGY RESEARCH ACCELERATOR (ERA) AIMS TO FOSTER RESEARCH AND DEVELOP NEW TECHNOLOGIES TO SHAPE THE UK’S ENERGY LANDSCAPE OVER THE NEXT 40 YEARS.**

The Thermal Energy Research Accelerator (T-ERA) is one of the three work streams that form the Energy Research Accelerator (ERA), a capital investment of £60m from Government capital funding, supported by an additional £120m of co-investment secured by industry and academic partners.

Led by the University of Birmingham, T-ERA is driving the development and integration of a range of thermal and cryogenic energy technologies and collaborating with industry to convert innovation and emerging technologies into practical solutions with powerful global benefit. It will deliver jobs and apprenticeships, wealth creation and the next generation of scientists and engineers in the energy sector and emerging industries.

## INTERNATIONAL THERMAL ENERGY MANUFACTURING RESEARCH ACCELERATOR (ITEMA)

In partnership with Loughborough University, we are working with the Manufacturing Technology Centre (MTC) to develop ITEMA; co-funded by Government, industry and universities. Leveraging Industry 4.0 and other novel manufacturing approaches, ITEMA will scale up and modularise the production of technologies that will improve the efficiency of thermal energy systems.

### INDUSTRY 4.0

Heralded as the ‘Fourth Industrial Revolution’ Industry 4.0 promises to transform the way we manufacture products; improving productivity and competitive advantage by leveraging digital technologies to create cyber-physical systems and informatics for ‘Smart Factories’ of the future.

## FACTORY IN A BOX

The Factory in a Box (FIAB) concept is a modular approach to factory design, where the manufacturing process is segmented into a number of pre-fabricated elements, which can be transported to the desired location. Industry 4.0 techniques help in the design of FIAB applications. The T-ERA will leverage Industry 4.0 to produce the next generation of innovative, thermal energy technologies at scale.

**www.era.ac.uk**

# THERMAL ENERGY STORAGE

**THE BIRMINGHAM CENTRE FOR THERMAL ENERGY STORAGE COMPRISES OF NEW LABORATORIES, STATE-OF-THE-ART EQUIPMENT, AND A PILOT MANUFACTURING LINE FOR THERMAL ENERGY STORAGE MATERIALS, COMPONENTS AND DEVICES. OUR RESEARCH HELPS TO PROVIDE A BALANCE BETWEEN THE ENERGY DEMAND AND SUPPLY, AND UTILISE WASTE HEAT GENERATED IN VARIOUS APPLICATIONS INCLUDING ENERGY PRODUCTION, CONVERSION PROCESSES AND IN THE PROCESS INDUSTRY.**

GLOBALLY, HEATING AND COOLING IN BUILDINGS AND INFRASTRUCTURE ACCOUNTS FOR MORE THAN HALF OF TOTAL ENERGY CONSUMPTION AND **IS SET TO GROW DRAMATICALLY OVER THE NEXT 15 YEARS.**

## WHAT IS THERMAL ENERGY STORAGE?

Thermal Energy Storage (TES) refers to the family of technologies that store excessive energy in the form of heat and uses the stored heat either directly or indirectly through energy conversion processes when needed. TES is based on heating a storage medium so the thermal energy in the system can be used at a later time.

TES increases system efficiency and reduces CO² emissions by making use of waste heat. The integration of TES in fossil fuel and nuclear power plants can also increase their peak shaving capability. Additionally, TES can play a pivotal role in large scale solar thermal power generation.

GLOBALLY, ENERGY CONSUMPTION FOR COOLING IS PROJECTED TO EXCEED HEATING WITHIN 40 YEARS, **YET 84% OF HEATING AND COOLING IS STILL GENERATED BY THE BURNING OF FOSSIL FUELS.**

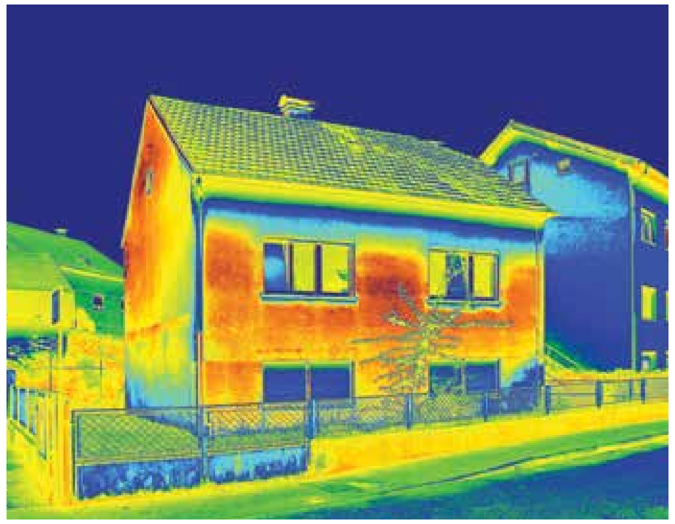
## THERMAL ENERGY STORAGE RESEARCH

BCTES focuses on the following research activities:

- Phase change based microstructured composite materials for applications between approximately the room temperature and 1500°C;
- Novel nano-pore based insulation materials for elevated temperature applications;
- Components and devices using the composite materials;
- Applications through integration and optimisation with energy networks and industrial processes;
- Advanced manufacture technologies for materials, components and devices, including scale-up;
- Economic analyses and policy.

**The first five research areas are interconnected, covering tens of orders of magnitude.**

**www.birmingham.ac.uk/BCTES**





# CRYOGENIC ENERGY STORAGE

**THE BIRMINGHAM CENTRE FOR CRYOGENIC ENERGY STORAGE IS THE FIRST IN THE UK TO HAVE A RESEARCH FACILITY FOR ENERGY STORAGE USING CRYOGENIC LIQUIDS, COMPRISING NEW LABORATORIES, STATE OF THE ART EQUIPMENT, AND A MAJOR DEMONSTRATION FACILITY.**

## WHAT IS CRYOGENIC ENERGY STORAGE?

Thermal energy storage is often commonly thought of in terms of heating and high temperatures; however, energy can be stored more effectively, and with a higher energy density, by cooling materials. Cryogenic energy storage (CES) technology uses off-peak electricity to liquefy a gases such as air and carbon dioxide, which is then stored in a tank ready to be used later. When heat is applied, the liquefied gas expands many times over and is used to drive energy generation equipment.

The CES technology helps to address the 'wrong-time, wrong place' energy generation and supply problem, such as excess wind power generated at night when demand is low. The system can also be applied to low-grade waste heat recovery from power stations, industrial processes, or renewable sources, such as solar and geothermal. CES can also be built alongside liquefied natural gas terminals to recover cold energy, and does not require scarce resource, and is not limited by geography or geology.

## CRYOGENIC ENERGY STORAGE RESEARCH

**At the Birmingham Centre for Cryogenic Energy Storage our researchers are looking at ways to use cryogenic liquids for more efficient and effective alternatives to air conditioning technology to meet the growing demand for cooling systems.**

**The Centre focuses on the following research activities:**

- **Novel cold storage materials** with an aim to further increase energy storage density and life span, improve charge-discharge kinetic performance and reduce costs;
- **New thermodynamic cycles and processes** with an aim of developing more efficient cycles and processes;
- **Systems integration, control and optimization** with an aim to develop tools for designing new technologies through integration of CES with energy networks;
- **Pilot-scale liquid air energy storage facility testing** with an aim to carry out detailed study for both component and system level performance improvement;
- **Cold economy** with an aim to investigate the societal and economic impacts of the cold chain for the UK and abroad.

The broad range of expertise across the Centre and the University ensures that our approaches are truly disciplinary and innovative.

**www.birmingham.ac.uk/BCCES**

# COLD AND POWER

**AROUND 14% OF BRITAIN'S ELECTRICITY AND £5.2 BILLION EACH YEAR IS SPENT ON ENERGY FOR COLD ACROSS THE GRID AND TRANSPORT. THESE FIGURES WILL BE SIGNIFICANTLY HIGHER IN WARMER COUNTRIES, WHILE IN RAPIDLY DEVELOPING NATIONS SUCH AS CHINA AND INDIA INVESTMENT IN COOLING IS STARTING TO BOOM.**

The world needs cooling in many forms – for thermal comfort, industrial processes, medical uses and a 'cold' chain of refrigerated food storage and transport. India, for example, needs to make substantial investment into its cold chain over the next five years; and China is on track to increase its refrigerated storage capacity 20-fold by 2017. The US, Europe and UK are all still seeing significant growth in cold transport. In fact, it is estimated that projected growth in global cooling demand to 2030 could equate to as much as three times the current power output of Brazil.

Almost every country has energy policies covering power, transport and heat, but cold currently receives far less attention. However, if soaring cold demand is satisfied using current technologies and fuels, the impacts on climate, air quality and cost will be substantial. So, it is vital that the primary energy required should not grow as fast as the demand for cold services.

**'WE ARE LOOKING AT THE CHALLENGES FOR MEETING THE FUTURE DEMANDS TO PROVIDE COLD AND POWER IN BOTH AN ENVIRONMENTALLY AND ECONOMICALLY SUSTAINABLE WAY, FROM THE PURE SCIENCE TO THE LOGISTICS AROUND SCALE AND POLICY IMPLICATIONS. DRAWING ON OUR OWN EXPERTISE AND BY WORKING IN PARTNERSHIP WITH OTHER HIGHER EDUCATION INSTITUTIONS AND WITH INDUSTRY, WE ARE BECOMING RECOGNISED AS A CENTRE FOR EXCELLENCE AND A CENTRE FOR ENERGY SOLUTIONS.'**

PROFESSOR MARTIN FREER, DIRECTOR OF BIRMINGHAM ENERGY INSTITUTE

## COLD AND POWER RESEARCH

**BCES focuses on the following research activities:**

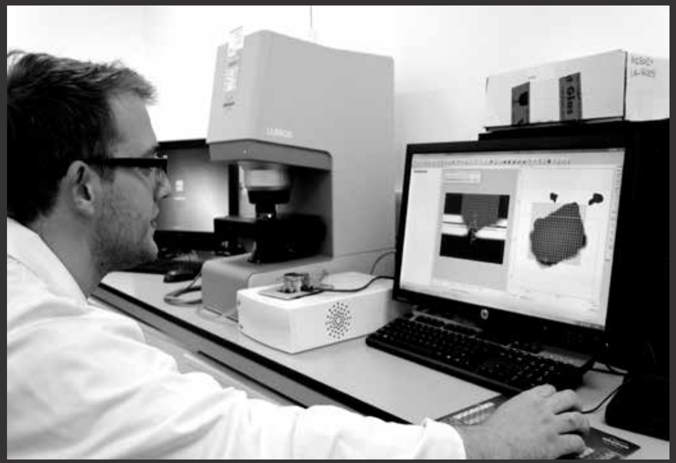
- **Storing cold and power** is an important part of how we can make best use of the resource, and also allows the storage of 'wrong-time' renewable energy to use in grid and transport cooling applications.This includes novel materials and methods for storing cold and power, efficient insulation materials and methods, and advanced materials manufacturing technologies.
- **Hybrid engines:** we are working to deliver a prototype transport auxiliary power and cooling system, funded by Innovate UK and in partnership with the Dearman Engine Company, and Hubbard Refrigeration Products. AuxPac will reduce $CO^2$ emissions from refrigerated trucks and air-conditioned buses. The Dearman Engine Company is developing a piston engine that runs on liquid air delivering both power and cold, and which can serve as an efficient and zero-emission transport refrigeration unit (TRU).
- **Economy and policy study** forms an integral part of the research at BCES on cold and power. This will provide guideline for the scientific and technological research, and also provide evidence for government, industry and funding agents for their decision making processes.



# SMART GRIDS AND INTEGRATION

Advanced facilities based at the University of Birmingham, funded by Advantage West Midlands (AWM) and the European Regional Development Fund (ERDF), as part of the Birmingham Science City initiative, are being used to further the understanding of the operation, control and management of smart grid systems powered by energy from distributed sources.

Large scale integration of renewable distributed generation into the power grid has significant potential to both reduce carbon dioxide emissions and provide secure and resilient power. The current UK grid is largely a one way system with power generated in large power stations and distributed through transmission and distribution lines, with no storage capability. The current system requires power generators to provide excess generation capacity to meet peak demands. The alternative is to develop smart grid systems which integrate power generation and storage through an intelligent communication system.



## OUTSTANDING FACILITIES

**The University houses facilities for the following research activity:**

- A smart power grid and real-time simulator that provides the capability to realistically simulate smart power grids with the integration of distributed power generation including wind, wave and fuel cell generation systems;
- Monitoring and control capability as well as real-time information integration, monitoring, protection and closed-loop control functions;
- Novel VSC HVDC simulations and control.

**The Power & Control Group at BCES have been working with companies such as National Grid, Western Power Distribution, E.ON, and ALSTOM Grid.**

**'THE THIRD ENERGY INDUSTRY REVOLUTION IS TAKING PLACE WHERE THE KEY IS THE DEVELOPMENT OF ELECTRICAL POWER GRIDS IN THE CONTEXTS OF SMART GRIDS. SMART GRIDS ARE PLAYING A PIVOTAL ROLE IN THE DEVELOPMENT OF A SUSTAINABLE ENERGY SUPPLY, ENABLING RENEWABLE ENERGY GENERATION AND ELECTRIFYING TRANSPORTATION IN TERMS OF ELECTRIC VEHICLES IN PARTICULAR. THERE ARE HUGE CHALLENGES FOR DESIGNING, OPERATING, CONTROLLING AND THE ECONOMIC ANALYSIS OF SMART GRIDS. THESE CHALLENGES NECESSITATE THE REVOLUTIONARY CHANGES TO ENERGY GENERATION, ENERGY DISTRIBUTION AND ENERGY CONSUMPTION AS WELL AS ENERGY STORAGE.'**

PROFESSOR XIAO-PING ZHANG, PROFESSOR OF ELECTRICAL POWER SYSTEMS AT THE BIRMINGHAM CENTRE FOR ENERGY STORAGE

## RESEARCH INTO SMART GRIDS AND INTEGRATION

Research focuses on the following activities:

- Technologies for smart grids;
- Application of power electronics such as FACTS (Flexible AC Transmission System);
- HVDC in transmission and distribution systems;
- Integration of PHEVs (Plug-in Hybrid Electrical Vehicle) into power grids;
- Super AC/DC power grids for large scale renewable energy delivery;
- Protection and control of distribution networks with distributed generation;
- Micro-generation and Micro-grid;
- Smart metering and wide area monitoring and awareness;
- Power system economics ;
- Large scale power system optimisation and planning;
- Analysis and control of power system stability;
- Power quality and harmonics;
- Energy Union;
- Global Power and Energy Internet

# ENERGY STORAGE RESEARCH PROJECTS

## SUPERGEN ENERGY STORAGE HUB

The SUPERGEN Energy Storage Hub is a £4 million collaboration, funded by the Engineering and Physical Sciences Research Council (EPSRC) as part of the Research Council's UK Energy Programme (RCUK).

Led by the University of Oxford, The hub will draw experts from the University of Birmingham, Imperial College London, University of Cambridge, University of Bath, University of Southampton and University of Warwick, and fourteen industrial and governmental partners to address the technical and scientific challenges facing the wide variety of energy storage techniques. The activities will embrace energy policy, as well as a roadmap and vision for energy storage research in the UK stretching into the future - setting the agenda for UK energy storage.

## MULTI-SCALE ANALYSIS FOR FACILITIES FOR ENERGY STORAGE (MANIFEST)

MANIFEST is a £5m Engineering and Physical Sciences Research Council (EPSRC) funded project set to tackle key challenges facing energy storage technology. Led by the University of Birmingham, the project will involve senior investigators with internationally leading reputations from across the UK, including academics from Imperial College, Loughborough University, University of Sheffield and University of Manchester, as well as drawing significant industrial support from the energy sector.

The project, which will draw on the collective expertise and facilities that exist in the UK, will address research questions that span the storage technologies currently being developed and tackle key issues in the use of this technology. These include the materials used in storage technologies and integration into existing energy systems, as well as using process modelling and data from pilot plants to improve our understanding of these technologies.

MANIFEST will lead to improved understanding of physical processes and accelerated technology development, which will help maximise the impact from existing UK facilities in both the national and international energy landscape. A new 'Observatory for Energy Storage' will be based at Birmingham.

## CONSORTIUM FOR MODELLING AND ANALYSIS OF DECENTRALISED ENERGY STORAGE (C-MADENS)

Around 80% of the UK population lives in urban areas, with cities responsible for about 70% of UK energy use. The importance of cities in tackling key energy targets is increasingly recognised, as are the social, environmental and economic benefits to city residents of appropriate energy provision.

The Consortium for Modelling and Analysis of Decentralised Energy Storage (C-MADEnS) project, funded by the Engineering and Physical Sciences Research Council (EPSRC), is carrying out research into the role of decentralised energy storage within cities, focusing on the cities of Birmingham and Leeds. Led by the University of Leeds, C-MADEnS comprises academics and researchers from the University of Birmingham, University of Warwick and Loughborough University.

The project will use a variety of tools and methods, including technology validation, techno-economic modelling, innovation studies and public attitude surveys, to address specific barriers to the deployment of city-scale energy storage. Demonstration of these methods and tools will be used through a number of case studies; analysing opportunities for energy storage deployment in the cities of Birmingham and Leeds.

## ENERGY STORAGE FOR LOW CARBON GRIDS

The electricity sector could be almost entirely decarbonised by 2030 but there would be significant consequences for the UK electricity systems. The costs of system integration are a significant concern if radical change affects both the supply and demand within the UK low-carbon system, and could result in a considerable reduction in conventional electricity generation, transmission and distribution assets.

Energy Storage for Low Carbon Grids, funded by the Engineering and Physical Sciences Research Council (EPSRC), is a £6 million collaborative project, led by Imperial College London, and includes academic experts from University of Birmingham, University of Sheffield, University of Oxford, University College London, University of Durham and Newcastle University.

The project will develop new techniques to better evaluate the economic and environmental benefits of a range of energy storage technologies, and focus on four different storage technologies with particular relevance to grid-scale storage applications – Na-ion, redox flow batteries (RFB), supercapacitors, and thermal energy storage (TES) – each of which has potential to be transformative.

**Key outputs from the project will be:**

- A roadmap for the development of grid scale storage for UK implementation;
- An analysis of policy options to support UK deployment of storage;
- A blueprint for the control of storage in UK distribution networks;
- Patents and high impact papers relating to breakthrough innovations in energy storage technologies;
- New tools and techniques to analyse the integration of storage into low carbon electrical networks.

# ENERGY STORAGE RESEARCH PROJECTS (CONTINUED)

## NEXT GENERATION GRID SCALE THERMAL ENERGY STORAGE TECHNOLOGIES (NEXGEN-TEST)

The energy systems in both the UK and China face challenges of unprecedented proportions. In the UK, it is expected that the amount of electricity demand met by renewable generation in 2020 will be increased by an order of magnitude from the present levels.

In the context of the targets proposed by the UK Climate Change Committee it is expected that the electricity sector would be almost entirely decarbonised by 2030 with significantly increased levels of electricity production and demand driven by electrification of heat and transport. In China, the government has promised to cut greenhouse gas emission per unit of gross domestic product by 40-45% by 2020 based on the 2005 level. This represents a significant challenge given that over 70% of its electricity is currently generated by coal-fired power plants. Energy storage has the potential to provide a solution towards these challenges.

NexGen-TEST, a £1.3m funded project by the Engineering and Physical Sciences Research Council (EPSRC) for UK partners and National Science Foundation of China for Chinese partners, brings together a multidisciplinary team of internationally leading thermal, chemical, electrical and mechanical engineers, and chemical and materials scientists with strong track records and complementary expertise needed for comprehensively addressing the thermal energy storage (TES) challenges. Led by the University of Birmingham, the dynamic team comprises leading academics from the Beijing University of Technology, University of Nottingham, University of Warwick, and the Institute of Engineering Thermophysicist and Institute of Process Engineering in China, alongside seven industrial partners.

Numerous energy storage technologies exist currently, including electrochemical (batteries, flow batteries and sodium sulphate batteries etc), mechanical (compressed air and pumped hydro etc), thermal (heat and cold), and electrical (supercapacitors). Among these storage technologies, thermal energy storage (TES) provides a unique approach for efficient and effective peak-shaving of electricity and heat demand, efficient use of low grade waste heat and renewable energy, low-cost high efficiency carbon capture, and distributed energy and backup energy systems. Despite the importance, little has been done in the UK and China on TES for grid scale applications. This proposed research aims to address, in an integrated manner, key scientific and technological challenges associated with TES for grid scale applications, covering TES materials, components, devices and integration.

**The projects objectives are to:**

- Develop novel TES materials, components and devices;
- Understand relationships between TES material properties and TES component behaviour, and TES component behaviour and TES device performance;
- Understand relationship between TES component behaviour and manufacturing process parameters, and;
- Investigate integration of TES devices with large scale CAES system, decentralized microgrid system, and solar thermal power generation system.

## CRYOGENIC TEMPERATURE COLD STORAGE USING MICROENCAPSULATED PHASE CHANGE MATERIALS IN SLURRIES (MPCMSS)

Cryogenic Temperature Cold Storage using Microencapsulated Phase Change Materials in Slurries (MPCMSs), a £1 million project funded by the Engineering and Physical Sciences Research Council (EPSRC) will explore fundamental aspects on cold energy storage at cryogenic temperatures and develop associated applied technologies.

Cryogenic-temperatures cold storage is the Cinderella in thermal energy storage. DOE Global Energy Storage Database states that there are currently 166 thermal storage projects globally in operation, or under construction, for renewable energy time-shift and capacity, firming or electric bill management. The majority of these projects are molten salt heat storage for concentrated solar power plants (2552MW), alongside chilled water or ice slurry cold storage for demand side electricity consumption management (200MW). However, in recent years, the potential value of cryogenic-temperature cold storage has been widely recognised for the much elevated energy density and the capability of cogeneration of cold and power.

The project will utilise the applicants' developed skills and sophisticated research facilities in Micromanipulation laboratory within the School of Chemical Engineering and the Birmingham Centre for Cryogenic Energy Storage (BCCES), University of Birmingham, to formulate, characterise, and demonstrate the application of MPCMSs for cryogenic-temperature cold storage. Through this project we will gain the skills of MPCMSs fabrication depending on the applications as well as the capability of optimal design of related cold storage devices.



# A CLEAN BREAK

**DEARMAN IS A TECHNOLOGY COMPANY DEVELOPING ZERO-EMISSION COLD AND POWER SYSTEMS FOR TRANSPORT AND THE BUILT ENVIRONMENT.**

The transport of food and medicine, management of data, and modern transportation all demand cooling, however, the need for cold is generally met with outdated disproportionately polluting diesel systems. Dearman is working with industry and academia to affect systemic change in the way cold and power is provided globally.

The Dearman engine, an innovative piston engine, utilises the rapid expansion of liquid air, or liquid nitrogen, to deliver efficient zero-emission power and cooling. Working with the Birmingham Centre for Cryogenic Energy Storage (BCCES) and partners across the Midlands such as the Midlands Technology Centre (MTC), Dearman is rapidly developing applications for this clean cold technology.

Partnership with BCCES has enabled Dearman to conduct durability and efficiency testing on the engine with a focus on tribology – the study of friction, wear and lubrication. More importantly, collaboration with BCCES has enabled Dearman to develop the knowledge and skills needed to develop its revolutionary clean cold technology, as it moves quickly from idea, to commercially available product.

In 2016, Dearman's first application, a zero emission transport refrigeration unit, was trialed by Sainsbury's. This is the world's first company to trail a truck cooled by a liquid nitrogen engine.

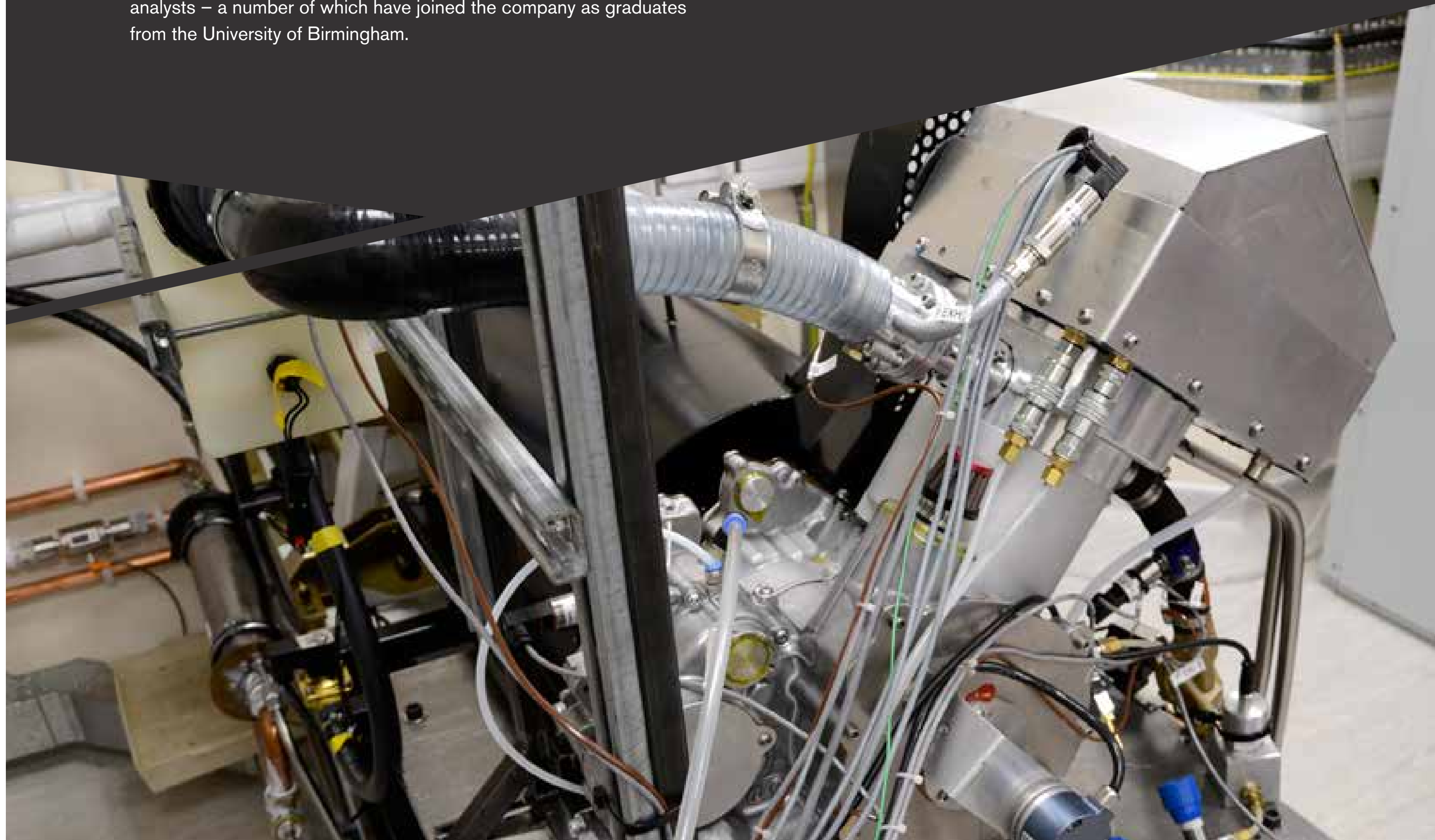
As the company grows, they are recruiting more talented engineers and analysts – a number of which have joined the company as graduates from the University of Birmingham.

## POLICY AND ECONOMICS

The commercial deployment of energy storage technologies will be dependent on viable business cases being made. Studies show that energy storage can reduce the costs of the transition to a low-carbon energy system. The policy and regulatory environment is especially important for energy storage, as the value of energy storage is spread across different markets and it will rise as intermittent generation increases.

In 2015, the University of Birmingham launched Doing Cold Smarter, a Policy Commission investigating how the growing demand for 'cold' and 'cooling', which is required to address global challenges of hunger, disease and population growth, can be met without causing environmental ruin. The commission delivers recommendations for new ways of providing cold in a sustainable way, specifically through a system level approach, as well as exploring the economic opportunities this new clean cold industry could present.

BCES's activity analyses energy policies and markets to enable take-up of effective energy storage, considering UK and global cases. Work also assesses the techno-economic case for deploying energy storage in energy systems at national and local scales.



# EDUCATION AND TRAINING

Globally there is a shortage of skilled engineers for designing, operating and controlling future electricity networks and heat/cold networks. These systems are playing a pivotal role in the development of a sustainable energy supply and enabling renewable energy generation.

Seeking to develop future engineers that are equipped to meet the demands of future energy challenges, we have developed a leading portfolio of courses, which include:

## UNDERGRADUATE PROGRAMMES

- BEng / MEng Energy and Engineering

## OUR POSTGRADUATE PROGRAMMES

- PhD Global Energy Systems: Powering the Future
- PhD Chemical Engineering
- MSc/Diploma Advanced Chemical Engineering Masters
- MSc/Diploma Biochemical Engineering Masters
- MSc Efficient Fossil Energy Technologies Masters
- MRes Materials for Sustainable Energy Technologies
- MSc Electrical Power Systems
- MRes Hydrogen, Fuel Cells and their Applications

## JOIN US

To learn more about the detail and impact of our research:

Birmingham Energy Institute
University of Birmingham
Edgbaston B15 2TT
United Kingdom

**www.birmingham.ac.uk/BCES**
energy@contacts.bham.ac.uk
@bhamenergy

Read our energy blog:
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UNIVERSITY OF BIRMINGHAM
Edgbaston, Birmingham,
B15 2TT, United Kingdom
www.birmingham.ac.uk