ENERGY RESEARCH ACCELERATOR

AT THE FOREFRONT OF ENERGY INNOVATION

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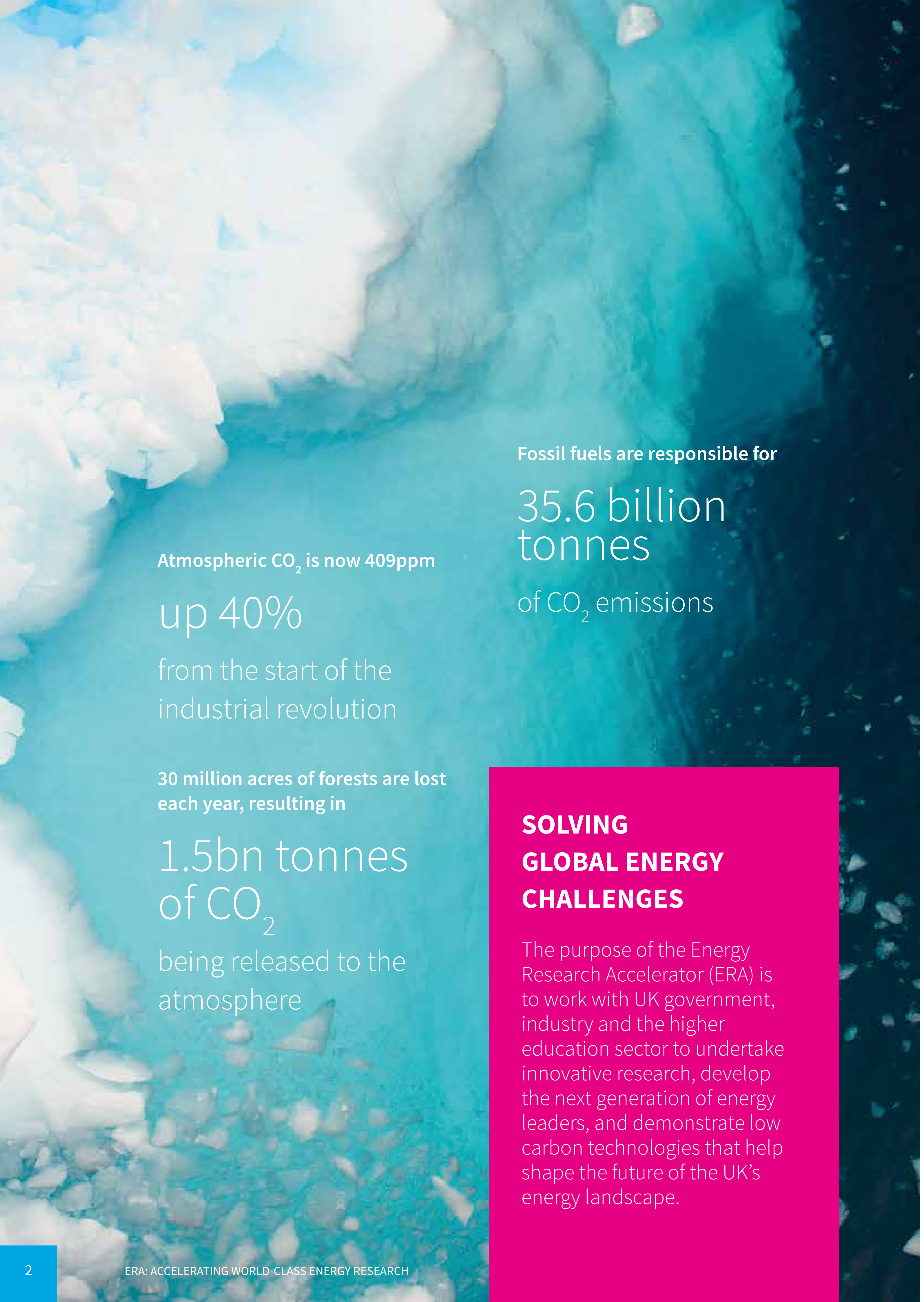
ACCELERATING WORLD-CLASS ENERGY RESEARCH



Atmospheric CO_2 is now 409ppm

up 40%

from the start of the industrial revolution

30 million acres of forests are lost each year, resulting in

1.5bn tonnes of CO_2

being released to the atmosphere

Fossil fuels are responsible for

35.6 billion tonnes

of CO_2 emissions

SOLVING GLOBAL ENERGY CHALLENGES

The purpose of the Energy Research Accelerator (ERA) is to work with UK government, industry and the higher education sector to undertake innovative research, develop the next generation of energy leaders, and demonstrate low carbon technologies that help shape the future of the UK's energy landscape.

Contents

CHAPTER 1
Delivering Clean Energy for the UK from the Midlands

In 2016, seven Midlands institutions launched the Energy Research Accelerator, ERA. The universities of Aston, Birmingham, Leicester, Loughborough, Nottingham and Warwick together with the British Geological Survey pooled their research expertise and capability to rapidly accelerate the rate at which clean energy research transitions into the market. In 2018, this expanded to include the universities of Cranfield and Keele. The project is funded through Innovate UK with £60M of research council funding matched by an estimated £120M of funding from industrial and business partners. The aim is to use the regional research base of over 400 academics with expertise in energy coupled with more than 1,000 PhD students to transition energy solutions to market, deliver low carbon energy solutions to the UK, grow much needed energy sector skills and create enhanced jobs and growth for the Midlands region.

Since 2016, the need for radical change has become even clearer. On the back of the COP21 Paris climate change agreement and the aim to limit global warming to less than 2 degrees, the government published its Clean Growth Strategy (CGS). The CGS outlined £2.5 billion of investment made in low carbon innovation and clean growth over the 2015-21 period; this included up to £500 million from the BEIS 'Energy Innovation Programme' to drive commercialisation of "clean energy technologies and processes". In September 2017, the Midlands Engine published a growth strategy, and clean energy is a key part of its vision. As part of this the Energy Research Accelerator (ERA), with the support of Innovate UK, has the mandate to develop beacons of excellence that demonstrate and show, not only the advantages of clean technology, but also how to develop them economically. Partnerships between universities and businesses are central to this.

The seven partners have internationally recognised leading research facilities and expertise. Ranging from the technology associated with energy in the built environment, hydrogen and fuel cells, energy storage, power grids, nuclear energy, bioenergy, carbon capture and storage, through to energy policy, economics, regulation and law. These foundations, properly aligned, provide the impetus to work in a collaborative mode and at a scale previously not realised, to deliver real and significant change.

ERA, working with business and industry, is creating an energy systems acceleration ecosystem. It has achieved this through investment in a technology readiness level (TRL) pipeline. This connects the R&D within the universities to the development of large scale demonstration capability and the essential manufacturing development that will allow businesses to scale up their product delivery into market. This is being achieved in collaboration with regional stakeholders such as city councils and the Energy Systems and High Value Manufacturing Catapults. This provides the platform to develop, demonstrate and manufacture all in a single regional location and the opportunity to catalyse inward investment and growth to establish the Midlands as the place to develop energy solutions nationally.

The ultimate aim is to establish a series of pan regional large scale energy system demonstrators, or Energy Innovation Zones. These will be ecosystems which are a mix of established and next generation solutions, locations where new regulatory and business models are developed and at a scale that provides solutions for the citizens of the region.

The size of the challenge nationally and internationally is such that working collaboratively is essential. ERA has recognised this through the present business and academic consortium but it is clear that even that is insufficient. One of the top priorities is to broaden and deepen the range of collaborative activities through the development of additional relationships with business and academia and the recent expansion to include the universities of Cranfield and Keele are examples of that widening collaboration.

The present document lays out the capability that exists within the ERA collaboration to provide an understanding of the research strengths and capability within the consortium. It is framed in terms of the thematic areas of Energy Transformation, Energy Storage, End User Energy Demand and Energy Integration. It also sets out the underpinning skills, education and training developments.

The Energy Research Accelerator team would be delighted to work collaboratively with you to help shape the future global energy system.

Professor Martin Freer
Chair of Energy Research Accelerator Research Committee

CHAPTER 2
Capability overview

The ERA mandate, as endorsed by the institutions that make up ERA, is:

- To develop and enable a broad based, clean energy research strategy that represents the strongest possible combination of technical expertise, demonstration facilities and academic collaborations across the Midlands, in addressing both national and international challenges. This is being undertaken in partnership with the ERA institution lead academics, based on internationally recognised world class research and endorsed by the ERA Research Committee.
- To create a co-ordinated skills programme that builds on the existing ERA Doctoral Training Programme and also investigates expansion into masters and undergraduate programmes and community outreach activities.
- To enhance and coordinate engagement with UK-wide industrial stakeholders, government and other institutions outside of the ERA partnership. This will provide an informed approach in attracting external funds and will ensure that the partner institutions continue to be international centres of expertise for low carbon energy research addressing real-world, industry-led research problems.

ERA's mission is to:

- Focus future academic research, industrial collaborations and the creation of a talented skills pipeline in Energy Transformation, Energy Storage, End Use Energy Demand and Energy Integration all considered in the context of the complete, integrated energy system.
- Turn the Midlands into a centre of excellence on clean energy that, through a suite of physical energy demonstrators, attracts further inward investment and delivers technologies that can aid growth relevant to both the national and the international markets.
- Strive to attract the best individuals to learn, develop and grow such that ERA is recognised for its contribution to a vibrant and successful Midlands skills base.

ERA capabilities across institutions

ERA's approach to the development of its research capability areas has been to focus on a number of key, industrially relevant topics that define 'what ERA is good at' within the wider context of the complete energy system. The detailed subjects covered under each topic area clearly change and evolve as the technology landscape of the UK changes. ERA believes that the following Capability Areas encapsulate ERA strengths, capabilities and skills and represent the best topics to focus on to ensure continued growth in the future.

Energy Transformation

To demonstrate a broad range of renewable and sustainable energy supply technologies that cover electricity, fuels, chemicals and heat.

End Use Energy Demand

To develop innovative technologies, incorporating social and economic considerations and appropriate business models, that will help to reduce UK emissions and lower the amount of energy demanded by both industrial and domestic end users.

Energy Storage

To make major contributions in advancing several different energy storage technologies thus enabling net-zero carbon energy utilisation to become both technically viable and affordable.

Energy Integration

To address technological challenges that enable energy systems to be fully integrated at scale, such that they are smart, flexible, socially acceptable and capable of realising the opportunities afforded to them by future advances.

It is essential in the development of any of the above that the social, cultural, economic, environmental and business impacts are all considered together with the technical development.

ERA's approach recognises that no element can be considered in isolation and that the fully integrated energy system in which each capability area sits is key.

ERA facts and figures

£120m
CO-INVESTMENT COMMITTED
From over
40 INDUSTRIAL PARTNERS

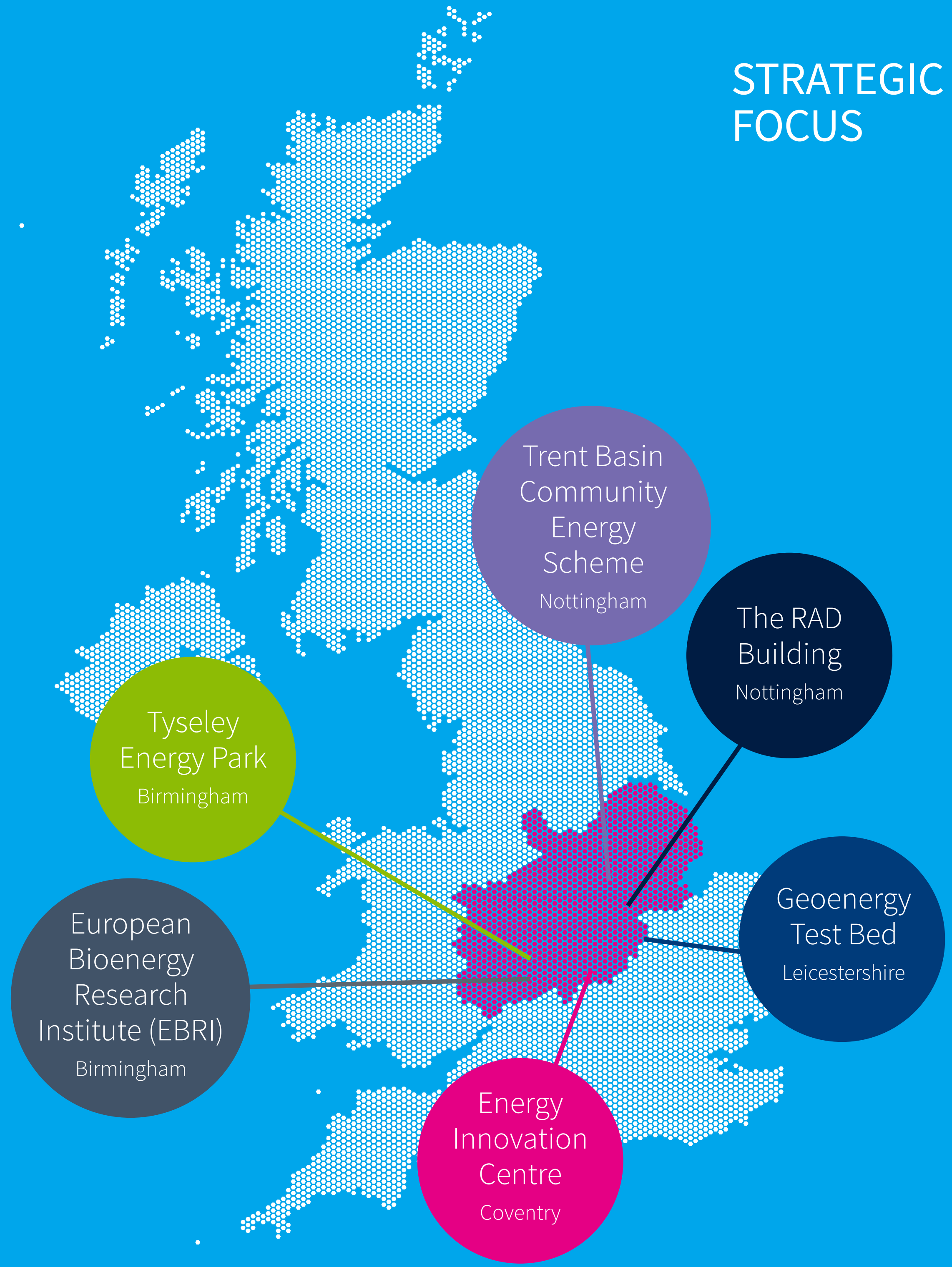
£60m
Capital funding via INNOVATE UK

9
Key Midlands partners

INVESTING IN OVER
30 new R&D facilities

More than
400
ACADEMICS

Over
1,000
RESEARCHERS



STRATEGIC FOCUS

- Energy Transformation
- End Use Energy Demand
- Energy Storage
- Energy Integration

SKILLS EXPERTISE

- **£2.5m** pump priming for an ERA Doctoral Training Partnership
- **3 cohorts** established
- **£2.5m** addressing future industry needs through **challenge-based PhD projects**
- Developing **future leaders** in low carbon energy

With 25,000m^2 of space, the **RAD Building** is the UK's largest working laboratory built to Passivhaus standards

The GeoEnergy Test Bed has 11 boreholes, each drilled to depths of up to 285m

The TCR demonstrator at Tyseley Energy Park is capable of processing 80 kg of waste per hour

More than 100 businesses have taken part in EBRI's bioenergy masterclasses

Over 20 companies work with the Energy Innovation Centre at any time

The 2.1 MWh Tesla battery at Trent Basin is the largest community energy battery in Europe

Innovate UK · Aston University Birmingham · University of Birmingham · Cranfield University · University of Leicester · Keele University · Loughborough University · University of Nottingham UK | China | Malaysia · Warwick The University of Warwick · British Geological Survey Natural Environment Research Council · Midlands Innovation

CHAPTER 3

Research capability areas

Pictured: Home to ERA – the RAD building is designed to meet both Passivhaus and BREEAM energy efficiency standards – the first of its type in the UK to achieve this.

This document is structured around a description of the capability areas and the forward-looking priorities that define the steps the ERA institutions.

Each capability area describes individual technical themes to ensure that ERA provides clarity and a consistent basis for communicating with its partners and stakeholders. There is a great deal of interdependence between the capability areas and ERA encourages cross institutional discussions to ensure that all are fully aware of the capabilities held within ERA.

In essence ERA's approach is to work with academia, industry and stakeholders to undertake innovative research across the energy portfolio, develop the next generation of energy leaders and demonstrate low carbon technologies that help shape the future of the UK's energy landscape whilst fully addressing social, cultural, economic, environmental and business impacts. It will do this through the delivery of innovative projects aligned with the capability areas of Energy Transformation, Energy Storage, End Use Energy Demand and Energy Integration.

ENERGY TRANSFORMATION

ENERGY STORAGE

END USE ENERGY DEMAND

ENERGY INTEGRATION

ENERGY TRANSFORMATION

OBJECTIVE

To demonstrate a broad range of renewable and sustainable energy supply technologies that cover electricity, fuels, chemicals and heat.

The UK is transitioning away from fossil fuel technologies and moving towards a more sustainable energy system based on renewable energy. These cover technologies such as solar, wind, geothermal, bioenergy, tidal & wave power and hydroelectricity. In the Government's recently published Clean Growth Strategy[1] (CGS), it was announced that £177 million will be invested in reducing the cost of renewables in areas such as improving offshore wind turbine blade technology and developing "advanced solar PV technologies". Ministers are working with industry to create a 'Sector Deal' for offshore wind and the Government wants more people investing in solar without their support. Small scale low carbon generation beyond 2019 was also singled out for future investment. Whilst ERA institutions have R&D projects ongoing in each of the various energy vectors of electricity, fuels and heat, this particular Capability Area is focused on the ones where ERA can demonstrate real unique capability – either in its facilities, academic excellence or a combination of both.

The scope of the R&D described in this Capability Area aligns very strongly with the ICSF challenges of **"Prospering from the energy revolution"**, **"Manufacturing & Materials of the future"** and **"Satellite and Space technology"**. It will be essential for ERA to demonstrate the institutional strengths, world leading facilities and collaborative opportunities that exist across the seven organisations in order to secure ISCF support in the future.

1. Clean Growth Strategy, https://www.gov.uk/government/publications/clean-growth-strategy, Oct 2017

Social, business, economic, behavioural and environmental impacts

Photovoltaics	Wind generation	Bioenergy and waste conversion	Carbon capture

<<<<<<<< ENERGY TRANSFORMATION >>>>>>>>

Fuel cells	Energy in extreme environments	Energy choices	Alternative energy vectors

Photovoltaics (PV)

The UK government is keen for many types of renewable generation to be developed, and ministers hold the view that innovation can continue to deliver substantial benefits across the PV and solar sector. The Centre for Renewable Energy Technologies (CREST) at Loughborough University is a significant contributor to this national knowledge base and has unique capabilities, especially focused on advanced solar PV technologies and maximising the energy density associated with PV panels. The University of Nottingham focuses on higher efficiency solar cells through the development of new materials and components and extensive laboratory facilities are currently being developed across other ERA institutions. Another key opportunity for ERA is the development of PV systems for off-grid applications, both in the UK and abroad. Social factors such as specific community needs relating to installation, operation and maintenance are all fundamentally important elements that are being considered in the design of these technological solutions.

Development of bespoke PV systems is also an important topic in developing countries and is an opportunity for ERA to leverage its unique capability and facilities abroad. ERA is focused on attracting increased funding for advanced solar PV technologies to enable progress of new materials and components from early stage lab ideas to viable prototype systems. These can then be realised in a timely way that attracts both national and international funding opportunities.

Wind generation

A crucial step in the development of sustainable energy systems lies in the replacement of fossil fuel technologies with renewable energy sources. Energy generation through the harnessing of wind power is an area that represents a significant strength within the ERA portfolio and enhances ERA's credibility as a collection of energy institutions that can cover a wide proportion of the clean energy research agenda. The Supergen Wind Hub, which includes the Universities of Loughborough and Cranfield, has funding until 2019 and takes a leadership role in bringing together the underpinning research efforts in Wind Energy in the UK and links them strongly to the development research being supported by other funding organisations. Improving the design of wind turbine blades and making them more efficient is a key strength at the University of Nottingham, as is access to the Cranfield University National Wind Tunnel Facility and their expertise in through-life structural analysis of wind turbines. Cranfield is a technical leader on project SLIC (Offshore Wind Structure Lifecycle Industry Collaboration), funded by a consortium of ten offshore wind operators that informs the design of future wind farms. By researching the way wind energy is harnessed and used by the national grid, ERA uniquely links this energy generation technology with energy distribution and storage. The ERA institutions of Nottingham, Loughborough and Cranfield, together with local engineering businesses, will continue to assess the potential of collaboration in this area, especially that linking wind generation with energy distribution and storage.

Bioenergy and waste conversion

ERA is investing in a number of different Bioenergy and Waste Conversion technologies. All produce combinations of low carbon fuels, heat, electricity or other useful chemical by-products such as hydrogen, from a supply of organic material that is either grown specifically for the purpose or is a waste product. The four described here are:

1. Biomass and Waste Conversion
2. Thermo-Catalytic Reforming (TCR®)
3. Hydrothermal Carbonisation (HTC)
4. High Temperature electrolysis

1. Biomass and Waste Conversion

ERA currently supports several demonstration facilities associated with sustainable biomass energy and resources from organic waste, i.e. the conversion of a wide range of biomass and other carbon-based residues into affordable, advanced biofuel for transport and industrial applications/products. These facilities address the practical challenges around energy / waste and seek to get innovative solutions implemented. With the global community consuming more energy than ever before, the demand is rising at a time when climate change and the use of fossil fuels is a growing concern.

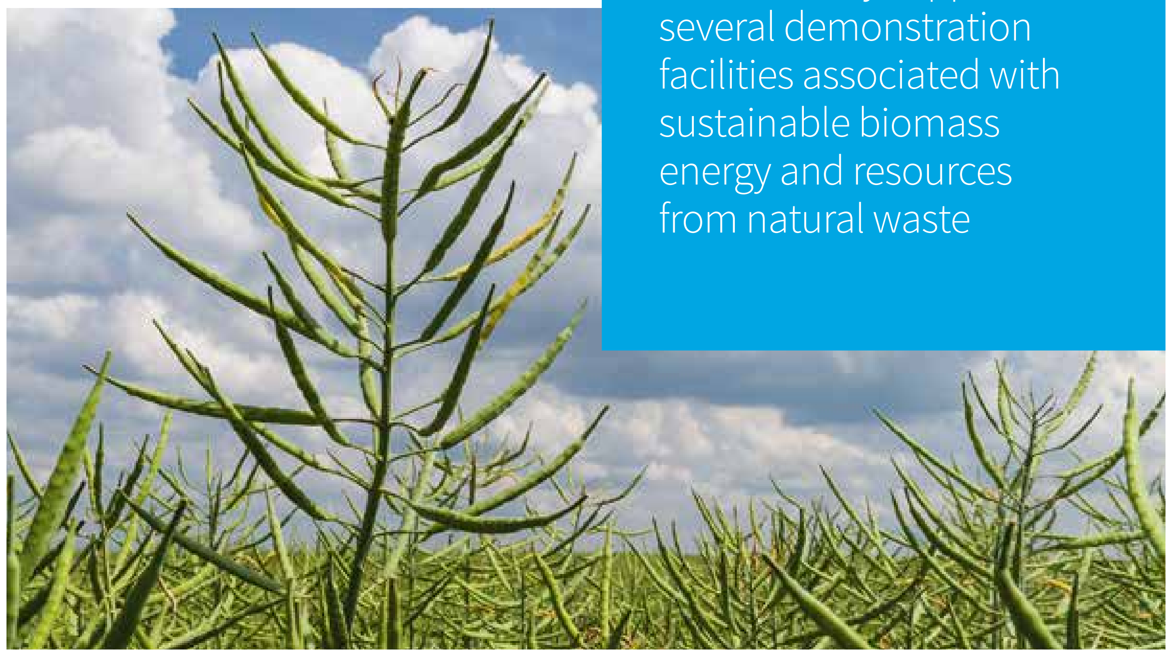
There is also a significant need to manage our resources better with more practical processing and exploitation of waste, with a greater focus on the production of energy and biofuels from waste. The European Bioenergy Research Institute (EBRI) at Aston University is unique in the UK with capability to understand the role of Pyrolysis and Gasification on a variety of different materials. ERA currently invests in EBRI through the 5BIO project that looks to stimulate research, innovation and knowledge transfer between businesses, scientists and chemical engineers across five key areas: biomass, biorefining, bioenergy, biofuels and bioproducts. This is partly done in close collaboration with local businesses and industry, who already have relationships with EBRI through their Bioenergy for Business and European funded Master Class programme.

ERA intends to increase its role within biomass and waste conversion technology development to support the upgrading of key infrastructure relating to energy generation, storage and the promotion of diversification into different forms of energy input. In addition, ERA institutions will explore the opportunities offered by alternative fuel technologies, including low carbon gaseous fuels such as synthetic natural gas (SNG – which is pure methane) and hydrogen across multiple applications, including heating, energy storage and transportation.

2. Thermo-Catalytic Reforming

One example of ERA's current investment is in collaboration with the University of Birmingham and the Fraunhofer Institute on demonstrating the Thermo-Catalytic Reforming technology, based at the Tyseley Energy Park, Birmingham. This is a central hub for energy innovation as part of the Energy Capital vision for the West Midlands. Through a staged process, TCR® technology converts waste or residual biomass into high quality syn-gas, bio-oil, biochar and water. The syn-gas can either be converted to synthetic natural gas (SNG) by methanation or be purified to hydrogen; both pathways are being pursued in collaboration with the University of Birmingham. The carbon footprint of such energy vectors is low as the carbon input is derived from biomass and the processing energy demand is limited.

ERA currently supports several demonstration facilities associated with sustainable biomass energy and resources from natural waste



A Tyseley based energy innovation zone would offer a natural and significant potential for integration with other ERA supported technologies

The system is designed to process a wide range of products including:

- fermentation residues including digestate from anaerobic digestion plants
- agricultural/forestry residues (for example, animal manure, waste wood and road side clippings)
- industrial biomass residues (for example, brewer's spent grain, paper sludges)
- municipal organic wastes such as sewage sludge from water treatment plants

The current demonstrator will process approximately 80kg per hour. The ambition is for the system to reach 500kg per hour for it to gain commercial viability. ERA's focus is to ensure that it attracts the appropriate industrial support such that local, UK based companies can keep the capability and knowledge developed through its engagement at Tyseley and take advantage of the subsequent IP in scaled up versions. If ERA focused on attracting industrial support to the TCR® as it becomes a key energy demonstrator, it would result in UK based companies developing knowledge, know-how and valuable IP leading to the creation of jobs and skills as the chain of commercial scale thermo-catalytic reforming plants are built around the city of Birmingham. This concept, known as the 'Thermal Belt', would have the potential to transform the way that the UK thinks about energy and waste and would provide a solution to the growing global demand for clean energy and fuels.

A Tyseley based energy innovation zone would offer a natural and significant potential for integration with other ERA supported technologies. It would offer a safe and unique regime where regulatory considerations would be more flexible to enable technologies to be tried and tested and provide the basis for evidence to influence the development of appropriate standards / policy / regulations and long-term strategic thinking.

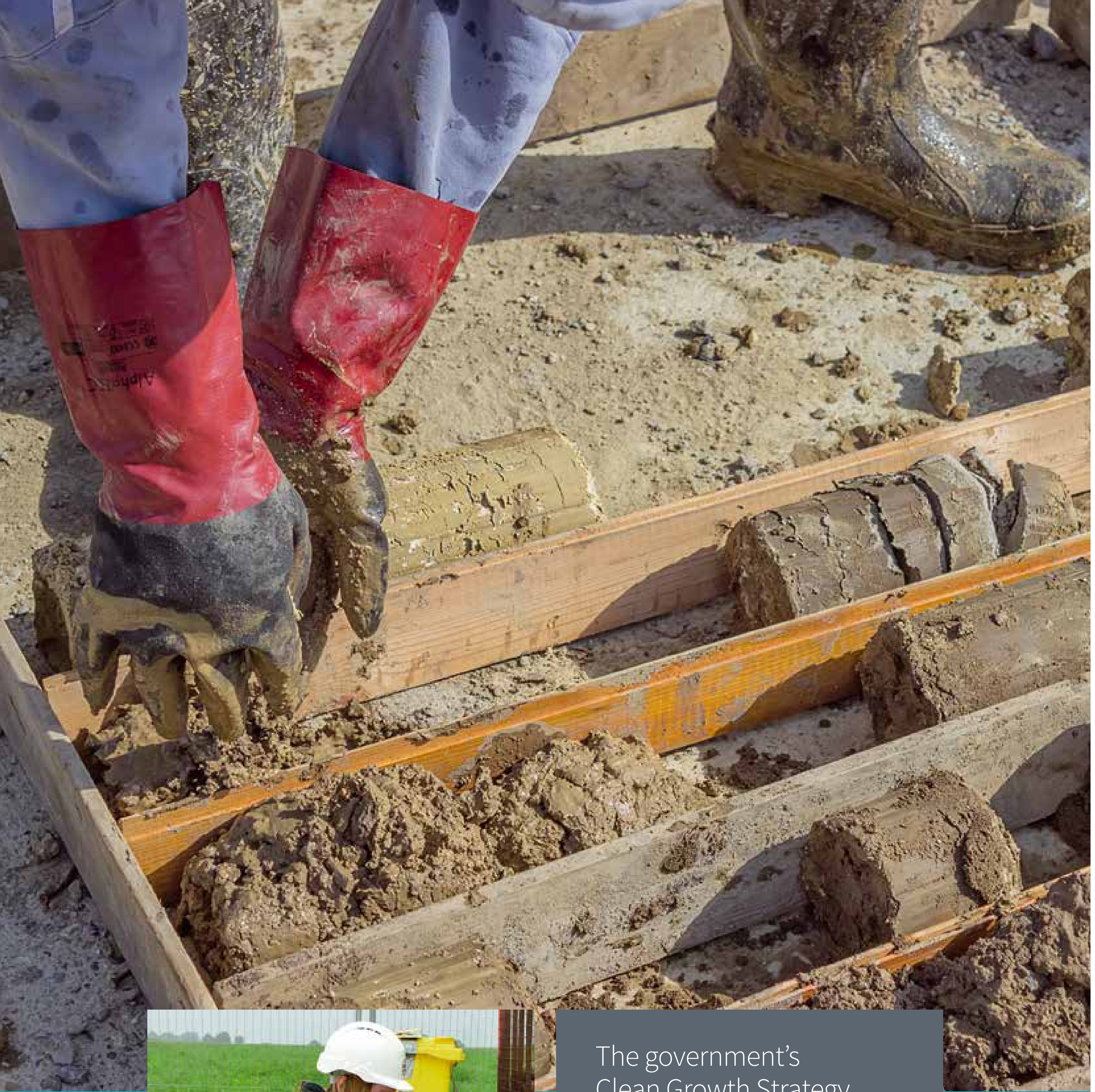
3. Hydrothermal Carbonisation

ERA is currently working with the University of Nottingham and industry representatives to produce a commercial scale, Hydrothermal Carbonisation (HTC) facility capable of converting biomass into solid fuels having coal-like properties. The technology, a first for the UK, is located in North Lincolnshire and converts high-moisture biomass into net-carbon neutral solid fuels (bio-coal) using moderate temperatures and high pressure. The process also produces some by-products such as liquid and gaseous wastes that require utilisation or disposal, which is a key area for future R&D. This facility effectively mimics the long-term natural process of coal formation, with the process taking a matter of hours rather than millennia. Once completed, the HTC facility will be operated by CPL, a major manufacturer and distributor of smokeless fuels, which already has products on the market containing a proportion of biomass material. Converting waste streams into value-added fuel products has both domestic and industrial applications. ERA institutions will continue to work closely with their industrial partners to demonstrate the commercial use of HTC technology to replace fossil fuels in home heating applications as well as investigating alternatives to coking coal in industrial applications such as foundries and smelters.

4. High Temperature Electrolysis and Reversible Fuel Cells

High temperature fuel cells (solid oxide fuel cells, SOFC) can be reversed in operation to act as electrolysers, splitting water into hydrogen and oxygen (solid oxide electrolysis, SOE). If the energy necessary to produce the required steam can be sourced from 'waste' heat, the efficiency of conversion from electricity to chemical energy in the shape of hydrogen can be close to 100%. SOE is therefore of high interest in the storage of renewable electricity. Additionally, these systems lend themselves to co-electrolysis of water with carbon dioxide, producing the same syn-gas as biomass gasification. In this way a loop can be closed between biomass on one side – being converted to syn-gas and SNG – and renewable electricity on the other, via SOE ending up in the same syn-gas, methanation and SNG. The SNG can then be seamlessly fed into the natural gas grid. This approach leads to a fully de-carbonised gas supply infrastructure that makes full use of the existing assets. At the same time the interim hydrogen and syn-gas products can also be converted into a variety of synthetic fuels, which can support decarbonisation of transport in the short term without the need to change the fuel infrastructure.

Using an SOFC in both fuel cell and reverse (electrolysis) mode is attracting increasing interest, as it leads to a single unit acting both as a fuel-to-energy converter as well as a fuel production unit. Future options include the use of these as grid balancing units in the function of flexible generators / loads in smart grids, as facile electricity storage units that convert electricity to fuel and back again at a longer time scale than for short term balancing and as energy storage devices for remote locations. In the latter case they can not only potentially deliver power and heat, but also transport fuels.



The government's Clean Growth Strategy emphasises the need for technologies like Carbon Capture, Usage and Storage to enable the UK to meet its post 2030 greenhouse gas emissions targets

Carbon capture

The government's Clean Growth Strategy emphasises the need for technologies like Carbon Capture, Usage and Storage (CCUS) to enable the UK to meet its post-2030 greenhouse gas emission targets, as agreed at the COP21 Paris climate change meeting. The UK Government have committed up to £100 million through the BEIS Energy Innovation Programme to CCUS innovation and deployment, and will create a ministerial led council, with industry, to review progress, monitor costs and explore deployment potential. The Government will also convene a "CCUS Cost Challenge Taskforce" to deliver a plan to reduce the cost of deployment. ERA institutions have recognised capability in CCUS research and innovation crossing all TRL levels, a position that ERA intends to capitalise on.

Capturing CO_2 before it is released into the atmosphere is a key R&D area for the University of Nottingham, Cranfield University and its geological storage within the British Geological Survey (BGS). The use of new, high capacity adsorbents capture CO_2 either pre or post combustion, compress then store it in geological structures deep below the seabed. This provides a widely recognised option for mitigating atmospheric CO_2 emissions. Cranfield University's pilot plant and associated techno-economic studies on low carbon power plants, aim to support the UK in minimising CO_2 emissions from power and energy intensive industry sectors, whilst the BGS has a world leading reputation for research in many key issues around geological storage. BGS staff have a wealth of expertise and experience that is recognised both nationally and internationally and undertake world-leading research into selecting and appraising storage locations, monitoring the storage location both in terms of deep and shallow monitoring, and simulating site behaviour using predictive models and advanced experimental models.

ERA is currently investing in the Geoenergy Test Bed (GTB), based at the University of Nottingham's Sutton Bonington campus, a national facility for future research, technology development and industrial equipment testing. Using this facility, there will be many opportunities to accelerate the development of technologies that reduce cost, increase efficiency and support deployment, all of which are directly aligned with the direction that the Clean Growth Strategy is taking. Two key projects are the ENOS and SECURe projects, which BGS have received with support from University of Nottingham, both of which will utilise the capabilities at the GTB. ERA is also currently funding the Research Acceleration and Demonstration Centre (the RAD building) on the University of Nottingham Jubilee Campus, which will be the home a biomass gasifier demonstrator with carbon abatement technology.

BGS are also key partners in the ELEGANCY project, which will provide cutting-edge practical solutions to key research and technical challenges to support the low-carbon economy through hydrogen production with CCUS in the UK. It will consider the systems and technologies needed to decarbonise power, heating and transport using molecular hydrogen (H_2) as a low-carbon fuel for heating, cooling, transport and industrial processes. The hydrogen is generated by the reformation of natural gas with offshore geological storage of the produced CO_2. In addition, BGS are the UK lead for the ALIGN project that is developing plans for optimised CO_2 capture at industrial clusters and storage sites in the North Sea.

Another interesting opportunity for ERA within this topic relates to combining its expertise within CCUS with the Bioenergy and Waste Conversion capability to undertake R&D in Bio-CCUS, where a carbon capture and storage project is combined with an industrial facility that burns biomass to create energy, or uses biomass as part of an industrial process, resulting in overall negative CO_2 emissions. Plants absorb CO_2 from the atmosphere and use this CO_2 to grow, through a process called bio-sequestration. When these plants are combusted to produce energy, the CO_2 is released back into the atmosphere. Energy produced from biomass is usually accounted for as 'carbon neutral', because it absorbs the CO_2, but then that CO_2 is released back into the atmosphere when combusted or processed. However, when the CO_2 from the combustion or processing of the biomass is not released into the atmosphere, but is captured and then stored in geological formations, this results in the net removal of CO_2 from the atmosphere, hence, negative CO_2 emissions.

ERA will investigate the combination of these two areas of expertise to leverage the capability that it has across the ERA institutions. Future R&D will focus on developing storage pilots that allow commercial operators to optimise injection and monitoring technologies and enable the research community to improve their understanding and ability to predict long-term site behaviour to reduce risks and consequent storage liabilities.

It is expected that hydrogen will play a key role in moving towards a sustainable alternative to petrol and diesel transport applications

Fuel cells

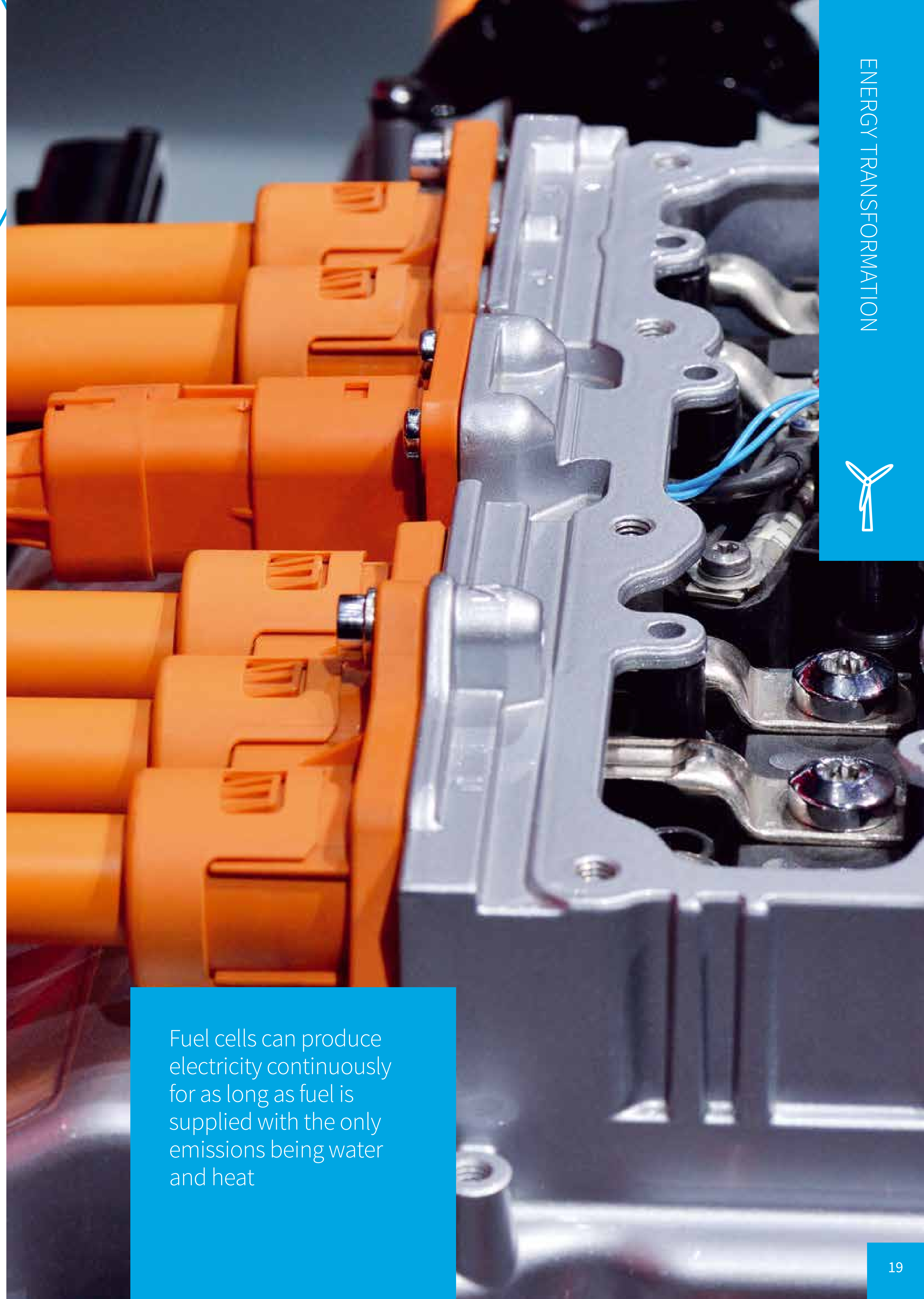
It is expected that hydrogen will play a key role in moving towards a sustainable alternative to petrol and diesel transport applications, but a major stumbling block to its widespread use is clean production and the need for new storage devices that can provide hydrogen where and when required. Fuel cells are the logical element in transforming the transport system by turning hydrogen into electricity for driving electric vehicles at high efficiencies. With ERA focusing on hydrogen production, hydrogen storage, biomass, and waste conversion synthetic fuels elsewhere in this document, it is logical to also focus on the use of such fuels in fuel cells. The Midlands region is strong in the development of fuel cell technologies and is host to several companies that produce fuel cells, fuel cell vehicles, or offer fuel cell technology consultancy. Hydrogen production via electrolysis results in virtually zero greenhouse gas and pollutant emissions if the electricity used is derived from renewable energy sources. Today's grid electricity is therefore not the ideal source of electricity since most of it is generated using technologies that result in greenhouse gas emissions and are energy intensive, thus creating a considerable 'carbon footprint' that does not reflect the potentially zero-emission character of hydrogen and fuel cell technology.

ERA institutions cover various aspects of fuel cell technology, ranging from materials research to the integration of full fuel cell systems on a variety of vehicles on anything from passenger cars to heavy duty, marine, rail vehicles, manned and unmanned aircraft. Fuel cells convert chemical energy from a fuel into electricity and are therefore distinctly different from batteries in that they require a continuous source of fuel to sustain the chemical reaction, whereas in a battery the chemical energy comes from chemicals solely present in the battery. Fuel cells can produce electricity continuously for as long as fuel is supplied, with the only emissions being water, heat and carbon dioxide, the latter depending on the fuel source.

The main problems addressed in ERA research today are the longevity of fuel cells (guaranteeing them for ten years of operation), reducing the cost, reducing the sensitivity to impurities in the fuel (as a result of reducing cost by reverting to 'cheaper', less pure fuels), increasing overall robustness and generally increasing performance with the goal to reduce system size and weight.

The Centre of Doctoral Training in Fuel Cells, directed out of the University of Birmingham, already ties together the activities of Loughborough University and the University of Nottingham, together with Imperial College and University College London. This group has proven to be an effective and powerful platform for research into fuel cells and hydrogen.

With hydrogen buses arriving in Birmingham, alongside a hydrogen refuelling station, electric vehicle charging stations, and the ERA funded biomass gasification demonstration plant at Tyseley Energy Park (which produces hydrogen from waste), this project is a key energy demonstrator for the region. With the broad industry base in the Midlands and with the fuel cell sector capabilities that have been growing over the years, ERA institutions are fostering a critical mass of expertise in the region. Improving fuel cell systems by increasing the temperature of operation and on the development of novel materials for high temperature cells enable them to potentially use natural gas, biogas and ethanol as a fuel. This new concept of transport fuels is far removed from today's infrastructure that practically solely relies on oil.



Fuel cells can produce electricity continuously for as long as fuel is supplied with the only emissions being water and heat

Energy in extreme environments

The challenge of energy generation in extreme environments on earth and in space, where other forms of energy generation are not feasible, enables different industry sectors to work together to develop innovative technology solutions. The ERA consortium has the expertise to design and develop technology solutions for harsh environments. Coupled with novel electrical and thermal energy storage technologies the solutions presented offer a technical solution for distributed power systems in critical infrastructure projects.

Extreme environments on earth are quite diverse, but share some common challenges linked to limited access to power grids and applications that require innovative solutions due to the inability to use fossil fuels or renewables. Examples include:

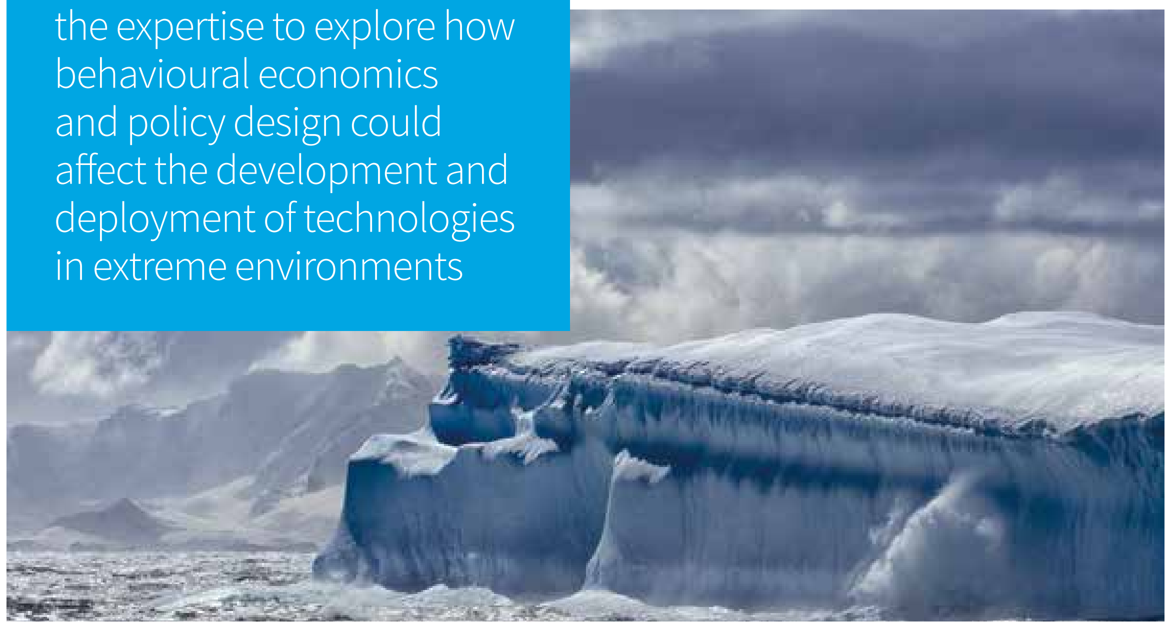
- the cryosphere where access to remote regions of the Arctic and Antarctic, for scientific and environmental purposes, is limited by the extended periods of darkness and the temperatures at which power generation and storage solutions have to operate
- volcanic regions where excessive temperatures and remote locations with limited infrastructure require power solutions that can operate continuously irrespective of day / night cycles and at high temperatures
- environments that store radioactive materials including geological repositories
- disaster monitoring in regions that suffer major catastrophic events, where self-powered sensors and monitoring systems can be deployed and can operate continuously without requiring access to the grid or other power generation infrastructure
- the colder, darker, distant and more inhospitable regions of the solar system where solar power cannot be used.

Differences in temperature can be exploited to produce electricity by thermoelectric generators, simple semiconductor materials with no moving parts tailored to the operating temperature requirements that they are mounted in. The UK has been leading the development of space nuclear power systems as part of a collaboration between the National Nuclear Laboratory (NNL) and the University of Leicester, Airbus UK, Lockheed Martin UK, Thales Alenia Space UK and Ariane Group. The technologies being developed are aimed at enabling a range of space missions that would not otherwise be possible. These systems are designed to use natural decay heat produced by the radioisotope americium-241 to produce electricity. The americium, which is an abundant constituent of the reprocessed separated civil plutonium stored at Sellafield, can be extracted by a chemical process developed by NNL, and has the advantage of purifying the plutonium, which can then be used for other purposes within the civil nuclear fuel supply chain.

Differences in temperature also exist in the Antarctic between the water beneath the ice and the surface of the ice; in volcanic regions where, high temperatures can exist beneath the earth's surface compared with atmospheric temperatures and in buildings between outer surfaces and inner spaces.

Adopting new technologies, even if there are economic, scientific or societal benefits, can sometimes present additional obstacles. The ERA institutions have the expertise to explore how behavioural economics and policy design could affect the development and deployment of technologies in extreme environments. The use of radioisotopes in power generation solutions presents a unique opportunity to engage with both the scientific and technical ERA community. ERA institutions continue to promote the convergence of energy storage (thermal and electrical) with energy transformation in the form of a thermo-electric generating prototyping activity. These solutions could provide a range of products that could be deployed for distributed power systems in critical infrastructure projects.

> The ERA institutions have the expertise to explore how behavioural economics and policy design could affect the development and deployment of technologies in extreme environments



Energy choices

Traditional energy generation in the UK has involved industrial scale power stations owned by large energy companies connected to the national grid. Reducing carbon from the UK's energy budget not only requires utilising many different new sources of energy but also generating capacity changing to small-scale distributed installations. Thus, renewable energy aids not just decarbonisation, but also resilience and security of supply.

There are multiple renewable technologies that may be suitable for installation in the UK, including wind turbines (at many scales), solar power, small scale hydro-power and heat pumps powered by either water or geothermal heat. Therefore, a tool that aids landowners or developers to choose which renewable energy technology is the most suitable for their site has obvious value. In a heavily populated nation like the UK, resource issues are not the only, or even most frequent, reason why planned developments are delayed or fail. At least as important are the multiple factors that affect decision making, including proximity to infrastructure and buildings; development controls in and around many types of protected landscapes (Sites of Special Scientific Interest, Areas of Outstanding Natural Beauty, National Parks etc); Limits on noise and proximity to radar to name just a few.

An example of the potential benefits related to the exchange of knowledge across the ERA institutions is the Innovate UK funded Data For Sustainable Energy (D4SE) project. This was developed through a collaboration between ERA institutions and the British Geological Survey together with a local SME – LQM Ltd and the not-for- profit Nottingham Energy Partnership. D4SE allows landowners, developers and consultants to assess the renewable potential of a site for multiple technologies, associated with a specific project area (currently limited to within the East Midlands). Using sophisticated WebGIS mapping technology, D4SE utilises multiple data streams and business intelligence to deliver a decision support tool. This improves decision making, eliminating impractical options and allows resources to be prioritised on realistic opportunities. These underpinning ideas are being further developed by BGS, collaborating with other ERA institutions, to identify new sites suitable to develop other energy technologies where geospatial factors are critical constraints (for example, proximity of industrial heat sources and buildings suitable for district heating) guided by new requirements from potential end-users.

D4SE highlights the needs to understand the total market, the opportunity that this presents and potential charging mechanisms. Testing this using case studies from across ERA is providing much more targeted advice.

Alternative energy vectors

In addition to the main Energy Transformation vectors described above, the ERA institutions also demonstrate significant world leading capabilities in other less mature, but still significantly important forms of energy transformation. Hydrogen production through the hydrolysis of water in fuel cells, synthetic natural gas production (SNG) through the synthesis of methane using hydrogen and the production of synthetic transportation fuels from Bioenergy processes are all important future technologies that the ERA institutions are investing heavily in. The concept of using hydrogen to serve as a chemical raw material that can be used directly or be converted into fuel for end use heating, electricity or transport is a ground-breaking, disruptive technology that ERA will continue to develop. In parallel, biomass and other organic hydrocarbon wastes (including many plastics and industrial wastes) that can be converted to hydrogen-rich gases that consist of methane (biogas) or that can be synthesised to SNG, could also present significant energy transformation opportunities for ERA in the future.

ENERGY STORAGE

OBJECTIVE

To make major contributions in advancing several different energy storage technologies thus enabling net-zero carbon energy utilisation to become both technically viable and affordable.

By harnessing the concept of energy storage and smarter business models, the UK has the opportunity to have one of the most efficient, productive energy systems in the world. The upgrading of the country's energy system is an important part of the Government's Industrial Strategy as reducing energy costs through the efficient integration of innovative technologies contributes significantly to raising productivity throughout the economy. The transition towards clean and flexible energy systems is a global trend, presenting a significant industrial opportunity. Energy storage can open up many possibilities, helping to integrate low carbon generation, reduce the costs of operating the system and help avoid or defer costly reinforcements to the network.

As previously discussed, the ERA investment in the RAD building in Nottingham will be the home of various energy related R&D facilities. One of these will be an integrated energy storage lab, and through this capability area, ERA plans to maximise the cutting-edge technology development that takes place in this unique UK facility.

The 'Energy Storage' capability area is focused on developing different forms of energy storage technology to support this changing landscape.

The scope of the R&D described in this Capability Area aligns very strongly with the ISCF challenges of **"Prospering from the energy revolution"**, **"Faraday battery challenge, clean and flexible energy**" and **"Manufacturing and materials of the future"**. This will form the basis of ERA attention moving forwards.

Social, business, economic, behavioural and environmental impacts

Hydrogen (H_2)	Thermo-mechanical	Thermo-chemical	Electro-chemical	Hybrid systems	Generation integrated

<<<<<<<< ENERGY STORAGE >>>>>>>>

Hydrogen

Hydrogen is used in a wide variety of industrial applications and as such, efficient, cost effective methods for the production and storage of it in a less energy intensive way than that which exists today would be a key shift towards a cleaner and more sustainable society.

The cost of wind and photovoltaic power has continued to drop across the past decades, so much so that they have now become one of the most cost-effective sources of energy in use today. Their inherent variability though, requires additional effort in matching power generation and load above the traditional mechanisms already in place for balancing load variations. In times of excess electricity production from wind farms for instance, generation is commonly curtailed. Nevertheless, in contrast to today's conventional approach, it should be possible to use excess wind, solar and other renewable electricity to produce and then efficiently store hydrogen. Since renewable electricity can be relatively well predicted 24 hours ahead, the expected power generation could be introduced to the power system scheduling as 'firm power'. Hydrogen and other storage devices can then be used to eliminate the forecasting error thus turning renewable electricity production into a 100% reliable contribution to the grid. Work at the University of Birmingham is concentrating on ways to predict renewable power generation and manage hydrogen storage systems. Locating equipment of this type close to renewable sources offers an attractive mechanism to increase the commercial viability of wind power. High-temperature electrolysis offers a high efficiency option to produce hydrogen from renewable electricity (Power2Gas). Turning renewable electricity into a gas that can be easily stored and returned to electricity at high efficiencies opens up a number of pathways to interlink the three currently distinct markets of electricity, heat, and transport fuels (sector linking). Hydrogen therefore can also contribute to considerably reducing the carbon footprint of the transport system and of domestic heating.

ERA is currently investing in the Hydrogen Systems Test Bed as part of the current capital investment programme. This is a flexible test facility for the evaluation of hydrogen as an energy source and energy storage medium. The University of Nottingham plays a significant role in hydrogen system research that includes solid state storage technologies and the development of new materials used in hydrogen stores. This includes various high temperature hydrides used in thermal energy storage plants and high-pressure hydrides for low noise hydrogen compressors. As the Hydrogen Systems Test Bed comes on line, ERA institutions will have access to world leading R&D test equipment that will enable a further step change in capability in this sector.

Thermo-mechanical

Thermo-mechanical energy storage embraces a wide spectrum of technologies using only the principles of mechanics and thermodynamics to store energy. Pure thermal storage refers to the storage of heat or coolth (coldness) for direct use later. This is quite distinct from the storage of heat or coolth for the purposes of recovering work – usually to generate electricity.

1. Thermal Storage for direct use

Heating and cooling dominates society's use of energy. 45% of total final energy consumption in the UK is currently used for heating purposes with approximately 80% derived from fossil fuels. The European Commission's Heating and Cooling Strategy[2] recognises that each sector has the potential to reduce demand, increase efficiency and shift to more renewable sources. In most cases, the temperatures are not far from the normal range of ambient temperatures and the range -40ºC to 100ºC would cover over 95% of all requirements. The heat/coolth required here is therefore described as low-grade heat/coolth. One very good aspect of low-grade heat/coolth is that of water, which with very inexpensive additives, can cover the temperature range and this potentially makes the storage very affordable. This topic is a particular strength of the University of Nottingham and the British Geological Survey.

Another capability that ERA has, predominantly through BGS, is in relation to geological heat storage. Underground Thermal Energy Storage (UTEL) uses geological strata ranging from soil or sand to solid bedrock and aquifers to act as the ultimate store. Technologies include aquifer thermal energy storage (ATES), where the heat (or cold) storage medium is the water and the substrate it occupies. Germany's Reichstag building has been both heated and cooled since 1999 with ATES stores. In the Netherlands there are > 1,000 ATES systems. BGS has initiated lab experiments on the feasibility of UK wide high-temperature underground storage but the regional potential of the Midlands has not yet been explored.

2. https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling

45% of total final energy consumption in the UK is currently used for heating purposes with approximately 80% derived from fossil fuels

2. Thermal Storage methods for exergy

Exergy is the thermodynamic term used to represent mechanical work or electrical energy. Although heat and exergy are measured in Joules (J), they are very distinct. A very large amount of low-grade heat may contain very little exergy. e.g. 1000 J of heat at 50ºC above ambient has <150 J of exergy. For exergy storage, high-grade heat and coolth are used. This high-grade heat/coolth can exploit both latent heat phase-change (for example, melting of aluminium at 660ºC, freezing of ethanol at -114ºC). Three of the main grid-scale thermal energy storage technologies under development include Cryogenic Energy Storage (CES), Heat Energy Storage (HES) and Pumped Thermal Electricity Storage (PTES).

Cryogenic Energy Storage (CES) can use different storage media including air, nitrogen, natural gas or even some organic liquids. The most developed CES technology uses nitrogen, which stores high grade cold in the form of liquid nitrogen at an extremely low temperature of about -196ºC. For routine commercial use, CES would probably use liquid air and would re-vaporise this mixture to release all of the energy used to liquefy it. The ERA Institutions, and the University of Birmingham specifically, are internationally leading in CES research and development. CES is currently at pre-commercial stage. A 350kW/2.5MWh full pilot plant has been built by Highview Power Storage Ltd, on the University of Birmingham campus and has demonstrated feasibility. The company is currently building a larger scale plant rated at 5MW/15MWh.

Heat Energy Storage (HES) High energy densities and acceptable round-trip efficiencies are also achievable through storing high-grade heat. Temperatures up to 600ºC are familiar in power-generation contexts and so this same range is the primary target. The thermal store format may simply use sensible heat (typically in packed beds of rock). The Universities of Nottingham and Birmingham have collaborated on projects to evolve low-cost heat stores based on rock beds in non-pressurised containments. Alternatively, the thermal store may exploit some latent heat - typically using encapsulated phase change materials to concentrate enthalpy in tight temperature ranges and these have been explored extensively at the University of Birmingham.

Pumped Heat Energy Storage (PHES) systems feature both a hot and cold store. A particular feature of these systems is that in charging or discharging, there is negligible net heat exchange with the environment. That heat exchange is a noteworthy bottleneck in the case of both the CES and HES systems described above. Within the UK there is a rich legacy of understanding of how extraordinarily cost-effective a pure PTES system can be. Through their work on adiabatic compressed air energy storage systems, the Universities of Leicester, Birmingham and Nottingham have developed a very particular and unique insight into the integration of thermal energy storage facilities within compressed air energy storage plant.

All of the above thermal exergy storage configurations share the characteristic of being suited for charge/discharge timescales in the order of 4 hrs – 24 hrs. For shorter periods, the marginal costs of the power-conversion equipment would become prohibitively expensive. Another characteristic shared by all of these configurations is that they have very strong potentials for integration with other elements of the energy system as a result of heat flows. The Universities of Birmingham, Loughborough, Nottingham and Warwick have leading expertise in research, development and demonstration of thermal energy storage technologies and systems. Their research groups are involved with several large collaborative projects in the UK and are partners on numerous other £1m+ projects. Each University works closely with industry to demonstrate and test the innovative technologies.

3. Purely mechanical approaches to energy (exergy) storage.

No modern discussion on energy storage would be complete without some mention of pumped-hydro, compressed air energy storage (CAES) and kinetic energy storage systems (KESS) involving flywheels. Pumped hydro is highly location-specific and is under very active development by researchers in countries where the natural geography is favourable. The ERA institutions deliberately eschew working directly in this area because the scope for additional impact in the UK is minimal. By contrast, there is strong activity on CAES and KESS.

Compressed Air Energy Storage (CAES) involves compressing air, storing it and managing the subsequent heat generated. The "High Performance Compression & Expansion Laboratory" in the ERA-funded RAD building at Nottingham, will house facilities for the development and evaluation of high efficiency gas compression and expansion – mainly motivated by the potential of storage. The University of Nottingham has worldwide leadership in underwater storage of compressed air in so-called "Energy Bags" and BGS has obvious authority in the area of understanding potential resources associated with UK salt deposits for both CAES and exergy storage applications.

Kinetic Energy Storage Systems (KESS) are predominantly implemented in the form of flywheels. Most flywheels are designed to spin at very high rotational speeds to use the strength of the rotor material fully. Work within the ERA institutions is addressing the design of very large flywheels that spin at the relatively low speed of 1500rpm, aimed at restoring real inertia to the electricity grid to solve the problem of reducing inertia through the retirement of conventional generation in favour of wind turbines and photovoltaic panels.

Thermo-chemical

The universities of Warwick, Birmingham, Nottingham and Loughborough all have activities connected with exploiting the two-way transformation between heat and chemical state. Typically, injection of heat causes complete separation of two components and the re-combination of those components enables heat to be released. These systems have the potential for very long-term storage and transportation of heat. By keeping the components well-separated, such energy storage systems have a feature of virtually zero self-discharge. An example of this is the metal-hydride work at the Universities of Nottingham and Birmingham where heat injection drives hydrogen out of a metal hydride and the heat is recovered by re-introducing hydrogen to the powdered metal.

Electro-chemical

ERA has already made a significant investment into joining up the value chain for electro-chemical energy storage, or battery storage, from materials to integration. This value chain covers many aspects of fundamental science and engineering, including materials, materials processing, electrode engineering, cell engineering and testing, module and pack assembly and finally the recycling and 2nd life aspects of cells after use. These activities align with the current Industrial Strategy and Faraday Challenge and provide a hub in which different research groups and industrial partners can interact at various stages of development. The knowledge and resources within ERA can aid the progression in the value chain and rapidly accelerate the development process. This capability to support R&D from raw materials to end of life is unique in the UK, highlighting the requirements for the interconnection of many disciplines and differing aspects of electrochemical energy research from materials, devices and simulation.

Battery storage facilities are one of the key components of new, smart energy systems. They not only offer facilities to house electricity for periods of peak demand, they also make it easier to connect renewable energy sources to the grid, free up network capacity and reduce electricity prices. Battery storage facilities are attracting increasing attention from both policy makers and network operators, who recognise that they are becoming an efficient way to help secure the UK's future energy supply. For electrode design and fundamental research, a significant quantity of material is required to obtain repeatable results for further optimisations, which is beyond the capacity and capability of most research labs. Hence ERA is keen to focus on materials synthesis research and fundamental engineering research in powder scale-up and processing in order to obtain a consistent material for these aspects of cell development.

ERA has already made a significant investment into joining up the value chain for battery storage, from materials to integration

In addition to these early TRL research questions, ERA institutions also focus on moving towards applied research and demonstrating this technology in real devices. The research questions the testing and validation of these technologies in a real drive cycle, enabling information relating to the failure and degradation mechanisms of these devices to be researched. Through forensics and diagnostics, the ERA institutions can elucidate cause and effect, which can lead to improved operation, or improvements in the materials and chemistries. The understanding of these degradation mechanisms upon the breakdown of the chemistries within these cells through novel diagnostic techniques and forensic analysis, can give insights into further materials and hence performance improvements for a range of applications. In addition to this there is also a major opportunity within the Faraday Challenge to address the issue of delivering a circular economy for batteries focused on recycling and the recovery of recyclable materials. This work includes both the Universities of Warwick and Leicester and is supplemented by contributions from BGS relating to the management of risks at the beginning (and end) of the supply chain. As the volume of battery manufacturing ramps up in the UK and elsewhere, security of the primary supply of lithium and other metals may be at risk. BGS are the UK custodian of not only the borehole core and associated downhole data relating to minerals, rock type and properties but also have the knowledge of UK and worldwide mineral statistics. BGS is also researching the availability and sourcing of rare earth elements, including lithium, and on the extraction of critical metals from deep geothermal waters.

The industrial opportunities are immense and represent a significant opportunity for ERA. There is a pull from industry for a new generation of high performance batteries designed to be more economic and stable yet boast higher energy density levels than those currently available on the market. This is fuelled by the growth in the UK automotive industry, where the increase in sales of electric and hybrid vehicles is likely to exceed capacity of the cell manufacturing supply chain in the next few years.

ERA institutions are already playing significant roles in the Faraday Challenge. The University of Warwick is included in two projects looking at extending battery life and battery system modelling. The University of Birmingham is working with the University of Leicester, and others, in order to facilitate a circular economy for lithium ion batteries. The projects are striving to establish the technical, economic and legal infrastructure to make the recycling of 100% of the materials contained in lithium ion batteries from the automotive sector possible.

In addition to the energy storage work at Warwick, ERA also has strengths relating to new cell chemistries, novel electrolytes and materials, metal deposition and the dissolution process. Within the University of Leicester's Materials Centre, work on ionic liquid electrolytes is exploring the safety and performance of cell materials as well as the recovery of metals for recycling. Utilising its strong links into industry, with both cell testers and battery recyclers, Leicester is playing a significant role in the Faraday Challenge and on other key Horizon 2020 and Innovate UK funded projects.

By continuing to support the development of state of the art testing facilities at Warwick University, coupled with key R&D activities on future emerging cell chemistry technologies being undertaken at the University of Leicester, institutions will further develop their understanding of the processing of materials, electrode formulations and testing. This will also help to advance knowledge on the circular economy when applied to electro-chemical energy storage.

Improvements in the following key performance areas are all being actively worked on in ERA institutions and will be key for any future automotive adoption 'at scale' to take place:

- **Cost reduction** – more than 50% reduction in cell and pack price
- **Energy density** – a doubling of energy density per cell
- **Power density** – a fourfold increase in power density of each power pack
- **Safety** – improvement in the thermal runaway at pack level to reduce pack complexity
- **1st life** – a doubling in the lifetime of packs from 8 to 15 years
- **Temperature** – a widening of the temperature range over which cells can efficiently operate
- **Predictability** – an improvement in the predictability of performance of in situ and aging batteries
- **Recyclability** – an increase from the current 10-50% recyclability of battery materials to circa 95% levels.

Hybrid systems

A consensus among all who work on energy storage technology development is that they span a wide range of timescales, energy scales and power-scales. No one single technology is a panacea for all cases. Hybrid systems enable the best of two or more component systems to be extracted resulting in the benefits associated with the combined system being more than those of the individual components added together. One example would be the integration of Liquid Air Energy Storage (LAES) and CAES. The LAES, for which the University of Birmingham has world leading expertise, provides the potential for several tens of hours of energy storage whilst the CAES system provides shorter-term but higher-efficiency storage. Another example is the integration of flywheel energy storage with CAES, where the flywheel system delivers highly robust very short-term, high efficiency storage (providing "real inertia" to the grid), whilst the CAES gives some extended-duration storage enabling the flywheel to vary significantly in speed from the synchronous generator to which it is connected. used to develop electricity from fuel cells.

Generation integrated

The UK's electricity supply system has always depended fundamentally on storing energy in a compact form close to the generation plants and releasing the energy into the form of electricity when demand is high. Traditionally that compact energy form has been stored as fossil-fuels, but other alternatives exist. The University of Nottingham is pioneering cost-effective Generation Integrated Energy Storage (GIES) systems for wind energy, enabling 100hrs of storage to be implemented with large wind turbines (using storage of both heat and coolth). The Universities of Loughborough and Birmingham are each developing thermal storage approaches that can be combined with conventional thermal power stations such as nuclear power plant or fuel-combusting stations. Work at the Universities of Loughborough and Nottingham is also underway to exploit sunlight directly to achieve/assist hydrogen production where the produced hydrogen can be used to develop electricity from fuel cells.

END USE ENERGY DEMAND

OBJECTIVE

To develop innovative technologies, incorporating social and economic considerations and appropriate business models, that will help to reduce UK emissions and lower the amount of energy demanded by both industrial and domestic end users.

The 'End Use Energy Demand' capability area focuses on many different potential energy vectors that all need to be optimised and challenged if the UK is to meet its ambitious carbon reduction targets. End Use Energy Demand is focused on providing energy in a particular way that ensures that demand is met in an efficient, low carbon manner. Cities represent three quarters of energy consumption and 80% of CO_2 emissions worldwide and represent the largest of any environmental policy challenge. The UK has a stock of aging and poorly insulated homes that significantly increase energy use. This, coupled with a strong customer affinity for existing gas heating systems, and a non-punitive UK tax system for domestic gas use, means that the challenge facing the UK to make significant inroads into this carbon dioxide source is significant. However, to accelerate the provision of low cost, low carbon housing this work needs to be underpinned by research and large-scale demonstrators. Actual demonstrators must involve real consumers in order to offer researchers the opportunity to access real data, understand real constraints and hence enable development of a robust pipeline of the very best generation of research leaders.

Despite best intentions, current demand and the need to ensure energy security will see the UK continue to rely on fossil fuel resources for some time. This means that work to find cleaner and more efficient methods of using conventional fuels and research into capturing and storing the resulting carbon is vital. The 'End Use Energy Demand' capability area will look to continue to gain leverage from the world class research base of the ERA institutions coupled with the unique, physical ERA facilities that are currently being developed.

The scope of the R&D described in this Capability Area aligns very strongly with the ICSF challenges of **"Transforming construction"** and **"Manufacturing and materials of the future"**. With which ERA will focus on moving forwards to secure ISCF support.

Social, business, economic, behavioural and environmental impacts

Community energy schemes	Energy efficiency in the built environment	Heating and cooling	Transport

<<<<<<<< END USE ENERGY DEMAND >>>>>>>>

Community energy schemes

The Nottingham Waterside Trent Basin Community Energy Scheme has provided an experimental environment on a large urban regeneration site. This Community Energy demonstrator helps to understand where and how efforts should be focused to reduce energy usage. It aims to increase domestic energy efficiency and energy security through smart technologies and innovation.

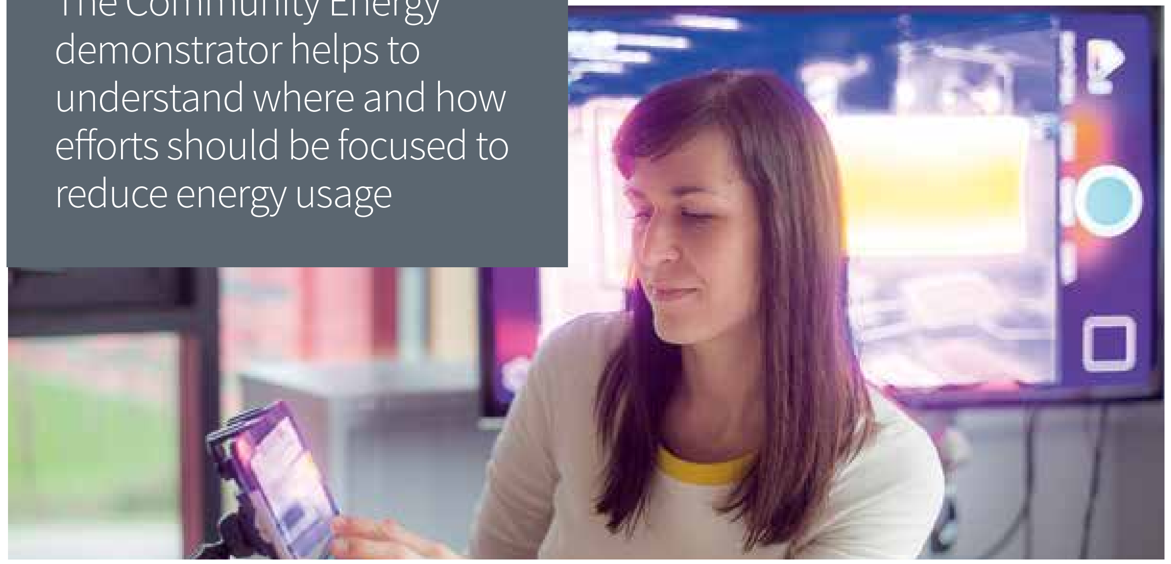
The Community Energy Project in the Trent Basin consists of 240 affordable houses on one of the largest former brownfield sites in Europe. ERA institutions are currently ensuring that these houses are built with efficient use of clean energy as the centre of their design rather than added afterwards and that the homeowners are engaged with the innovative research projects that are taking place. Each resident is fully aware of the innovative nature of the development but have the option of opting in or out of the 'Community Energy Scheme'. To date there has been 100% uptake by residents. The project brings together the ambitions of Nottingham City Council, a private developer, academia and industry to redevelop a long neglected area. It is acting as a major catalyst for change and creating a model low energy community that could be replicated at many other UK sites. The uniqueness of this demonstrator comes from the combination of real homes owned by members of the public, that have an integrated smart heat and power microgrid, ultra-low energy demand buildings, that incorporate a large community energy storage capability. This is a lighthouse project for the UK, spurring on industry to meet the Government's ambition of having, by 2020, one million homes sitting on microgrids with a local community energy production capability.

The developments at Trent Basin could also easily be translated to other Community Energy Schemes across the UK. As part of Birmingham's Energy Capital initiative there are plans to redevelop the Wolverhampton Canalside Quarter with the construction of new best-in-class energy efficient houses. With integrated solar, battery storage, EV charging and smart technology (for energy monitoring, control and use), the technology mirrors that of Trent Basin. Transferring learning and experiences relating to how technologies perform when real people live in real homes, from one scheme to another, is an important opportunity for ERA. A longer aspiration is for ERA to move towards a user-centered design where the needs of the user are used to develop the technology rather that designing in the abstract and then testing it on people.

The key to sustainable energy costs, particularly in affordable housing, is to develop and deliver such user-centred technologies (that suit both the new build and retro-fit sectors) that can continue to demonstrate the latest ideas. Nottingham Waterside Trent Basin provides an opportunity to trial innovative technologies in real households and businesses, especially in future stages where an additional 2380 homes will be built and put on the open market. Such scale would create replicable templates for housing and community energy schemes throughout the UK whilst providing a potential platform for de-risking technology, modelling, testing new devices and ensuring that data and user feedback is captured, analysed and used in future decision making.

Given Government targets for carbon reduction in new homes and the need to retrofit 25 million homes by 2050, there is enormous potential for job and wealth creation through the development and manufacture of new smart energy technologies that have been designed with people in mind, energy refurbishment technologies and new low cost low carbon homes.

The Community Energy demonstrator helps to understand where and how efforts should be focused to reduce energy usage



Job creation, especially through apprentice training opportunities in the manufacturing sector, would also thrive, as local companies get early opportunities to manufacture smart energy technologies. The establishment of a potential Centre for Residential and Community Energy Research, that includes at the heart of it social science as well as technology development, could create a critical mass and link it with taught courses to train the next generation of researchers and professionals capable of delivering sustainable communities, designed with the user at the forefront. Any Nottingham Waterside Trent Basin based education programme would have a multidiscipline approach, driven by actual end user feedback coupled with technical demonstration capability, not just theoretical scenarios developed in a university setting. The Trent Basin test bed is unique in the UK and should encourage universities to push the social and technological boundaries that engage with actual people as actual users.

ERA institutions are now focusing on potentially developing Nottingham Waterside Trent Basin into a virtual 'Centre for Residential and Community Energy Research' such that the technological advances developed in phase 1 of the development can be rolled out to all future phases. They will also interface closer with the Energy Capital initiative to ensure that ERA continues to play a key role in its establishment, specifically with the integration of Community Solar Hot Water, EV Charging Points and Passivhaus technology. It is essential that all future phases of Trent Basin and Energy Capital are completed with real households engaging with innovative technologies that are trialled in each new phase. Technologies, such as ground source heat capture from the River Trent and data analytics in support of community Health and Wellbeing programmes, could all be fully integrated into the developments and building performance monitoring systems made active across the community.

Energy efficiency in the built environment

People using energy in the Built Environment is a significant contributor to greenhouse gases, with the energy use within buildings in the UK accounting for over 50% of CO_2 emissions. Whilst there is a considerable amount of work in the region on the technologies for new houses, just as relevant are the issues associated with improving existing infrastructure, particularly the 25 million homes that exist today, most of which will still be in use in 80 years' time. Addressing the issues of fuel poverty in some sectors in society, reduction of the national energy demand for heating, and increasingly cooling, and understanding from a social science perspective why projects and technologies in this area have often failed are all key future challenges. How existing buildings have to be adapted to become more energy efficient is now a major challenge. Future phases of development of the Nottingham Waterside Trent Basin will include new house technology that connects into existing housing stock adjacent to the site. The Trent Basin will become an exemplar of how older 'harder to treat' properties can adopt new, innovative energy technologies. But clearly, this in only a part of the challenge that is just as much about social and economic considerations as it is about technical ones. The dissemination of ideas, manufacturing techniques, engagement with real people living in real houses and training lies at the heart of the process that could encourage the creation of locally based 'whole house retrofit' companies. These would employ local people and would be able to apply local knowledge to the wholesale retrofitting of existing housing.

One key opportunity identified for the retrofit market that ERA has strength in is the development of high performance materials and nanomaterials. These maintain their essential properties while providing additional capabilities such as enhanced durability, lightness, tensile strength, conductivity, insulation, roughness and resistance to high radiation and temperatures.

Image © Lewis and Hickey, Architects.

In recent years, industry has had some success in developing high performance materials for insulation with products including aerogel and vacuum insulation panels. There are many potential uses for nanomaterials in the built environment due to their inherent strength, light weight and insulting properties.

ERA is currently funding the RAD building on the University of Nottingham Jubilee Campus, which will be the home to, amongst other facilities, a multidisciplinary lab developing new devices from novel energy materials. This RAD building is one of the first research centres to combine the rigorous sustainability standards of BREEAM (Building Research Establishment Environmental Assessment Method) with the principles of the German Passivhaus system. Passivhaus is based on the creation of a building with excellent insulation and a high level of airtightness, in which air quality is maintained via a whole building mechanical ventilation system.

Passivhaus is based on the creation of a building with excellent insulation and a high level of airtightness in which air quality is maintained through a whole building mechanical ventilation system

In addition to the technical aspects of retrofitting into the built environment, understanding the social contexts of decisions is also an increasingly important consideration for companies. It is key for social scientists and engineers to work together to understand better the broader aspects of energy technologies in society, including any unanticipated consequences. By doing this, researchers are beginning to understand how people interact with new technological systems and how learning from users will shape future designs. ERA institutions continue to undertake research that brings together architects, engineers and social scientists to develop cutting edge technologies, including new high-performance / nanomaterials, that are compatible for retrofitting into existing houses, factories and industrial properties.

Heating and cooling

CO_2 emissions from domestic heating represents a significant proportion of the UK greenhouse gas (GHG) emissions. 55 million tonnes of all of the emissions are from domestic gas boilers amounting to 15% of UK CO_2 and 12% of total greenhouse gases. Hence any technology that helps to address this is a key enabler for future CO_2 reductions. A heat pump uses energy to heat a house with more than 100% 'efficiency' by pulling in heat from the outside air or the ground. Heat pumps, which are predominantly electric or gas driven, have 30-40% less fuel consumption, running costs and emissions but are not currently capable of being considered to be direct replacements for gas boilers. There will be a need for both gas and electric heat pumps for a long time and the exact mix will depend on the quantity and source of future zero carbon electricity. The mix is difficult to predict but both technologies are needed to ensure flexibility to adapt to an uncertain future. The electrical grid would not be able to cope with a complete move to electric heat pumps as the required infrastructure upgrades would be vast. The universities of Warwick and Loughborough are currently working together, with other UK institutions, on a Research Council funded project called i-STUTE, an interdisciplinary centre for Storage, Transformation and Upgrading of Thermal Energy. It develops technologies that aim to reduce energy consumption and deliver cost-effective heating and cooling that will help the UK achieve its target of a reduction in greenhouse gas emissions of 80% by 2050. i-STUTE brings together cutting-edge engineering advances with economic, behavioural and policy expertise to produce solutions that are both technically excellent but also appealing to business, end-users, manufacturers and installers. Over the next 12 months ERA institutions will continue to focus on using interdisciplinary Gas Heat Pump research into actions closer to market deployment, together with more technical based research in lower TRL solutions that offer significant improvements in performance.

19% of UK electricity is used for cooling and the proportion is rising both in the UK and worldwide. As it is predicted that the energy used for cooling will exceed that used for space heating within 50 years, it is key that the UK assesses what approaches could reduce and decarbonise energy use in this sector. The University of Birmingham is expanding multi-disciplinary research into Clean Cold through a variety of cutting edge technological applications and consideration of user requirements and demand management.

Transport

With greenhouse gas emissions from transport representing over 20% of total UK domestic emissions, decarbonising transport must be part of any end user energy demand solution. Moving to a low carbon transport system presents huge opportunities; not just for climate change but for the UK's prosperity, health, and the wider environment. Good transport systems and services are fundamental to the economy and quality of life but have adverse impacts on the environment. Low carbon travel must become a genuine, viable and attractive option for businesses and people.

Across the ERA institutions, investment in many different low carbon transportation options are taking place as has already been discussed in this document under Hydrogen storage and Biomass / Waste Conversion. In addition to these the University of Nottingham Electrical Drives Centre already works extensively with industrial partners on the design and advancement of electrical machines and drives for use in transport applications. The University of Warwick have a considerable focus on the study of propulsion technology for hybrid and electric vehicle applications in the automotive industry: internal combustion engines, electric machines and their associated control mechanisms and are clearly leading the approach through the Faraday projects that have recently been announced, in partnership with other ERA institutions.

All of these individual projects and areas of focus collectively result in ERA demonstrating significant capability in its efforts to reduce the carbon impact associated with different forms of transport.

CO_2 emissions from domestic heating represents a significant proportion of the UK greenhouse gas emissions

ENERGY INTEGRATION

OBJECTIVE

To address technological challenges that enable energy systems to be fully integrated at scale, such that they are smart, flexible, socially acceptable and capable of realising the opportunities afforded to them by future advances.

As we move to a smarter, more flexible energy system we need to ensure that the opportunities afforded by future advancements in technology are acceptable to society and can be realised. Existing energy systems were not designed with new forms of smart technologies in mind and the manner of meeting demand is highly time-of-day sensitive, as is the scale of the demand. A solution to a small residence or collection of properties is completely different to that of a town or city. With the appropriate licensing, planning connections, user engagement and charging mechanisms, smart systems empower consumers by ensuring households and businesses can use energy when it is cheapest and reward them for being flexible when they use energy. Domestic electricity consumption varies over a day, and industry, businesses and schools, etc. have other time-varying power signatures that further complicate the energy distribution system. These contribute to an overall electricity consumption profile, which varies on a daily and weekly basis, and has been traditionally matched by ‘dispatchable’ generation – i.e. generation from fossil fuel resources, such as large power stations that are centrally controlled and can respond quickly to changing operating conditions. Over the next two decades energy transmission and distribution systems must maintain this high-level of system resilience (and low energy cost) whilst adapting to five major changes:

- A move to renewable energy resources that are intermittent
- Decentralisation of generation (for example, ranging from PV systems – domestic and solar farms – to biomass generation at the user end of the electricity system
- Increasing electrification of transport (for example, tram, electric vehicle)
- Increasing electrification of heat (for example, heat pump systems)
- Increasing levels of electrical energy consumption

The ‘Energy Integration’ capability area is a new area for ERA to focus on, and is not currently being funded as part of the Innovate UK capital investment. However, analysis has shown that ERA does have significant strengths in this area and could leverage these specific capabilities such that it can take advantage of the opportunities that could emerge. Any effective, efficient future energy system must be acceptable to the users it is aimed at as well as including many facets of the research and technologies explored in the four ERA Capability Areas detailed within this document.

Social, business, economic, behavioural and environmental impacts

Flexible energy systems	Power electronics and control	Gas use and distribution	Thermal energy distribution

<<<<<<<< ENERGY INTEGRATION >>>>>>>>

Flexible energy systems

Upgrading the energy distribution system to make it smarter and more flexible is a key part of the Industrial Strategy. The government has committed to developing a business environment where new entrants to the market can compete. ERA’s energy demonstrator capabilities and academic excellence positions it well to benefit from the additional government focus and investment.

Flexible Energy Systems, or the holistic management of energy over an entire system, bring together a variety of electrical energy sources and methods of production, distribution and intelligent metering in order to minimise energy demand, share resources and optimise efficiency. Over a quarter of the UK’s electricity is being generated through renewables such as wind and solar, much of it located close to homes and businesses. It is essential that technologies that help store and manage energy are developed and tested such that they are fit for the future. Consistent with the ERA mission of supporting a suite of physical energy demonstrators, ERA intends to develop this capability area into a series of university-based demonstrator sites that will involve a variety of wide ranging power and energy consumption patterns including:

- Domestic halls of residence and other individual residences
- Commercial, academic and administration departments
- Industrial engineering and science laboratories including equipment with high power consumption profiles that are representative of industry
- Transportation bus services between campuses

Laboratory scale, real-time emulation of a smart campus can provide a safe environment for testing equipment/algorithms before commercial deployment. University campuses contain different consumer elements found in a typical electricity distribution system and, having peak power demands of several megawatts, would be considered to be a large-scale system. This makes them ideal platforms for demonstrating both the challenges and solutions of future energy systems. Keele University has recently won funding from ERDF and BEIS to reduce the carbon footprint of its 600-acre campus by 30% by 2021. The new target has to be achieved even if the population on the campus increases. The plan is to introduce significant amounts of renewable energy and to integrate the various energy vectors together. As a consequence, there are opportunities to develop Keele as a living test bed where energy innovation can be trialled. These opportunities need to recognise however that delivering the 5MW of clean power is a precondition on keeping the ERDF money, so a relatively conservative approach is likely to be taken until the 5MW limit is passed.

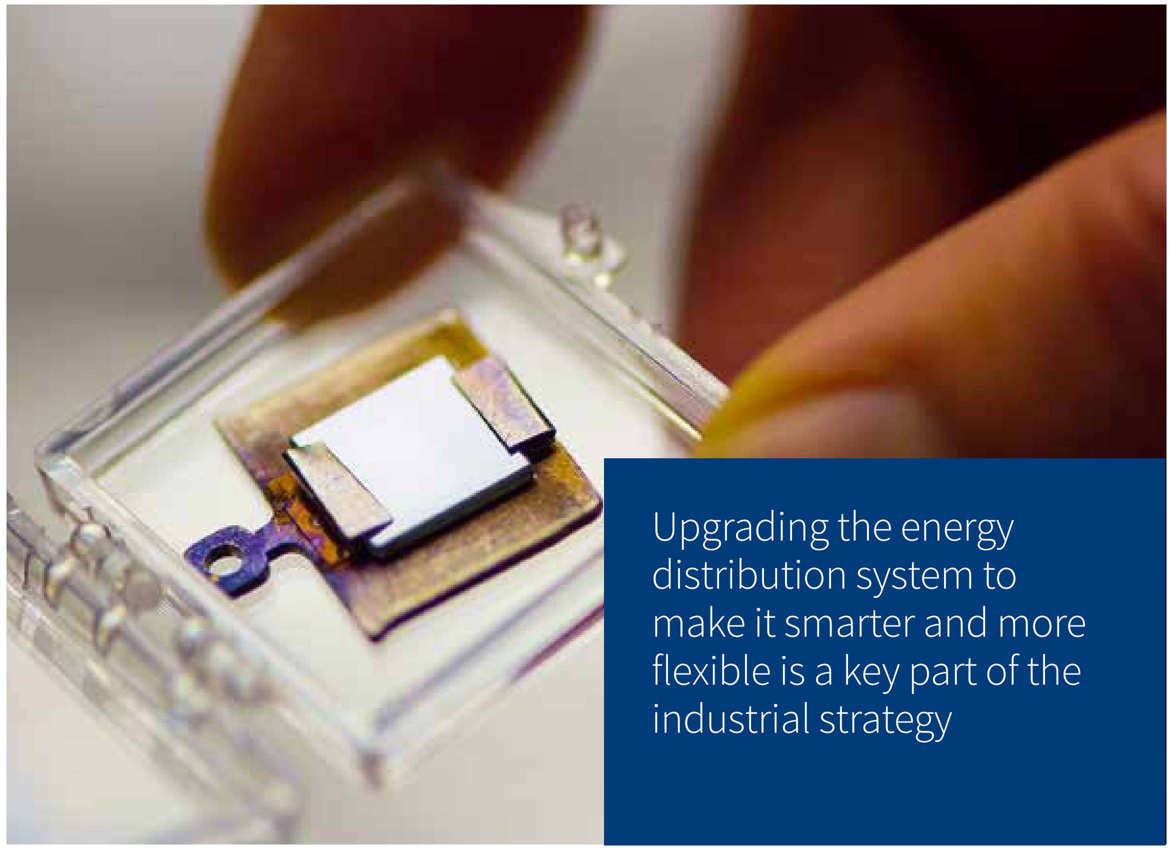
In relation to future R&D, the ERA institutions are focused on addressing the societal and technical issues associated with more localised energy networks that can talk to one another and share energy across multiple vectors. This would help to smooth out energy demand and would give users the ability to control how they use their energy. Clearly, the size of the energy networks play an important role here in how easy this integration is to achieve.

Power electronics and control

Renewable technologies, with their production of varying amounts of energy from day to day, are driving 'energy productivity' – that is, doing more with the same, or less. A power electronics control system helps to address intermittency and variability of supply as embedded sources of generation change from bulk to more discrete producers. It copes with the changing nature of supply that has gone from high inertia rotating mass to more discrete, relatively unstable renewable suppliers. Additionally, with the rise of the Internet of Things, where the connected factories share data for management and maintenance, power monitoring systems need to play an increasing role in keeping track of the energy consumed to show when a component needs to be replaced because it is using too much power. Timely replacement, or maintenance before repair, can reduce downtime as well as save energy. There is a shift in industry from testing new products with motors, drives and inverters to a hardware in the loop system in which hardware simulates the motor and sensor in real time.

The ERA institutions are involved in many aspects of power electronics and control R&D, including the integration of energy storage to allow renewable generating plants to behave like conventional power stations, thus helping to balance inputs and outputs on the grid. Nottingham and Warwick are founder members of the EPSRC Centre for Power Electronics (with Nottingham acting as the centre lead) that brings together the very best research groups in a UK-wide, world-leading, multi-disciplinary, virtual centre. This is leading the UK's research into power semiconductor devices, power device packaging, reliability and thermal management, and has access to extensive facilities for fabrication and characterisation of new devices. The University of Nottingham is world leading in converter circuits for applications ranging from Smart Grids and high voltage DC through to aerospace and automotive. This ERA power electronics testing environment builds on the fact that the Midlands has the highest concentration of power electronics companies in the UK.

A strength that ERA has, through the University of Leicester, is associated with the performance and reliability of power semiconductor devices and modules under both healthy and accelerated aged conditions. Power semiconductor modules are employed in modern high voltage power system applications such as high voltage direct current transmission systems. Such applications include voltage source converters that are used for the transmission of electrical power over long distances, the interconnection of asynchronous conventional AC power grids and the transmission of off-shore renewable energy wind farms. ERA institutions continue to leverage their involvement with the EPSRC Centre for Power Electronics and focus on underpinning technology research into materials, resilience, converter circuits and systems, and control for applications ranging from low voltage domestic (interfaces for solar etc) through to High Voltage DC, for automotive, rail, marine and aerospace use. R&D focuses on demand side management and energy storage technologies to improve the use of domestic generation for the benefit of both customer and grid operator. These align well with the other ERA capability areas.



Upgrading the energy distribution system to make it smarter and more flexible is a key part of the industrial strategy

Gas use and distribution

In 2017, the Minister of State for Business, Energy and Industrial Strategy, Claire Perry, announced funding for two innovative clean energy projects that would create local investment opportunities across the country[3]. Under the new investment, £25 million will be invested in potential uses of hydrogen gas for heating, testing the possibility of using domestic gas pipes for the distribution of a mixture of natural gas and hydrogen as well as developing a range of innovative hydrogen appliances such as boilers and cookers. Heating accounts for one third of UK CO_2 emissions so any project that reduces this impact supports the Government's tough 'decarbonisation' targets. At the point of use, H_2 emits zero emissions compared to 180gm/kWh CO_2 equivalent for methane (despite methane being the lowest CO_2 emitter per unit of energy of any fossil fuel).

The University of Loughborough has developed a hydrogen enrichment process that converts methane gas into hydrogen and carbon, that would significantly contribute to a reduction in the CO_2 emissions, if this blended supply was subsequently used in domestic heating appliances. This project could support Keele's work on the HyDeploy project, which is studying the feasibility of injecting up to 10% H_2 into the gas network. The HyDeploy consortium includes National Grid, Northern Gas Networks, Keele University, The Health and Safety Laboratory (HSL), ITM Power and Progressive Energy and aims to demonstrate that a blend of hydrogen and natural gas can be distributed and used safely and efficiently in a gas distribution network without disruptive changes for customers. The availability of low cost bulk H_2 in a gas network could revolutionise the potential for H_2 vehicles and, via fuel cells, support a decentralised model of localised power generation. Converting the gas networks avoids the need to persuade householders to raise the funds and give up space to install other complex low carbon technology.

Loughborough's hydrogen enrichment process also produces carbon nanotubes as a by-product, which are a valuable commodity and can be further processed to add value and make new products. Nanomaterials, which are defined as being smaller than 100nm in any of their dimensions, include nanotubes, quantum dots, aerogels and graphene. As well as strength and conductivity, they have been shown to demonstrate a vast range of useful properties including self-lubrication and creep resistance. The very pure carbon has a high surface area, is highly conductive and is sought after in both the catalyst and electronics industries.

3. http://www.renewableenergyinstaller.co.uk/2017/06/government-invests-35-million-in-innovative-clean-energy-projects, June 2017

Thermal energy distribution

A heat network – sometimes called district heating – is a distribution system of insulated pipes that takes heat from a central source and delivers it to a number of domestic or non-domestic buildings. The heat source might be a facility that provides a dedicated supply to the heat network, such as a combined heat and power plant; or heat recovered from industry and urban infrastructure, coal mines, deep aquifers, canals and rivers, or energy from waste plants. Heat networks form an important part of the UK's plan to reduce carbon and cut heating bills for customers (domestic and commercial). They are one of the most cost-effective ways of reducing carbon emissions from heating, and their efficiency and carbon-saving potential increases as they grow and connect to each other. They provide a unique opportunity to exploit larger scale, and often lower cost, renewable and recovered heat sources that otherwise cannot be used. The university campuses at Warwick, Nottingham and Keele all have installed heat networks, with various plans for larger scale future improvements in place. BGS is investigating how to 'mine' geothermal energy through its Glasgow, UK Geoenergy Observatories project (UKGEOS), as an integrated component of heat storage and transport using the subsurface as a store as well as a source. There are further opportunities for mine geothermal in the East and West Midlands, and Staffordshire coalfields, using the technology that will be developed at the Glasgow site. Geothermal opportunities also exist in deep aquifers to the east of the Midlands, and throughout the region in ground source heating and cooling.

By using these significant, physical infrastructure assets, which already cover many different energy vectors, ERA would be able to demonstrate real capability at scale in this area.

Energy innovation zones

As part of ERA's remit to focus on the integration of technical expertise, demonstration facilities and academic collaborations, it is proposed that the recommendations contained within this document have a longer-term alignment to the creation of new or use of existing, UK-based, Energy Innovation Zones (EIZs).

Birmingham's Energy Capital, together with the University of Birmingham and the Energy Systems Catapult, have recently unveiled a policy commission report making the case for the creation of Energy Innovation Zones in the West Midlands[4]. The commission, which was chaired by Sir David King, calls for four pilot energy hubs to be located in and around the region and states that the main focus of the EIZs will be to integrate low carbon technologies, to develop the business models and infrastructure needed to support new approaches to clean energy as well as overcome the regulatory barriers necessary for them to flourish. They will be designed to stimulate local clean energy innovation and drive productivity within the region, exports and growth.

EIZs – integrate low carbon technologies, to develop the business models and infrastructure needed to support new approaches to clean energy, and also help to overcome the regulatory barriers necessary for them to flourish

Energy Innovation Zones make it easier for industry, innovators and the public sector to come together to deliver the diverse clean energy infrastructure needs of our different cities and counties. They are geographically defined areas, a district or city, in which innovators can showcase their latest innovations and solutions for the energy industry and will provide a platform for companies to take centre stage in collaboration with industry.

Energy Innovation Zones will provide areas for deploying integrated smart energy solutions with the support of local businesses and regulators. It is envisaged that the ERA institutions will be able to develop and contribute to a suite of national and international Energy Innovation Zones covering all of the ERA capability areas. Energy Innovation Zones provide the missing link in the UK innovation ecosystem for energy – opportunities to be deployed commercially and as part of an integrated system at a scale customers can relate to.

4. https://www.energycapital.org.uk/powering-west-midlands-growth-regional-approach-clean-energy-innovation/

CHAPTER 4

ERA skills capability and potential

ERA SKILLS ACADEMY

The vision for the ERA Skills Academy is to realise the aspirations for the UK to be a world leader in the energy sector and build on the infrastructure investment by accelerating the development pipeline of the next generation of energy research leaders.

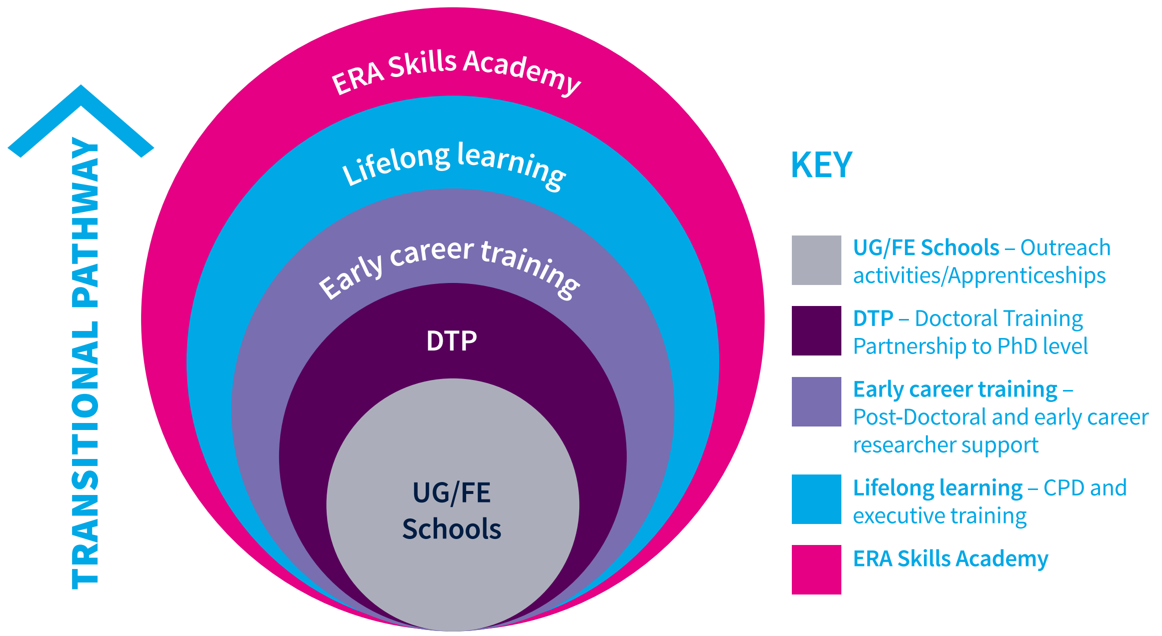
Whilst the committed capital investment through ERA has started to bring businesses and the research base closer together, none of this would be possible without a healthy pipeline of talented young scientists and engineers, from schools through to universities and industry. According to the UK Commission for Employment and Skills (2016) the energy skills demand is set to increase. The energy sector as a whole now employs over 300,000 people and accounts for 4% of national output and around 1% of employment. However, the workforce is older than that of other sectors and investment is required to ensure a healthy flow of new graduates into the sector in coming years. According to the Clean Growth Strategy, the low carbon economy could grow by 11% per year up to 2030, a growth that is 4 times faster than the economy as a whole. There have been positive signs recently of this pipeline beginning to establish itself, with apprenticeship starts in engineering and manufacturing technologies increasing by up to 52% between 2010 and 2014 (Source: Jo Johnson, 2016). The recently announced apprenticeships levy should also support this pipeline moving forwards. There remains, however, the need for a more joined-up approach to the development of energy talent that transcends all levels of skills development and which secures the UK's status as a Centre of Excellence in energy innovation and technology.

Expansion and growth within the UK's Energy sector could be severely limited by a lack of high-level skills, and the ability to innovate and commercialise technological development. The sector's full potential and highest performance will only be achieved by attracting, retaining and refreshing talent.

The long-term aspiration of the ERA Skills Academy is to combine the features of a truly collaborative large-scale partnership model, with a flexible training structure that can draw upon the very best training and expertise wherever it resides. It is proposed that the Academy would have multiple transition pathways towards and supporting skills development and career paths in industry, academia, policy, governance and entrepreneurship. The ideal model would cover the full spectrum of multi-disciplinary energy-related education, training and skills development from apprentice training through to post-doctoral and beyond.

The proposed pathways through the Academy will provide a set of distinct developmental routes, with multiple entry and exit points for skills development. In this way it affords a clear pipeline for talent development, as well as providing a structure for the effective deployment of resource from multiple institutions and disciplines to address complex societal problems. Employability, succession and talent development will be at the core of the Academy's mission with the delivery of a series of centres and skill development interventions that will help to create a national energy talent base and also an awareness of the global importance of the energy sector.

The Transitional Pathway



Going through the Transitional Pathway (diagram on previous page), a wider awareness commences with interaction with schools and STEM programmes, encouraging young people to think positively about the energy sector and its challenges as they embark on their career decisions. It is envisaged that ERA PhD students will undertake outreach activities to highlight the opportunities in the energy sector. In collaboration with partners already experienced in the apprenticeship sector, a series of programmes would be delivered across the ERA institutions. At the HE level there would need to be a reshaping and coordination of undergraduate programmes (BSc and Masters) to develop a stream of graduates to deliver both research capability and high-quality recruits to industry. The Academy endeavour would build on undergraduate research schemes, placements, continuous professional development (undergraduate and modular Masters) and the STEM activities of the ERA institutions and their associated University Technology Centres (UTCs). In line with the Government's new flagship Degree Apprenticeship scheme, ERA could propose working with industrial partners to establish an ERA Degree Apprenticeship in Energy; a practical, vocational degree course allowing the combination of both academic study from a traditional university degree with practical experience and wider employment skills.

The provision beyond graduate level is covered by the initial investment in the ERA Doctoral Training Partnership (DTP) and the pipeline through to early career training. Through CPD and lifelong learning partnerships, the Academy would be able to work with industry partners to develop industry-led projects and explore opportunities to shorten the time to chartered status.

The establishment of the ERA Skills Academy should be viewed as a multi-phase endeavour taking place over 3-5 years, at the centre of which is the doctoral training provision which ERA has pump-primed as an initial activity, to develop the higher-level skills urgently required by the sector. This enables the ERA institutions to both rapidly mobilise collaborative activity around the capital investment and build on the considerable energy research activity which already exists within the individual institutions.

> "A qualified, experienced and adequately skilled workforce will need to be attracted and retained to meet many of the challenges facing the energy system."
>
> Energy Barometer, 2018

The ERA Doctoral Training Partnership (DTP)

The set-up and establishment of the ERA DTP is a unique proposition that provides a global hub for the development of energy research talent at the doctoral level. The DTP links to an overarching ERA Skills Academy endeavour and provides a vehicle for realising the full value of the ERA capital investment.

The vision for the ERA Doctoral Training Programme (DTP) is to grow and accelerate the acquisition of skills needed for the energy leaders of tomorrow. The ERA DTP has a multi-disciplinary focus nurturing the broad range of social, economic and technical capabilities needed to conceive, deploy and operate our future energy infrastructure. It would encompass the whole ERA remit, from national-scale energy transformation and integration, through to regional and community energy initiatives, to end user energy demand and efficiency in individuals' homes, and places of work. The ERA capital expenditure, together with existing laboratory and full-scale field test facilities, provides a nationally unique training ground. The broad range of industrial links held by the ERA institutions provides access to otherwise unavailable equipment, data and expertise. The scope of the investment and critical mass of expertise maximises the ability to create a truly integrated and holistic energy training venture that extends beyond that which is possible through current research council Centres for Doctoral Training (CDT) or DTP offerings. The ERA DTP promises a completely new proposition in doctoral training and a vehicle for realising ERA's aspirations. It draws together the currently disparate strands of energy training, whilst also facilitating new evolving pathways and collaborations. This builds on the historic work of the Midlands Energy Consortium and the Network of Energy CDTs, but in a much more ambitious and holistic way.

The aspiration of the ERA DTP is to combine features of a collaborative large-scale DTP model with a more flexible training approach that can draw upon the very best training and expertise wherever it resides. ERA estimates that within the ERA institutions there are over 1,000 energy researchers who are considered

The broad range of industrial links held by the ERA institutions provides access to otherwise unavailable equipment, data and expertise

a critical mass of both current and potential PhD supervisors. Current energy societal challenges would form the basis of projects within an ERA theme, along with input from industrial partners to identify where the skills need exists. The ERA DTP could then cluster students from across the institutional partnership around these problems, so they can be explored through an 'interdisciplinary lens'. Teams will therefore be resourced in accordance with the scale of the problem and may comprise traditional PhD students, iCASE and EngD studentships, along with other resources as appropriate. Funded equally by the partners, industry and research councils, the ERA DTP would cover the full spectrum of multi-disciplinary energy-related education and training, thus spanning across the divides between the remits of EPSRC, NERC and ESRC. ERA would also work with industry partners to develop industry-led PhD projects, which are united around a defined problem.

Initial commitment to develop an ERA DTP cohort

The development of a more integrated and holistic energy postgraduate training offer through the ERA Skills Academy requires a staged approach. Phase 1 (Years 1&2, 2016/17-2017/18) has focussed on initiating this endeavour, including a review and alignment of existing training provision and the pump-priming of collaborative training with an initial cohort of doctoral students.

A key focus of phase 1 was to establish a sound business model and foundation on which the ERA Skills Academy and key centres, programmes and initiatives could be developed. Part of this included articulating the initial energy challenges to be addressed by the ERA institutions, underpinned by the capital investment. The institutions are building an integrated ERA doctoral training offer from existing training modules and resources. This is a genuinely collaborative and innovative approach and more importantly, cross-institutional. Pump priming the Phase 1 initiative with a cohort of over 30 students in the first two years, has enabled a programme of doctoral research to be initiated that demonstrates the effectiveness of the DTP model. All ERA identified areas of capability are covered with at least one student undertaking research in each of these focused topic areas.

In terms of enhancing the phase 1 programme, ERA plans to review current internal and external funding allocations and support, as well as developing and implementing other initiatives, to deliver the ERA Skills Academy ambition. Doctoral students are being brought together within a cohort-training offer and a programme of activities has been established, both informed by and with input from the students. A review of modules across the consortium has already been undertaken and an initial offering made to the students. However, due to their geographical spread and interest, a review of the best mode of delivery now needs to be undertaken along with a review of the most accessible modules. Initial focus had been on technical modules, but since all of the students can access these at their own institutions, a programme of broader topics has now been identified. Initial work to ascertain the interest of industry in providing short-term placements has also been undertaken. This needs to be followed up and opportunities highlighted to students to enable them to develop their CPD and therefore assist in achieving chartered status. Going forwards all ERA PhD students will be encouraged to develop outreach activities to address interest in STEM subjects at school and FE level. This may be part of the individual institutions community days but would also form part of the activities into schools to coincide with national events such as EU Sustainable Energy Week and World Environment Day.

The ERA Academy will work closely with UKRI and other institutions, including the Royal Academy of Engineering and the Royal Society, to link to existing fellowship schemes in the energy space

Developing a Research Training Pathway

ERA is providing a training ground for broad-based energy aware research leaders, addressing ERA's capability areas. ERA thus presents an opportunity to deliver a real step-change in the number of energy literate undergraduates and postgraduates by enhancing the training environments available to them and providing strong routes for dialogue with major employers through the wider ERA industrial network.

ERA proposes to include an extended Early Career Researcher Training Pathway, that will enable ERA to support and sustain the best talent and realise the full potential of the next generation of researchers. The ERA Academy will work closely with UKRI and other institutions, including the Royal Academy of Engineering and the Royal Society, to link to existing fellowship schemes in the energy space. In addition, the Academy will investigate creating new opportunities to address skills gaps and shortages, including supporting those moving into or out of the industry.

It is proposed that the ERA DTP could graduate 300+ PhD/EngD students over 5 cohorts. The pipeline of talent development would be extended to include postdoctoral provision providing a link from PhD level through to fellowships with the hosting of 50-100 fellowships/Early Career Researchers. The Academy would therefore be seen as a 'hub' for energy research and innovation, providing a strong pull to engage regional, national and international collaborators through its research infrastructure, excellence and world-leading training offer developing the research leaders of the future.

Longer term development of the skills academy

The long-term aspiration of the ERA Skills Academy is to combine features of a truly collaborative large-scale partnership model, with a flexible training Academy structure that can draw upon the very best training and expertise wherever it resides. It is proposed that the Academy have multiple transition pathways supporting skills development and career paths in industry, academia, policy, governance and entrepreneurship.

The ideal model would cover the full spectrum of multi-disciplinary energy-related education, training and skills development from apprentice training through to post-doctoral and beyond and become a global hub for the development of world-class energy research talent.

> The ERA Skills Academy is to combine features of a truly collaborative large-scale partnership model, with a flexible training Academy structure

In developing this further the ERA partners would initially:

- investigate options to develop:
  1. executive training to enable lifelong learning and expand the reach and support of ERA
  2. apprenticeship training to address the skills shortage at technician and UG level (degree apprentices)
- put forward a case for expanding the initial investment in an ERA DTP into a national provider of energy skills covering the pipeline of training needs, clearly articulating the added value provided by ERA and those elements owned by the individual institutions
- engage with UKRI, the UK Energy Research Centre (UKERC), the Energy & Utility Skills Council and other training partners such as the Energy Institute to further this ambition.

In the short term, the priority is to focus on the following:

Scale, scope and aspiration

The scale and scope of existing energy doctoral training activity which is undertaken by the ERA partners requires review and consideration as to how this best aligns to ERA research strengths.

- The thematic focus and value-added beyond existing CDTs and current training will be clearly articulated. This activity is currently underway with initial work having been undertaken by Loughborough University. An initial mapping demonstrates that the current training provision does not effectively cover all of the ERA capability areas, nor is it is currently integrated or holistic.
- A significant amount of work has gone into highlighting the training available but finding a suitable method of delivery to the students still needs to be undertaken.
- The DTP aspect of the Academy model will need to focus on adding value to the employability of the graduates, for example, by providing industry relevant training to ensure the PhD students meet the talent pool requirements on graduation.

Creating a sustainable financial model

The financial details of the current energy doctoral provision within ERA institutions, for example sources of existing funding, different PhD durations, models and stipend levels, will be reviewed across ERA and options for an aligned and integrated model presented. Due to the variation across institutions and existing CDTs, there is a need to carefully consider how this evolves within ERA. The wider postgraduate funding, industry and training landscape also needs to be considered.

Key stakeholders, including the EPSRC, ESRC and NERC will be involved in the development at appropriate stages. Initially it is proposed that development activity will be mobilised with institutional support via the ERA institutions. For subsequent iterations of the ERA DTP, a resource and finance model will need to be developed in close discussion with UKRI and industry. Attracting the sponsorship will be key as it could be used to part-fund the students and so increase the total number of studentships on offer from existing DTP allocations, but also ensure that industry are fully engaged in the challenge-based approach adopted by the ERA DTP.

> The ideal model would cover the full spectrum of multi-disciplinary energy-related education, training and skills development

Innovative training involving co-creation

This strand has a wide range of elements that need to be drawn together in a short-time period.

- It will include a review of existing energy CDT training provision and institutional differences in the models of training. Given that ERA institutions are partners in most of the EPSRC and NERC energy-related CDTs and DTPs, many training modules exist that could be repurposed for the Phase 1 delivery. Harnessing these modules and the experience of directing and managing CDTs and DTPs to deliver an integrated provision, within a short timescale, will be challenging but is achievable.
- The notion of co-creating the training offer with industrial partners will also be at the forefront of any development activity. Broader training will be considered, and work has already begun to identify companies that may be interested in postgraduate placements (industry-linked), conferences and networking events and international exchange opportunities.

APPENDIX 1
Current Innovate UK funded facilities

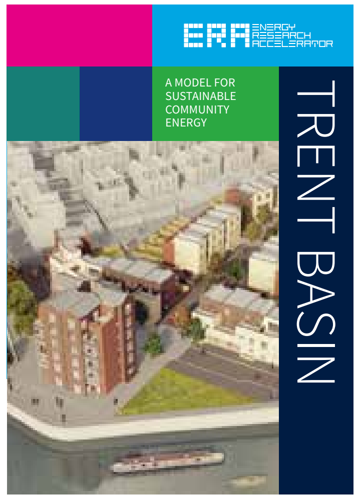
Facility Title	Description	Location
Advanced biomass processing facility	Expand analytical and processing capability in biomass, biofuels, biochemical and bioproducts.	EBRI, Aston University
Advanced insulation, glazing and solar collector laboratory	Test facilities to develop high performance insulation materials, façade systems for improved building energy performance.	CREST, University of Loughborough
Battery abuse facility	Bespoke facility for abuse testing of cells beyond their normal operating limits.	Energy Innovation Centre, University of Warwick
Battery forensics lab	For the stripdown, autopsy and analysis of cells to understand reasons for failure.	Energy Innovation Centre, University of Warwick
Cell and module characterisation labs	For cycling and testing cells under a range of environmental conditions.	Energy Innovation Centre, University of Warwick
Cell scale up manufacturing facility	Pilot line for the manufacture of cylindrical and pouch format batteries.	Energy Innovation Centre, University of Warwick
Community energy homes	Local, integrated energy system supplying power for the local community.	Trent Basin Development, Nottingham
Cryogenic engine test facility	Support the development of cold engine technology.	Wolfson School, University of Loughborough
Geoenergy test bed	Comprising set of 11 boreholes and various sensors and data recording infrastructure / office accommodation. The facility will be used to carry out research into new technology sensors and for research related to the geology of the site and into gas injection including CO_2.	Sutton Bonington Campus, University of Nottingham
Hardware in the loop (HIL) lab	Bespoke facility for the simulation of drive cycles, incorporating motors/batteries.	Energy Innovation Centre, University of Warwick
High performance compression and expansion lab (HPCEX)	Facilities at University of Nottingham and University of Leicester for research into gas compression, expansion energy storage.	Jubilee Campus, University of Nottingham
Hot and cold thermal materials manufacturing laboratory	Newly refurbished space for the Birmingham Centre for Energy Storage to continue its work into researching and manufacturing cryogenic, sensible heat and high temperature energy storage materials, components and systems.	Metallurgy and Materials Building, University of Birmingham

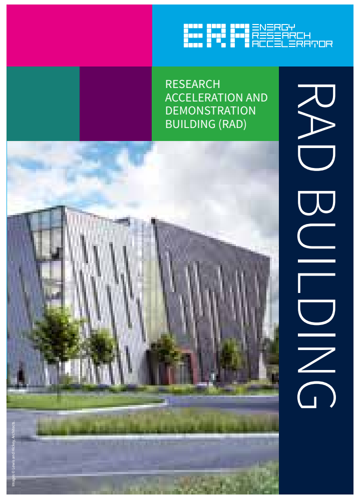
Facility Title	Description	Location
HPCEX-IESTV	Research into gas compression, expansion energy storage.	Department of Mechanical Engineering, University of Leicester
Hybrid cryogenic generation facility	Hot and cold hybrid engine research facility, building on the existing EPSRC 8 Great Technologies funded Liquid Air engine test laboratory. The new facilities allow wider integration with thermal, and in particular, cold chain technologies through the development of the applications of liquid air.	Mechanical and Civil Engineering Building, University of Birmingham
Hydrogen lab	A flexible test facility for the evaluation of hydrogen as an energy source and energy storage medium.	Jubilee Campus, University of Nottingham
Hydrothermal carbonisation rig	Facility for the evaluation of low carbon bio fuels produced from waste materials.	CPL Works, Immingham
Latent heat energy storage laboratory	Materials characterisation laboratory and test facilities for PV.	CREST, University of Loughborough
Multi disciplinary lab (MDL)	The MDL is equipped with state of the art facilities for near-ambient pressure photoelectron spectroscopy, nanoscale imaging, gas-storage & separation, thermal analysis, fuel cell testing & accelerated gas cycling.	Jubilee Campus, University of Nottingham
Pack scale testing facility	For testing of full vehicle battery packs up to 1MW, 900V.	Energy Innovation Centre, University of Warwick
Research and demonstration building	An Energy efficient building constructed to meet Passivhaus standards that will house research facilities for clean, low carbon & renewable energy research.	Jubilee Campus, University of Nottingham
Second life testing facility	For testing and integrating second life packs/ modules into a range of applications including vehicle charging and static storage.	Energy Innovation Centre, University of Warwick
Small scale materials lab	For the development of new battery materials and chemistries <1kg.	Energy Innovation Centre, University of Warwick
Solid looping adsorber	Facility for the evaluation of improved means of scrubbing CO_2 from combustion products.	Jubilee Campus, University of Nottingham
Sorption heat pump laboratory upgrade	Development of thermal energy materials.	Faculty of Engineering, University of Warwick
Thermal belt demonstrator facility	Develop novel biomass conversion technologies for the production of biofuels.	Tyseley Energy Park, Birmingham
Thermal technology companies manufacturing assessment and support to FIAB demonstrators	Development of thermal energy manufacturing capability. Create digital/ virtual manufacturing environment and two factories in a box to demonstrate Industry 4.0 principles in the thermal energy sector.	Manufacturing Technology Centre
Upgraded vehicle energy facility	For the testing of electric and hybrid vehicle drivetrains, including electric motors.	Energy Innovation Centre, University of Warwick

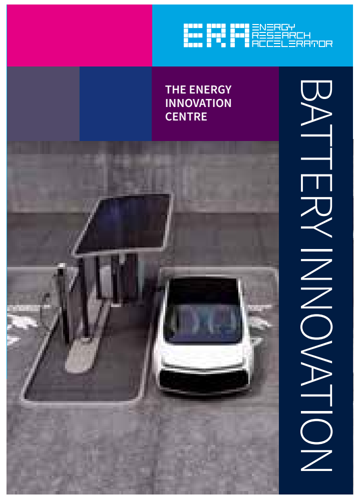
ERA publications

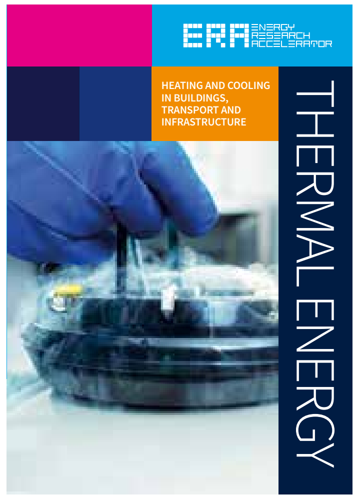
For more information about the work of the Energy Research Accelerator, download our publications. These include our overview brochure and a range of facilities and equipment guides, as well as information about our skills offer. An electronic version of this capabilities document can also be downloaded from our website. Visit our ERA downloads page at:

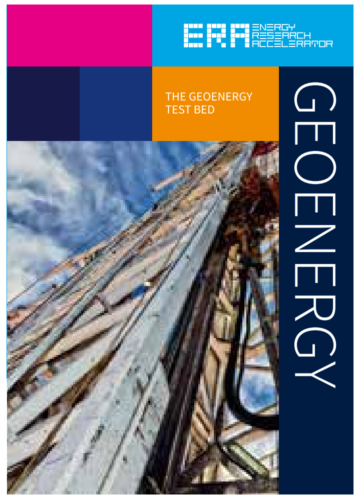
era.ac.uk/ERA-Downloads

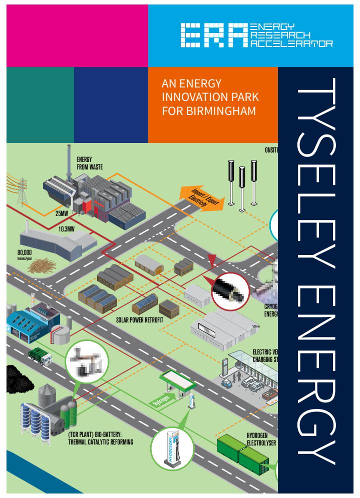


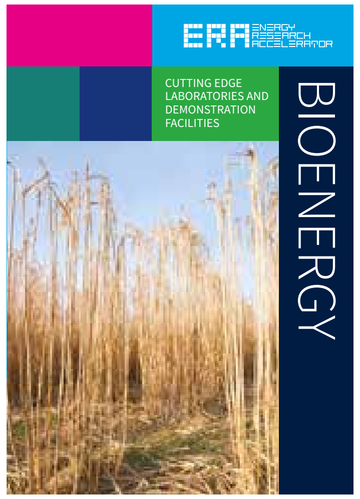


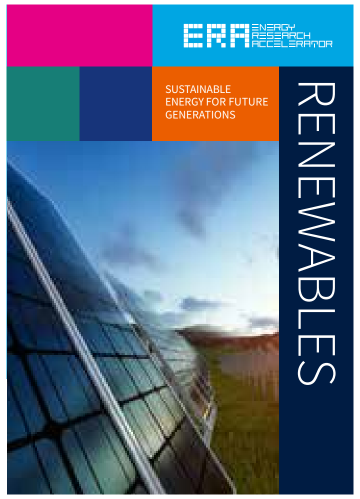


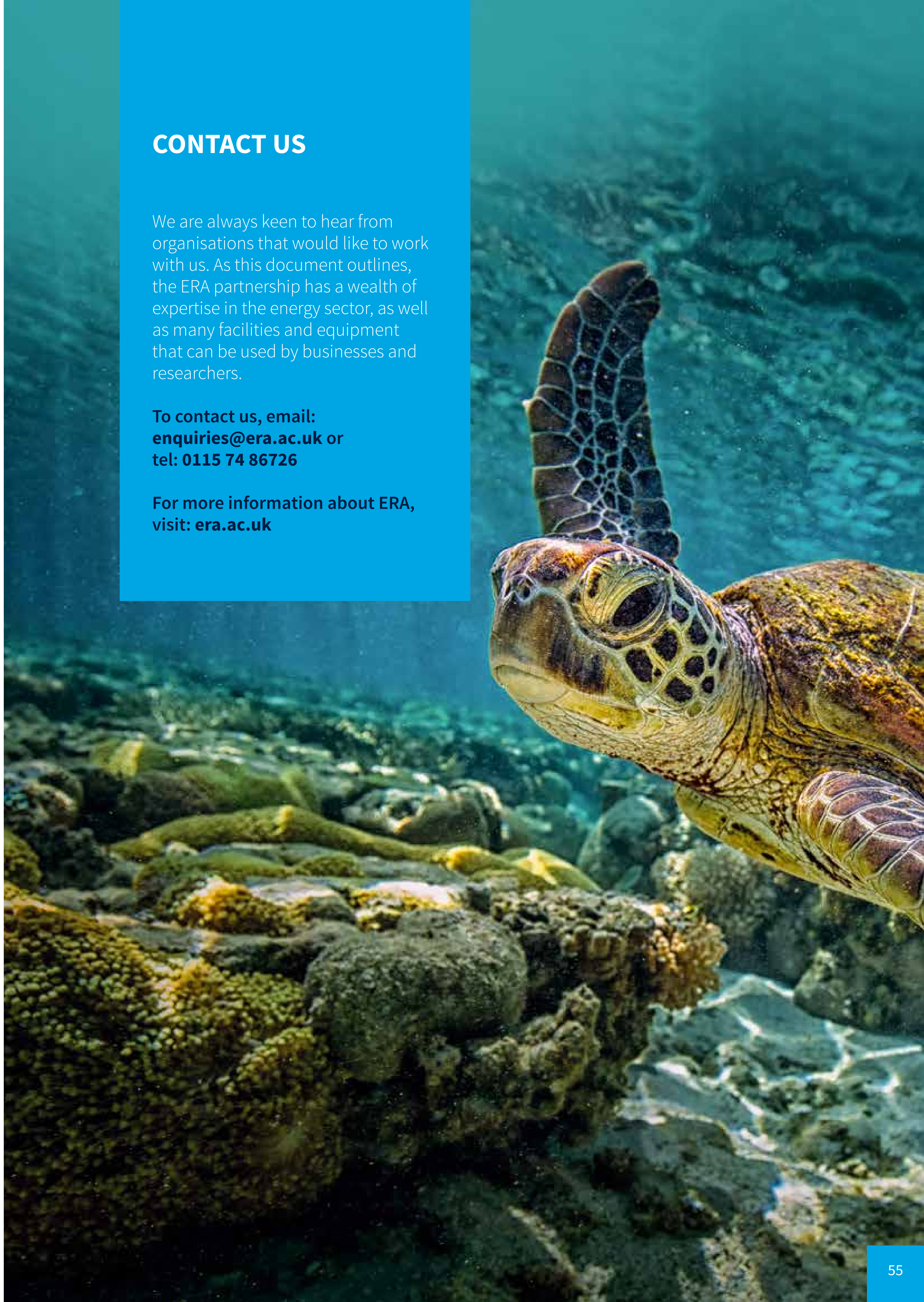












CONTACT US

We are always keen to hear from organisations that would like to work with us. As this document outlines, the ERA partnership has a wealth of expertise in the energy sector, as well as many facilities and equipment that can be used by businesses and researchers.

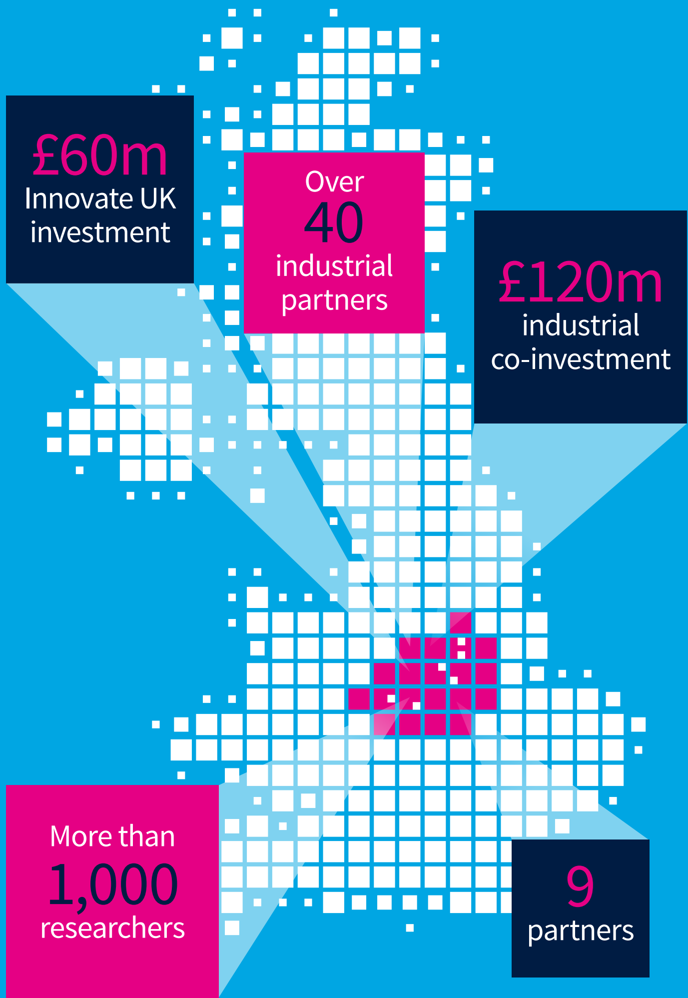
To contact us, email:
enquiries@era.ac.uk or
tel: 0115 74 86726

For more information about ERA, visit: era.ac.uk

ERA
ENERGY RESEARCH ACCELERATOR

ABOUT US

ERA is an Innovate UK funded programme within Midlands Innovation. ERA involves a consortium of eight midlands based research intensive universities, together with the British Geological Survey, who are harnessing the Midlands' combined research excellence and industry expertise to play a critical role in tackling some of the biggest energy challenges facing the UK. The recent addition of Keele and Cranfield universities to the Midlands Innovation partnership, further strengthens ERA's research capability.



CONTACT US

ERA welcomes engagement with research, industry and policy-makers across the energy sector.

For more information visit:

- **era.ac.uk**
- **enquiries@era.ac.uk**
- **@EnergyRA**

Find out more at **era.ac.uk**

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