# ACHIEVING A RESILIENT NATION

Highlighting the contribution of engineering & physical sciences research



### A RESILIENT NATION

A Resilient Nation provides citizens with sustainably-managed resources, reliable infrastructure and the ability to combat natural and man-made threats.

The Engineering and Physical Sciences Research Council (EPSRC) helps achieve this through substantial investment in excellent engineering and physical sciences research and innovation. This is delivering the products, processes and technology that are needed to affect economic and social change.

What people may find surprising is the breadth of engineering and physical sciences research that contributes to building a Resilient Nation. Mathematics, physical sciences, computing and engineering are fundamental to the new thinking and innovation needed to increase resilience. The EPSRC is investing over £600m a year in ambitious research focussing on a wide range of relevant issues applicable to local, regional and national challenges. Research outputs providing solutions have the potential to benefit policymakers and practitioners in areas as diverse as the construction industry, the financial sector, urban and city planning, risk management, utility management, input to regulations, local and central government policy, cyber security, and many more.

This booklet provides a snap-shot of a range of current research projects contributing to achieving a Resilient Nation. It is necessarily brief and certainly not comprehensive, but aims to illustrate the breadth of evidence and knowledge from research that can help inform policy and practice. Nearly all research projects include significant engagement with stakeholders; partnerships and collaborations help maximise and accelerate the benefit of research outputs to all.

# RESILIENT NATION – Adaptive, prepared, protected, secure, safe, sustainable

F J e s e	t1: Achieve energy security & efficiency	R2: Ensuring a reliable infrastructure which underpins the UK economy	R3: Develop better solutions to acute threats: cyber, defence, financial & health	R4: Manage resources efficiently & sustainably	R5: Build new tools to adapt to & mitigate climate change	
	FOR EXAMPLE:					
	Systems engineering, complexity science and uncertainty quantification to understand interdependences for better decision-making					RE
	Materials resea	rch and resource	efficiency to ena	able sustainable	use of assets	SEARCH
	nfrastructure e	engineering to de	esign, build and t	test across lengt	h-scales	CAPAB
	Data science and analytics to anticipate, understand and model threats and optimise solutions					
Generation, storage and transmission technologies for future energy options and reducing energy consumption and demand						

### EPSRC VISION: PROSPERITY OUTCOMES

#### **A Resilient Nation**

Investments in engineering and physical sciences research and skills development support four inter-linked outcomes which collectively underpin UK prosperity.



EPSRC invests in research discovery and innovation. Our contribution to the UK is the world-leading research and postgraduate training which have benefits for society and the economy. We deliver highly skilled, numerate individuals who become leaders in industry, academia and the public sector.

"Safeguarding opportunities for future generations requires an ability to anticipate, adapt and respond to changes, natural or man-made, short or long-term, local or global. UK prosperity depends on the smooth and sustainable functioning of complex infrastructures: transport; communications networks; water, energy and waste utilities. Engineering, mathematics, ICT and physical sciences are fundamental to the new thinking and innovation needed to build a truly resilient nation and increase UK competitiveness. "

### RESILIENT NATION: ADAPTIVE

#### Tailored Water Solutions for Positive Impact (TWENTY 65)

#### • Joby Boxall, University of Sheffield

The UK water sector faces many challenges over the coming decades: increasing population, ageing infrastructure, and the need to better protect the natural environment all under conditions of uncertain climate change.

This research consortium is working in partnership with the water sector to build resilience, efficiency and adaptability into water systems, networks and catchments to ensure clean water for all, sustainably, by 2065. Social and technological solutions are being developed tailored to specific challenges at particular locations which can then be combined to provide bespoke solutions appropriate to local conditions.

#### From Models to Decisions (M2D)

#### • Peter Challenor, University of Exeter

This network is looking at new ways of presenting uncertainty using, for example, narratives and visualisations to help decision makers who are including evidence from models to inform policy and practice. Today, many decisions are made using evidence from large and complex numerical models. Results from such models are uncertain, and new approaches are being developed to overcome difficulties in incorporating outputs into the decision-making process.

# Low Carbon Climate-Responsive Heating and Cooling of Cities (LoHCool)

#### • Alan Short, University of Cambridge

Practical and economic low carbon options for re-engineering buildings in cities are being developed. This research is focusing on delivering economic and energy-efficient winter heating and summer cooling to cities in both the UK and China. It is looking at both new and existing buildings and the potential use of passive and active systems to improve living conditions. This builds on work examining environmental conditions within the National Health Service Hospital Estate and the practical economic opportunities for significant improvement whilst saving carbon emissions.

#### Centre for Advanced Materials for Integrated Energy Systems (CAM-IES)

#### • Clare Grey, University of Cambridge

This research is focusing on the development of advanced materials for energy conversion and energy storage for future renewable and clean energy systems. Development is targeted at specific applications such as off-grid and grid-tied applications, large- and grid-scale centralised energy generation, and storage and energy solutions for mobile internet communication technologies.

#### Multi-scale Infrastructure Systems Analytics (MISTRAL)

#### • Jim Hall, University of Oxford

National infrastructure provides essential services to a modern economy: energy, transport, ICT, water supply, flood protection, and waste disposal. This research uses systems analysis to guide infrastructure decisions by assessing how integrated infrastructure systems are performing, from local to global scales. Models are helping pinpoint vulnerabilities, the risks of failure and allow 'what-if' analysis of proposed investments.

#### Bed friction in rough-bed free-surface flows

#### • Vladimir Nikora, University of Aberdeen

Relevant to coastal and waterway engineering, this research is developing predictive capabilities for the quantification of hydraulic resistance in rough-bed open-channel flows that can be incorporated into applied hydraulic models. Results are helping to reduce uncertainties in the prediction of water levels and flood inundation events and to inform urban planning decisions, including the use of blue/green infrastructure.



### RESILIENT NATION: PREPARED

#### Next Generation Converged Digital infrastructure (NG-CDI)

#### • Nicholas Race, Lancaster University

In partnership with BT, this research is looking to inform the creation of a new architecture for autonomous operation of the UK's future internet and telecommunications services.

Developments such as 5G, virtual reality and self-driving vehicles will require a radical shift in the way networks perform and are maintained. This research is developing a network for the future with the capability to predict changes in networking demand and to reconfigure infrastructure with minimal human intervention.

#### **Sustainable Polymers**

#### • James Clark, University of York

Polymers are ubiquitous in everyday life and the polymer industry is a major UK employer. This materials substitution research is seeking to reduce the dependence of polymer production on petrochemicals by developing new processes using renewable resources such as waste biomass and waste carbon dioxide.

Working with industry, new chemical and mechanical processes are being explored to determine the scope for switching from fossil to sustainable sourcing within the polymer sector.

# Water Resilient Cities: Climate uncertainty and urban vulnerability of hydro-hazards

#### • Lindsay Beevers, Heriot-Watt University

Creating resilient, sustainable, water-secure cities depends on our understanding of the potential future risks from floods and drought, and our ability to increase our resilience to them. This fellowship is quantifying the uncertainty in future hydro-hazards and designing engineering and policy interventions to help increase urban resilience and to inform urban water security adaptation plans for cities and their surrounding areas.

#### A Platform for Hybrid Manufacturing Process Research

#### • Russell Harris, University of Leeds

The UK's innovation capability is critically dependent on manufacturing as the route to achieving commercialisation of new products, processes and services.

Hybrid manufacturing concerns digitally-driven and template-less manufacturing processes which are founded on cross-technology process platforms. This Hub is focusing on future generations of transformative products which will be realised through the combination of multiple process technologies within a single platform, while incorporating emerging research from across the physical sciences.

#### Transformative Engineering Materials for Reduced Energy and Waste Consumption in Advanced Manufacturing Processes (Carboglass)

#### • Paul Bingham, Sheffield Hallam University

This project will establish the technological potential of new glassy materials that can safely incorporate high levels of  $CO_2$  by locking it away within the structure of the material. In doing so it is believed this will present new properties which will enable transformative industrial changes in the way glass is manufactured, used and recycled.



### RESILIENT NATION: PROTECTED

### From membrane material synthesis to fabrication and function (SynFabFun)

#### • Ian Metcalf, Newcastle University

Membranes offer exciting opportunities for more efficient, lower energy, more sustainable separations and new process options. However, high performance membranes suffer from problems with decay in performance over time which seriously limits their application.

Through a combination of the synthesis of new membrane materials and the fabrication of novel composites, new membranes are being created with stable long-term performance.

#### Urban Flood Resilience in an Uncertain Future

#### • Colin Thorne, University of Nottingham

This project is focused on protecting UK cities against risks due to increased storminess, without constraining urban renewal and development. Research is studying how storm-water cascades through a city's drainage system, accounting for the dynamics of not just water, but also sediment, debris and contaminants carried by urban runoff. The performance of grey systems is being investigated to see how they can be improved by adding blue-green infrastructure and sustainable drainage systems to manage urban runoff, and integrating this with a better understanding of citizen and community preferences with respect to managing flood risk.

# Tackling Antimicrobial Resistance in Wastewater Systems with Sneaky Bacteria

#### • David Graham, Newcastle University

Domestic wastewater treatment is among the main reasons why community health has improved dramatically since Victorian times. But modern waste water treatments were never designed to remove contemporary contaminants such as microbial resistant bacteria and genes. By developing new treatment technologies to reduce multi-drug resistance levels in effluent, the aim is to inform strategies for increasing resilience in urban water infrastructure and thereby to protect health.

# Future Vaccine Manufacturing Hub: Advancing the manufacture and deployment of cost effective vaccines

#### • Robin Shattock, Imperial College London

Research is developing ways to respond rapidly and efficiently to viral threats such as Ebola and Zika. Global vaccination programmes have been a great success but the production and distribution systems for vaccines suffer from costs associated with producing and purifying vaccines and the need to store them appropriately.

This research hub is looking at methods to improve the way vaccines are manufactured, stabilised and stored so that costs are reduced, efficiencies are increased and existing and new diseases prevented.

#### National Centre for Nuclear Robotics (NCNR)

#### • Rustam Stolkin, University of Birmingham

Nuclear facilities require a wide variety of robotics capabilities. Research at this Centre is developing state-of-the-art robotics, sensing and artificial intelligence technologies to address the major challenges posed by nuclear environments and materials. This includes safely cleaning up nuclear waste; the UK has 4.9 million tonnes of legacy nuclear waste and environmental remediation must be carried out by robots as conditions are often too hazardous for humans.

Novel sensor designs, advanced algorithms for robotic perception, and new kinds of robots to deploy sensors into hard-to-reach locations are all being developed.



### RESILIENT NATION: SECURE

#### Cyber Security of the Internet of Things

#### • Jeremy Watson, UCL

The PETRAS Internet of Things Research Hub focuses on privacy, ethics, trust, reliability, acceptability, and security/safety issues. Today, we use many objects that are digitally connected: gas meters and lights in homes, healthcare devices, water distribution systems and cars. There is great potential for such technology to deliver economic and societal benefit, but there are also serious challenges and threats. This research is assessing how the Internet of Things can evolve in a trustworthy, resilient and secure manner so that individuals can understand and be comfortable with it.

#### Emergency Flood Planning and Management using Unmanned Aerial Systems

#### • David Butler, University of Exeter

Five million people live in flood risk areas in England and Wales, with one in six homes at risk of flooding. This project is using instrumented unmanned aerial systems to collect information about an unfolding flooding disaster. The aim is to provide emergency responders with the opportunity to assess the situation quickly, allowing the prioritisation of resources and their effective deployment. Data is also being combined with flood inundation models to generate detailed evacuation plans, and to predict the nature and progress of the flooding.

#### Engineering Complexity Resilience Network Plus (ENCORE)

#### • Martin Mayfield, University of Sheffield

As the physical and digital infrastructures in our manufacturing and service industries become more complex and interdependent, we are increasingly vulnerable to the cascading and escalating effects of failure in such systems. This network is developing new methods to improve the sustainable long-term performance of complex engineered systems. Initially, this includes cities and national infrastructure, and complex products such as aerospace engines. Later, it will include nuclear submarines, power stations and battlefield systems.

#### Building the Queen's University of Belfast Antimicrobial Resistance Network (QUBAN)

#### • Steven Bell, Queen's University Belfast

Antimicrobial resistance is a long term threat to our health system. The project is one of several 'Bridging the Gap' networks that were established to bring together researchers in engineering, physical sciences and medicine to tackle this challenge. At Queen's University Belfast, interdisciplinary collaborations built on in-house expertise in advanced materials and processing to develop novel approaches to combating antimicrobial resistance.

#### Research Institute in Trustworthy Interconnected Cyberphysical Systems (RITICS)

#### • Chris Hankin, Imperial University

This coordination activity provides a UK hub for evidence-based research aiming to identify, communicate and solve cyber threats to national infrastructure. It promotes cross-project collaboration and enhanced knowledge exchange with industry.

The research is responding to key questions in securing industrial control systems against cyber threats, including a) what physical harm do cyber threats pose to interconnected systems and business? b) can we confidently articulate these threats as business risk? and c) what are the novel effective and efficient interventions?



### RESILIENT NATION: SAFE

#### Resilient Materials for Life (RM4L)

#### Robert Lark, Cardiff University

New construction materials using the biomimetic approach are being created that can adapt to their environment, develop immunity to harmful actions, self-diagnose the on-set of deterioration and self-heal when damaged. This innovative research into smart materials will help stimulate a step-change in the value placed on infrastructure materials and provide a higher level of confidence and reliability in the performance of our infrastructure systems.

#### UK Robotics and Artificial Intelligence Hub for Offshore **Energy Asset Integrity Management**

#### David Lane, Heriot-Watt University

The offshore energy industry is seeking cost effective and safe methods for the inspection, repair and maintenance of their infrastructure. Robotics and artificial intelligence are seen as key enablers towards achieving autonomous offshore energy fields operated and maintained from the shore. This research is providing solutions that can be integrated with new and existing offshore assets.

#### Challenging RISK: Achieving Resilience by Integrating Societal and Technical Knowledge

#### • Tiziana Rossetto, University College London

This project is concerned with the socially integrated mitigation of multiple structural risks in the urban environment, with a focus on the linked risks of earthquake and fire.

From an engineering perspective, the research is developing and optimising strategies for the assessment and mitigation of multi-hazard risks which will lead to more resilient physical infrastructure within local communities. In parallel, a better understanding of risk perception at the individual and community levels is helping develop communication strategies to raise awareness and to stimulate action.



#### Managing Air for Green Inner Cities

#### • Paul Linden, Cambridge

This project responds to the challenge of how to develop cities with no air pollution and no heat-island effect by 2050. An integrated suite of models is being developed that together allow the city design and its operation to manage the air so that it becomes its own heating, ventilation and air-conditioning system, with clean, cool air providing low-energy solutions for health and comfort.

This will be achieved by using natural ventilation in buildings to reduce demand for energy plus green (parks) and blue (water) spaces to provide both cooling and filtration of pollutants.

#### Distributed Autonomous and Resilient Emergency Management System (DARE)

#### • Rahim Tafazolli, University of Surrey

In the event of failure of critical national infrastructure systems by either man-made or natural disasters, it is crucial to implement appropriate emergency management systems. However, current communication platforms for such systems are susceptible to being damaged during the disaster and also require substantial input. This research is developing a new Distributed Autonomous and Resilient (DARE) management system. that will be founded upon three main communication platforms: wireless sensor networks, ad-hoc networks and future cellular networks.



### RESILIENT NATION: SUSTAINABLE

#### **Opening New Fuels for UK Generation**

#### • Paul Fennell, Imperial College London

This research is investigating the potential of using waste materials for energy production in the UK, and assessing how the combustion of such wastes might affect the ability of power stations to respond to changes in electricity demand. The purpose is to understand how an efficient and integrated system can be designed to utilise all potential fuel streams in the future. This has the added advantage that many wastes are currently landfilled, meaning that both the energy content of the waste is lost and a bulky material ends up in waste disposal sites.

### Low Carbon Transitions of Fleet Operations in Metropolitan Sites (LC TRANSFORMS)

#### • Phil Blythe, Newcastle University

Low carbon vehicle fleets for personal mobility and freight have the potential to contribute to reduction of the climate impact from urban transport as well as to improve local traffic and air quality conditions. This research is addressing the challenges of transitioning urban fleets towards low, and ultimately zero, carbon operations, both in the UK and China.

#### Complex Built Environment Systems (CBES)

#### • Mike Davies, UCL

By 2030, it will be government policy that every home in the UK will benefit from measures to improve energy efficiency. However, there are many unintended consequences of energy efficiency interventions in homes and a systems thinking approach is needed to address these complex issues. In the new 'UK Centre for Moisture in Buildings' research on building engineering physics, health, building use, quality and processes is being combined to transform our understanding of the systemic nature of a sustainable built environment.



#### Biopolymer Treatment for Stabilisation of Transport Infrastructure Slopes

#### • Paul Hughes, University of Durham

Slope failures (landslides) cause significant disruption to our transport network resulting in frustrating delays and significant costs for repair. Failure is the result of long exposure to the UK's changing weather which causes the compacted clay soils which form the embankments to weaken over time. This project is investigating the use of biopolymers as a low cost, low-carbon solution to the problem of slope stability.

# Role of Digital Technology in Understanding, Mitigating and Adapting to Environmental Change

#### • Gordon Blair, Lancaster University

Digital technologies have a crucial role to play in helping to understand the natural environment and its complex web of interconnected ecosystems, and supporting strategies to respond to environmental change.

This Fellowship focuses on three major areas of digital innovation: the Internet of Things, cloud computing and data science. The Internet of Things has the potential to provide real-time data about the natural environment, cloud computing can bring together data from different locations and at different scales, and data science provides analysis techniques to make sense of the data and hence inform mitigation and adaptation strategies.



# SKILLS DEVELOPMENT & LEADERSHIP

Developing skills and leadership in research and associated knowledge exchange is central to ensuring maximum uptake, use and benefit from research. The ESPRC is training the next generation of research leaders through initiatives such as the Centres for Doctoral Training, Industrial Co-operative Awards in Science and Technology (CASE) studentships, and Postdoctoral and Early Career Fellowship awards.

<sup>11</sup>Our Building Leadership strategy recognises that it is inspirational scientists and engineers who lead excellent research and maximise its impact for the economy. We will invest in people with leadership potential across all career stages, enabling them to maximise their contribution within Universities, Business, Government and other research organisations.

#### More information

The EPSRC continues to work directly with stakeholders in responding to their requirements for evidence and knowledge from the research base. It encourages and facilitates engagement between researchers, policymakers and practitioners: from delivering salient outputs from a single project through to co-investment in major new research programmes.

More information from across the full research portfolio can be accessed via the EPSRC website (www.epsrc.ac.uk) and from Gateway to Research (www.gtr.rcuk.ac.uk); the Research Councils UK portal to outputs from publicly-funded research.











# ACHIEVING A RESILIENT NATION