University of Nottingham
Propulsion Futures

Revolutionising the way we travel

Propulsion Futures

Beacon of Excellence

nottingham.ac.uk/go/propulsion-futures

2019–2020

Pictured: Sample holder of X-ray Photoelectron Spectrometer

Contents

Reimagining and reinventing transport for a greener future. Mounting environmental, economic, social and political pressures are paving the way for a revolution in transport.

Annual report brochure

Activities from academic year 2018-19

Introduction

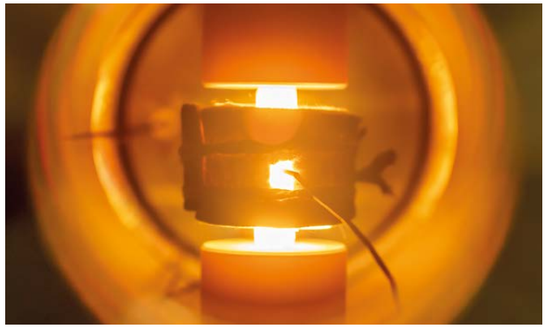
At the beginning of the academic year 2019/20, we have 28 projects now underway. From electric machines and materials discovery to high impact demonstrators prototypes that showcase the propulsion systems of the future, the Beacon is making excellent progress.

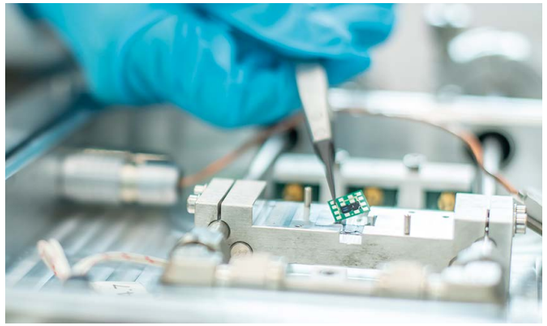
Unique research and equipment plays a key part of our investment strategy, with a focus on:

- **the Electrified Propulsion Centre** in the new Power Electronics and Machine Centre Building (2020)
- **the Beacon Devices Laboratory** in the Research Acceleration and Demonstration (RAD) building
- the **Beacon Advanced Materials Processing Laboratory** on University Park Campus

We are on schedule with the sourcing, build and installation of equipment, through 28 active projects worth £3.6 million.

We continue to lever support from industry and government funding at more than 3:1 ratio. We are growing our reputation and staff, including exciting new researcher appointments through internal and external fellowships.





Our aim is to deliver world-leading research that will enable the University of Nottingham to be a key player in developing the propulsion system of the future.

Pictured: Spark Plasma Sintering System

Overview

Our aim is to deliver world-leading research that will enable the University of Nottingham to be a key player in developing the propulsion system of the future.

Transport is responsible for almost a quarter of global carbon dioxide emissions. The industrial and scientific community is at the most important crossroads of change in transport to occur since the introduction of carbon-based fuels and engines over a century ago. This change will have greener, electric transport at its heart. We are proposing a pathway towards truly sustainable, responsible and carbon-neutral travel through electrification, based on new materials, novel technologies and seamless systems integration.

Through our seven visions, interdisciplinary research projects, investment in facilities and equipment, and our technology streams, we will deliver:

- significant scientific outcomes in green and sustainable new materials, electrification and propulsion
- new materials and propulsion systems for all forms of transport reducing the destructive impact on the environment and benefiting societies across the world
- hybrid and electric demonstrators for air, land and marine transport, developed through unique investments in infrastructure, equipment and people

We will also make a significant contribution to the goals of the Research and Impact Strategy:

Research delivery

Effective and efficient use of University investment to lever a significant increase in research awards over the lifetime of the Beacon.

Research quality

We will build on our capability in two ways:

1. We will recruit Nottingham Research Fellows, enhance bids for external fellowships, co-fund key PhD studentships and support the targeted projects to deliver the Beacon visions through 42 post-doctoral research associate years spread over the six-year business plan
2. We will provide an environment in which Fellows and existing middle/established career academics are highly motivated to apply for funding, build new collaborations, tackle the Propulsion Futures research challenges and to publish high quality papers

Research impact

We will deliver world-leading impactful research through:

- novel technologies
- unique devices
- new materials and energy storage systems
- demonstrators designed to attract industrial buy-in, partnerships and innovative research

There will be significant opportunities to commercialise technologies – which can then be adopted throughout the Beacon technology stream.

Research reputation

We will continue to build our reputation for research through high quality outputs, value of research grants and awards, building capacity, delivering impact to the economy and society, developing partnerships and collaborations, and delivering research-led teaching.

Snapshot of investment

Recruitment

3 Nottingham Research Fellows
Lee Johnson, Jesum Alvez Fernandez, Zhirong Liao

2 technicians
Grace Guan and Chris Varley

3 post-doctoral researchers
Barun Ghosh, Richard Glassock, David Rogers

1 synergy lead
Frank Kirkland

We have invested in:

Institute of Aerospace Technology Jubilee Campus and **Tower building**
University Park Campus

- **Bi-directional power supply and partial discharge detector**

Research Acceleration and Demonstration Building (RAD)
Jubilee Campus

- **Thermal conductivity equipment**
- **Thin film analyser**
- **Slot die coater**
- **Electrochemical and battery equipment**

Beacon Advanced Materials Processing Lab, Innovation Technology Research Centre (ITRC) University Park Campus

- **Plasma spark sintering facility**
- **Liquid plasma spray thermal barrier platform**
- **Arc melter, isostatic press and mills**

School of Physics and Astronomy
University Park Campus

- **Imaging ellipsometer**
- **MBE E-beam evaporator**

School of Chemistry
University Park Campus

- **Electro paramagnetic resonance**

Snapshot of grants, fellowships and publications

Grants

£78 million
grants submitted since March 2017

£18.5 million
EPSRC

£2.6 million
industry funding

£5.6 million
EPSRC Centre for Doctoral Training in Low-dimensional Materials and Interfaces

£6.5 million
EPSRC Centre for Doctoral Training in Sustainable Hydrogen

£1.5 million
Wolfson Award for Power Electronics and Machine Centre

£36 million
grants pending

Fellowships

Lee Johnson
UKRI Innovation Fellowship
£637k

Simon Woodward
Leverhulme Trust Fellowship
£138k

Graham Newton
British Council Newton Prize
£195k

Xuanli Luo
Leverhulme Trust Fellowship
£387k

Jonathan Hirst, Pritesh Tailor
EPSRC Research Software Engineer Fellowship
£200k

Vincenzo Madonna
(postgraduate student)
2018 ICEM Brian J. Chalmers Best Paper Award at the 23rd International Conference on Electrical Machines

Amalia Patanè
Chinese Academy of Science President's International Fellowship

Publications

402
Beacon publications
since 2018

312
Faculty of Engineering

72
School of Chemistry

18
School of Physics and Astronomy

Electric machines

Pictured: High power density aircraft electrical machine developed at Nottingham

The Multi-megawatt Propulsion Facility is a high-impact project for the Beacon. It will enable the development and test of innovative propulsion systems to high technology readiness together with academic and industrial partners.

The future of electrical propulsion

This project is an important example of hardware demonstration in partnership with industry. It will directly support the research and development of:

- electric fan motors for aircraft
- new electrical machine topologies
- new materials including insulation systems
- drive power electronics and controls

In its first phase, the project will test electrical fan motor drives for their steady state and transient loading performance, especially during load and power supply transients. It will enable us to assess insulation on the motor itself, as well as separate test sections in representative environmental conditions of high voltage and fast switching devices.

Much of the supporting equipment is now commissioned and working, including partial discharge detector and high voltage test equipment. This open-access facility will underpin future work through national initiatives such as UK Aerospace Research Consortium (UKARC) and UKRI's Driving the Electric Revolution and Future Flight challenges.

The University is collaborating with over 30 industrial partners including Siemens, SAFRAN and Rolls-Royce to address challenges for future propulsion. Our aim is to address the impact on climate change by accelerating the journey towards decarbonised air travel.

Working in a global environment

Our remit is to work with the best globally. Current research partnerships encompass European and international institutions. Several collaborative projects cover the development of key electrical technologies and their integration across transport sectors.

We are involved in the development of standards and roadmaps for future electrified transportation. Our international activities include:

- **Power Hardware in the Loop (PHIL)** – this will analyse and develop high-performance electro-mechanical power systems and components for enclosed, smart power systems, such as power amplifiers, DC-AC converters, flying probe testing equipment and other technologies related to the concept
- **Reliability of Electrical Systems for Aircraft** –As electrical drive systems are being developed for harsher environments, we are aligning with CleanSky2 initiatives to produce and test robust electrical systems. For example, wiring systems for aeroplanes that will work in very cold and hot climates. We are collaborating closely with industry to move devices to higher technology-readiness levels, getting them closer to market
- **Investigation and Maturation of Technologies for Hybrid Electric Propulsion (IMOTHEP)** – aims to support carbon-neutral growth of commercial aviation through the assessment of hybrid electric propulsion and build an aviation sector technical roadmap. The four-year project is supported by seven research and development institutes, 11 European industries, a service small to medium enterprise, seven universities from nine EU countries, plus six organisations from Canada and Russia

Materials discovery

Pictured: Preparing a sample for the Accurion nanofilm_ep4 ellipsometer

By integrating research groups across the University and enabling new national and international collaborations, our aim is to meet the challenges of fundamental materials discovery, deliver enhanced properties and develop more efficient devices. These projects are on the path to becoming the foundation of sustainable transport across the aerospace, automotive and marine sectors.

Thermal coating nanocomposites

Current state-of-the-art materials such as aluminium nitride have limited applications – due to their chemical volatility or instability. With a crucial need for new materials, we will explore the potential of using nanocomposite coatings with specific nanofillers and matrices to provide greater stability and meet the demanding conditions of high-density electrical power systems.

Effective thermal characterisation is key in this area. As such, we have installed high specification thermal analysis equipment to provide fast, versatile and precise measurements over a wider states.

Molecular Beam Epitaxy (MBE)

This project will target hexagonal boron-nitride (hBN) to explore its potential as a protective thermal, electrically insulating and wear-resistant coating for metals required for electric machines. This will allow them to be more compact and to operate at higher temperatures. It requires increasing flux to practical levels for devices and will be a major technological breakthrough. It will also be the only MBE system worldwide with such unique capabilities.

To simulate capability and quantitative analysis of materials and systems, we have full-time scientific computing support and essential modelling tools. Our aim is to provide scientific techniques for calculating force fields and optical properties of new materials, including materials used in batteries, fuel cells and hydrogen storage devices. Collaborations are underway in chemistry and engineering. This *in silico* modelling of complete components from atomic to macroscale will drive and support new design strategies in the Beacon.

Electron Paramagnetic Resonance (EPR)

New products and devices for advanced applications rely on the knowledge of the relationships between the structure and properties of their component materials. Here, molecular-level characterisation is key. This project has delivered an EPR spectrometer with improved sensitivity. It is currently probing materials for photovoltaics, energy storage and thermo-electrochemical cells, and provides data that is crucial for the success of other Beacon's projects.

Dynamic Nuclear Polarization (DNP)

New products for advanced applications cannot be developed without knowledge of the properties of their component materials. Our researchers are working on determining the properties of new materials at a molecular level.

A sustainable near-ambient pressure x-ray photoelectron spectroscopy (XPS) facility

While normal XPS enables us to look at the chemical and electronic structure of the atoms and molecules at the surfaces of energy materials, near-ambient pressure x-ray photoelectron spectroscopy (NAP-XPS) allows us to do this at pressures up to tens of millibars – bridging the pressure gap between surface science and real systems.

Beacon executive board and management team

David Grant
Propulsion Futures Director, Professor of Materials Science and Head of Advanced Materials Research
Vision lead Energy Carrying Systems

Michael Galea
Propulsion Futures Co-Director, Director of the Institute of Aerospace Technology China
Vision lead for Advanced Propulsors

Amalia Patanè
Professor of Physics
Vision lead for Onboard Energy

David Amabilino
Professor of Sustainable Chemistry
Vision lead for Sustainable and Greener Materials for Propulsion Systems

Chris Gerada
Professor of Electrical Machines
Vision lead for Fully Integrated Generation Systems

Seamus Garvey
Professor of Dynamics
Vision lead for Disruptive Technologies

Our experts

(Listed in alphabetical order)

Romina Davoudi
Head of Operations

Graham Harrison
Project Officer

Ifty Ahmed
Andrey Akimov
David Amabilino
Emma Barney
Chris Bennett
Elena Besely
Nick Besely
Peter Beton
Boyan Bonev
Serhiy Bozhko
Giampaolo Buticchi
Alasdair Cairns
Richard Campion
Neil Champness
George Chen
Jon Clare
Alex Conradie
Sam Dakka
Davide De Focatiis
Michele Degano
Carol Eastwick
Laurence Eaves
Tom Foxon
Mark Fromhold
Alessandro Galassini
Michael Galea
Juan Garrahan
Seamus Garvey
Mike George
Christopher Gerada
David Gerada
Barun Ghosh
Paolo Giangrande
Miguel Gimeno-Fabra
Richard Glassock
David Grant
Chris Hill
Jonathan Hirst
Xianghui Hou
Steve Howdle
Tanvir Hussain
Chris Hyde
Derek Irvine
Richard Jefferson-Loveday
Mark Johnson
Rob Jones
Debbie Kays
Anthony Kent
Andrei Khlobystov
Frank Kirkland
Christian Klumpner
Walter Kockenberger
Antonio La Rocca
Ed Lester
Ming Li
Pete Licence
Sanliang Ling
Xuanli Luo
Roderick MacKenzie
Vincenzo Madonna
Hanafy Mahmoud
Oleg Makarovskiy
Kandavel Manickam
Claire McIlroy
Jon Mckechnie
Jonathan McMaster
Christopher Mellor
Robert Mokaya
Graham Newton
Sergei Novikov
James O'Shea
Amalia Patanè
Stephen Pickering
Graham Rance
Karen Robertson
David Rogers
James Rouse
Giacomo Sala
Phil Shipway
Kathy Simmons
Cosimo Spagnolo
Alastair Stuart
Mark Sumner
Sharmila Sumsurooah
Andy Teale
Rob Temperton
Jeremy Titman
Begum Tokay
Chris Tuck
Gaurang Vakil
Katy Voisey
Gavin Walker
Darren Walsh
Richard Wheatley
Ricky Wildman
Pat Wheeler
Simon Woodward
Fang Xu
Yuying Yan
He Zhang
Wen Zhu

Nottingham Research Fellows

Jesum Alves Fernandez
Lee Johnson and
Zhirong Liao

Technical staff

Grace Guan and
Chris Varley

Postgraduate students supported by the Beacon

Filippo Begna
Nathan Cottam
Anubhab Dey
Lei Lei
Ferdinando Malagreca
Umar Musa
Letizia Liiro Peluso
William Towsend
Shihong Xie

Facilities for the next generation

Pictured: Sample undergoing Spark Plasma Sintering at 1500°C

Key to our strategy of delivering research with industrial and societal impact, we are developing a suite of demonstrator activities to showcase cutting-edge Beacon research.

Richard Glassock has been appointed as lead for this activity. The work builds on established projects and prospects, which have high visibility and merit for leading industrial, research and educational agendas within the propulsion domain, and also including materials, structures, human factors and operations.

Initial projects included producing a flying technology demonstrator to showcase cutting-edge research on hybrid, turbo-electric and distributed propulsion applied to a vertical take-off and landing (VTOL) capable unmanned aerial vehicle (UAV). Another project aims to build a prototype that will incorporate a hybrid electric motorcycle into an electric aircraft.

Thanks to exciting collaborations, we now have a light single-seat aircraft on campus, stripped in readiness for the electric motor demonstrator. This builds on success in 2018 when the University of Nottingham eBike achieved an impressive 2nd at the Isle of Man TT Zero – with a prototype low-weight/high energy density AC motor that doubled the power of its electric motor.

The Beacon Devices Lab

This lab features a comprehensive suite of facilities for building and testing prototype electrochemical devices based on materials and fundamental research. It will bridge the gap between Technology Readiness Level (TRL) one to three and those at TRL five to ten, and support a number of exciting initiatives.

For example, the Energy Storage Devices project will transition basic science and materials discovery into first stage prototype devices, targeting electrification of transport. It will also enable the development of devices drawn from the fundamental research performed at the University, including next-generation batteries based on Li-air, Na-ion and Li-sulphur battery technologies.

The Beacon Advanced Materials Lab

Now complete, with installation of equipment continuing, this lab will support projects such as the Liquid Plasma Processing Platform, which will deliver the first suspension plasma spray facility of its kind in the UK. Another example is the Spark Plasma Sintering (SPS) project, which offers many advantages over conventional sintering systems, including greatly reduced sintering temperature, and a much shorter sintering period. SPS offers entirely new possibilities to manufacture a wide range of materials with extraordinary characteristics, ideal for fuel cells and functional electrodes.

RExMoto_Phase1 project aims to build a prototype that will incorporate a hybrid electric motorcycle into an electric aircraft.

Pictured: RexMoto phase 1

University of Nottingham
Propulsion Futures

Discover more about our world-class research

David Grant, Director
david.grant@nottingham.ac.uk

Michael Galea, Co-Director
michael.galea@nottingham.ac.uk

Romina Davoudi, Head of Operations
romina.davoudi@nottingham.ac.uk

@UoN_Propulsion

Propulsion Futures Beacon
Innovation Technology Research Centre (ITRC) building
Room AM01
University Park Campus
NG7 2RD

nottingham.ac.uk/go/propulsion-futures

This publication is available in alternative formats.
+44 (0)115 951 5559

Published October 2019.