University of Bristol
Net Zero Capabilities

Introduction

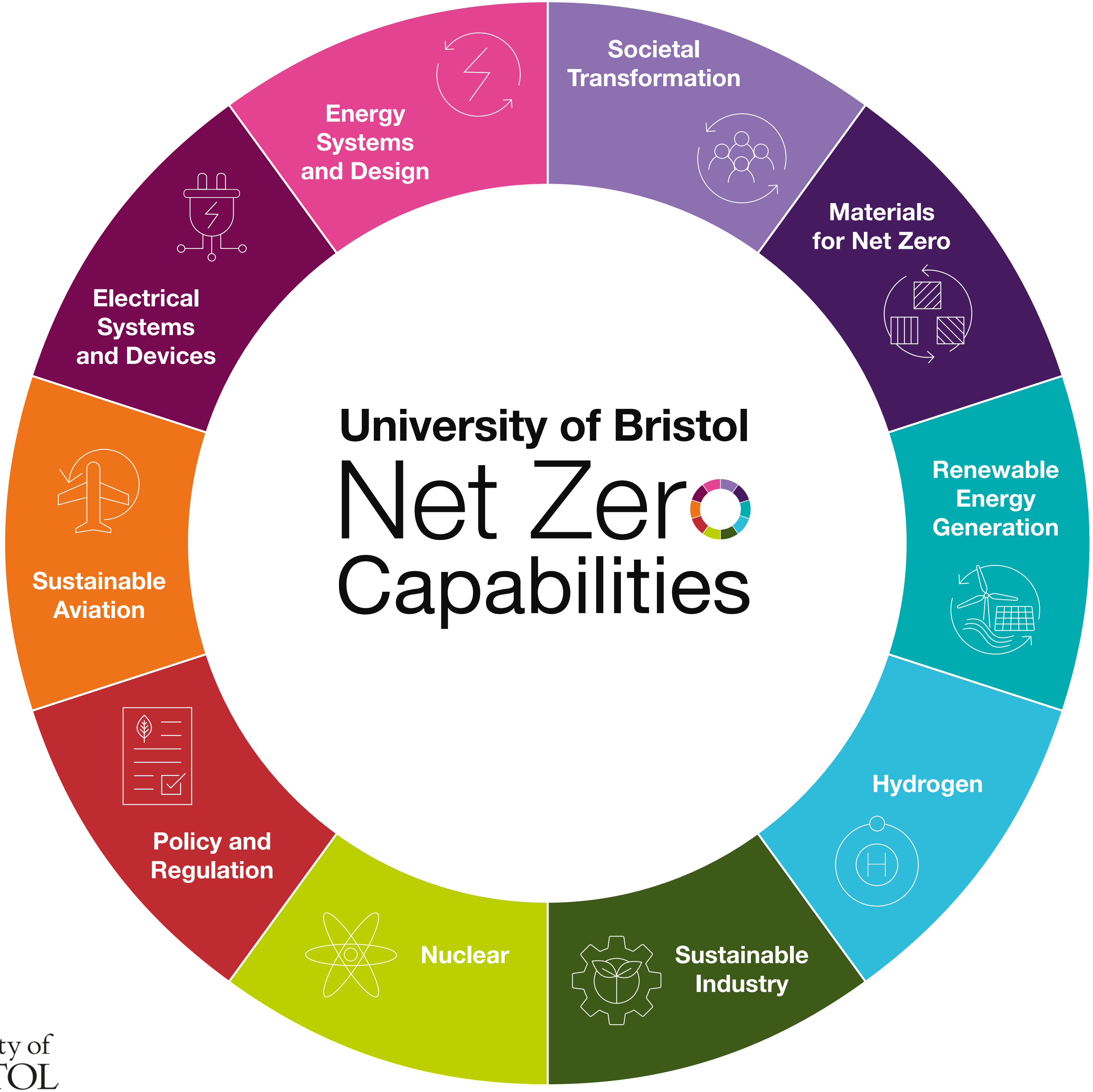
Net Zero Capabilities interactive PDF tool

With the UK Government making a legally binding commitment to achieve Net Zero emissions by 2050, a rapid period of change is required that will impact on all sectors throughout the UK economy. This will involve significant changes to policies, public behaviour, and the development and deployment of a plethora of new technologies to enable us to achieve this target.

The University of Bristol has extensive research capability across the myriad areas that make up this topic and has brought these together to determine how best we can support and enable the achievement of this goal through our internationally leading research. These capabilities are presented as part of a coordinated approach to supporting research excellence and real-world impact in Net Zero across the University through interdisciplinary collaboration and partnership building.

If you are interested in engaging on research and innovation with the University across any of these topic areas, please get in touch.
uob-netzero@bristol.ac.uk

University of Bristol Net Zero Capabilities



University of BRISTOL

Societal Transformation

Fundamentally our societies and behaviours must change if Net Zero is to be achieved. Whilst new technologies can support this transition it will be the radical change in our consumption practices now and into the future that will deliver the biggest reduction in carbon emissions. Realising this change in an equitable way will require whole new approaches to decision making, policy development, economic models, education, and public engagement and will underpin the transition to low carbon technology adoption.

Production and Consumption
More information

Justice
More information

Inclusion
More information

Education
More information

Imaginaries (Futures)
More information

Societal Transformation

Production and Consumption

- Investigating how improved transport systems and policy can enable decarbonisation through reduced energy consumption while improving outcomes for communities
- Sustainable production and consumption through economic organisation and social and behavioural change
- How organisations and forms of organising can transition to sustainable forms of production and consumption, in equitable and inclusive ways.
- Sustainability of current and future digital communication and entertainment

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Net Zero Capabilities

Societal Transformation

Production and Consumption

- Shifting modes of provision of goods and services and how these shifts can reduce the resource-intensity of everyday lives as well as the capacity for tackling issues around social inequality and wellbeing.
- Sharing economy & collaborative consumption on digital platforms to achieve decarbonization / Net Zero targets

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Societal Transformation

Justice

- Environmental justice at both the local and global scale
- Intersections between the climate emergency, gender inequalities, and structural injustices.
- Ensuring a just transition and exploring who gets to decide what this looks like, including the impact of following pathways set by decision makers
- Regulation and enforcement of Net Zero policies in the private renting sector
- Problematisation, critique, resistance and transformation of myriad forms of oppression, including climate injustice, ecocide, (neo)colonialism, racism, capitalism, and hetero-patriarchy.

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Societal Transformation

Inclusion

- Diversity and inclusion in the environmental sector
- Inclusive energy transitions and the impact of a Net Zero transition on vulnerable communities and consumers
- Action research, participatory, feminist, and arts-based inquiry in support of systemic change, encompassing climate action, social justice, gender and racial equality, and ecological sustainability.
- Fostering organisational and societal transitions for sustainable and inclusive futures.
- Democracy, participation, social activism, and civil society organising for sustainable futures

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Education

- Education on sustainability and climate justice both through specific taught courses and more broadly throughout the curriculum across all schools and faculties
- Alternative models of organisations focused around sustainability
- Examining the skills, jobs and pipeline of employment required to ensure a just and sustainable transition to Net Zero
- Teaching retrofit including supporting novel curriculum design and development for sustainability
- Environmental history including energy histories, petrocultures, pollution, energy justice, renewable energy geographies and the impacts that these have on communities, places and politics.

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Societal Transformation

Imaginaries (Futures)

- Climate activism and the use of civil disobedience including the strategies and discourses of civil disobedience in contemporary climate change activism.
- Societal acceptance and climate discourse of the transition to Net Zero
- Exploring the focus of our Net Zero transition and what it is that we want to transform
- Environmental histories, humanities and cultures
- The role of arts in constructing imaginaries
- Appropriate design for Net Zero
- Decolonial thinking and decision-making to avoid euro-centric approaches to Net Zero

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Materials for Net Zero

The development, characterisation and testing of novel materials will underpin a wide range of the technical solutions required to enable our goal of reaching Net Zero. Advancements made here support innovation across all technologies and applications, from hydrogen, to electrification, from supporting energy networks and generation to sustainable aviation, and interface with every other capability highlighted at the University across Net Zero.

Digital and Material Design

More information

Materials Development and Characterisation

More information

Lightweighting and Efficiency

More information

Materials for Net Zero

Digital and Material Design

- Design and computational characterisation of lightweight composite structures
- Advanced modelling techniques for new and emerging material formats
- Designing unique material properties to structural response features
- Virtual testing and manufacture for Net Zero materials and process development
- Validation of models through advanced experimentation

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Materials for Net Zero

Materials Development and Characterisation

- Development of low carbon and more recyclable materials such as bio-based and natural fibre composites, thermoplastics, novel polymeric materials, biomimetic and functional materials, and sustainable lubricants
- Advanced experimental techniques for materials characterisation including high fidelity and data rich experiments
- Advanced experimental techniques for validation of numerical models
- Characterisation of materials and their degradation mechanisms for energy and transport applications including nuclear, wind and aerospace

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Materials for Net Zero

Materials Development and Characterisation

- Design and development of high-performance compound semiconductor materials and metal oxides, based on Earth abundant materials, for applications including solar PV, power electronics, catalysis, and superconductivity
- Advanced material fabrication facilities including diamond chemical vapour deposition, metal organic chemical vapour deposition and atomic layer deposition

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Materials for Net Zero

Lightweighting and Efficiency

- Design, manufacture, testing and modelling of novel lightweight materials for structural applications, such as wind turbines
- Design methods and tools for cryogenic pressure vessels for hydrogen storage
- Sustainability, circularity and life cycle assessment of materials for Net Zero applications
- Design tools for deployment and optimisation of novel and sustainable material systems

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Renewable Energy Generation

The Government has set out ambitious plans to deliver 50GW from Offshore Wind by 2030 with a further 70GW of electricity generation from solar by 2035. These ambitious targets will require improved efficiency of existing technologies as well as the development of more sustainable and resilient novel materials and manufacturing processes. Regionally, renewables accounts for 11% of energy consumption with most of this coming from solar and onshore wind.

Wind

More information

Solar

More information

Other

More information

Wind

- Increasing efficiency and performance of turbine blades through increased blade size, improved turbine efficiency using bio-inspired lubricants, improved maintenance cycles, and increased aerodynamic efficiency of both individual turbines and multiple turbines in sequence.
- Materials and manufacturing including; circularisation of blade material life cycles, developing bio-based resins and polymers, improved materials selection, more efficient manufacturing processes and life cycle analyses.
- Geotechnics for the installation of these turbines and selection of the best sites for wind farms based on the suitability of the local geography as well as the potential impact on local infrastructure and wildlife.

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Solar

- Maximising absorption in solar cells and minimising losses due to reflection/emission of energy
- Solar-thermal technologies to concentrate sunlight as a means of heating objects or driving chemical interactions.
- Combining solar-PV with phase change materials for thermal energy storage
- Life cycle analysis for solar power in order to embed sustainability into device design.
- Materials and technologies for thin-film photovoltaics systems designed for integration into buildings and infrastructure
- Emerging new technologies such as space-based photovoltaics

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Other

- Using hydropower to create renewable energy microgrids to electrify off-grid communities in Nepal.
- Design and failure analysis of tidal energy turbine blades

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Hydrogen

With increased capacity provided through renewables and nuclear, the generation, transmission and storage of green hydrogen are an attractive proposition that will provide flexibility and capacity in the grid when demand is high. Zero Emissions Aviation plans set out in the ATI strategy see hydrogen playing a critical role in long term commercial flight. However, the use of hydrogen across the energy and aviation sectors alone, will provide a vast set of technological, policy and regulatory challenges.

Production, Storage and Transmission
More information

Energy Systems and Integration
More information

Emissions and Impacts
More information

Policy, Economics and Public Engagement
More information

Hydrogen

Production, Storage and Transmission

- Photocatalytic, electrocatalytic and corrosion-based evolution of hydrogen.
- High temperature nuclear (including both advanced fission and fusion) for efficient production of hydrogen.
- Design and development of materials and vessels for the storage of gaseous, liquid and solid-state hydrogen, accounting for extremes of temperature and pressure.
- Examination of novel and existing materials for hydrogen storage vessels including their properties, characterisation, testing and structural analysis.

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Hydrogen

Production, Storage and Transmission

- Examination of hydrogen permeation through materials at operando conditions (liquid and gaseous hydrogen), and development of hydrogen permeation barriers to prevent leakage and embrittlement.
- Design and development of a medium scale hydrogen storage demonstrator using depleted uranium from nuclear power (HyDUS).
- Compact hydrogen storage through its direct entrapment within materials (absorption and adsorption materials).
- Alternative methods for enhancement of hydrogen storage densities at more accessible temperatures and pressures.
- Subterranean storage of hydrogen in underground caverns.
- Development of hydrogen sensing materials for detection and metering.

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Hydrogen

Energy Systems and Integration

- Utilisation of hydrogen as a clean energy source across multiple sectors including aerospace and environmental control (heating/cooling).
- Systems thinking and approaches to explore the integration of hydrogen with existing energy systems and infrastructure taking into account safety concerns and leakage of hydrogen.
- Multi-vector energy systems and the required infrastructure for ensuring a resilient, sustainable UK energy supply chain.

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Hydrogen

Emissions and Impacts

- Hydrogen-induced degradation of materials during its production, transmission, storage and use.
- Extent and severity of hydrogen leakage and efforts to detect, quantify and mitigate/minimise this.
- Exploring hydrogen combustion via alternative hydrogen vectors and related emissions.
- Discerning the role of hydrogen as an indirect greenhouse gas and its subsequent impacts.
- Modelling of non-CO2 emissions for hydrogen fuelled aviation.

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Hydrogen

Policy, Economics and Public Engagement

- Development of economic models for a hydrogen economy.
- Labour impacts and skills shortages, both locally and regionally, including job displacement caused by the transition to a hydrogen economy.
- Geopolitical implications of moving away from fossil fuels and towards a hydrogen economy, including throughout the raw material supply chain.
- Policy and regulation of hydrogen as an energy source to ensure safety, equity and a just transition.
- Exploring the importance of public acceptance and how academic and industry engagement can enable this.

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Sustainable Industry

Industry world-wide will need to radically change the way in which it produces goods and consumes energy at a scale and pace that is unprecedented. The UK was one of the first major economies to produce an Industrial Decarbonisation strategy which sets out clear goals and roadmaps for emission reduction and abatement. This will require new chemical and agricultural processes, fuel switching, ultra-efficient manufacturing, regulatory frameworks as well as the acceleration of CCUS technologies.

Energy Efficient Computing
More information

Greenhouse Gas Emissions
More information

Decarbonising the Chemical Industry
More information

Sustainable Supply Chains
More information

Sustainable Industry

Energy Efficient Computing

- Energy efficient computing, with specific focus on assessing the environmental impact of digital services and their use
- Code optimisation to ensure minimal computational and therefore energy requirements for performing calculations

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Sustainable Industry

Greenhouse Gas Emissions

- Running UK DECC network of monitoring sites in the UK and Ireland measuring greenhouse and ozone depleting gases
- Developing systems to model transport and chemistry of atmospheric constituents to provide estimates on global, regional and sub-regional scale and improve the accuracy of UK greenhouse gas emissions inventory
- Development of systems for the removal and capture of harmful emissions eg: carbon capture from exhaust gases
- Improved design for efficient manufacturing and extended product longevity to reduce energy requirements throughout the product lifecycle

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Sustainable Industry

Greenhouse Gas Emissions

- Sustainable ecology, livestock rearing and pasture/crop management
- Modelling and assessing the global atmospheric methane budget
- Optimisation of dense CO2 for carbon capture and storage
- 3D printing democratization in attempting dematerialization and reduction of greenhouse gas emissions
- Tracking the movement of air parcels on urban and regional scale to understand distribution of emissions
- Monitoring, reporting and verification of greenhouse gas removal projects in forests and agricultural settings
- Long-term and secure sub-surface storage of CO2

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Sustainable Industry

Decarbonising the Chemical Industry

- Expanding use of digital tools, automation, photoredox & electrochemisty in chemical manufacturing processes
- Discovery of analogues for naturally occurring molecules and more eco-friendly raw material alternatives
- Improved and sustainable catalysis design and development
- Developing replacements for fluorinated “forever chemicals”
- Transformation of biomass and waste, including CO2, into high value chemical feedstocks and fuels currently sourced from fossil fuels.

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Sustainable Industry

Sustainable Supply Chains

- Working with companies and other stakeholders to coproduce new resilient supply chains with emphasis on circular economies throughout agriculture, manufacturing and services
- Understanding and theorising new sustainable value propositions for firms
- Link to work on digitalisation, using digital technologies (particularly 3D printing) towards sustainability
- Distributed manufacturing systems (relocalisation of production)
- Developing interdisciplinary methodological tools to map sustainability regional capabilities towards circular economies

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Nuclear

Nuclear power is the most energy dense, low carbon energy source the world has at its disposal and is key in meeting the UK's Net Zero targets. Nuclear technologies have the capacity to deliver beyond just electricity generation, with opportunities for it to be exploited for hydrogen generation, district heating and industrial processes. To fully harness the potential that nuclear technologies can deliver across the Net Zero challenge there must be an acceleration in fundamental research around materials, structural integrity, regulation as well financing to make the next generation of reactors and nuclear infrastructure a reality.

Fission

More information

Fusion

More information

Disruptive Technologies (Robotics and AI)

More information

Fission

- Research and development into next generation reactors (small modular reactors, advanced modular reactors).
- Lifetime extension of existing nuclear reactors (gas and water cooled).
- Earthquake engineering and ensuring resilience to geological events.
- Structural integrity of materials and components throughout the life cycle.
- Understanding materials degradation mechanisms (corrosion, creep and irradiation).
- Digital engineering, digital twins and surrogate modelling.
- Characterisation of nuclear waste.

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Fission

- Processing and management of nuclear waste.
- Developing nuclear as a source of hydrogen generation and storage.
- Nuclear forensics and security.

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Fusion

- Fuel production, use and sustainability (including Tritium and Lithium).
- Research and development into next generation reactors.
- Structural integrity of materials and components throughout the life cycle.
- Understanding materials degradation mechanisms (corrosion, creep, irradiation etc).
- Novel nuclear materials (including ceramic matrix composites, oxide-dispersed strengthened steels and copper-chromium-zirconium).

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Nuclear

Fusion

- Non-destructive testing for; reactor safety, and of manufactured components and products.
- Digital engineering, digital twins and surrogate modelling.
- Materials modelling.
- Manufacturing including joining technologies.
- High performance computing tools for plasma physics.

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Nuclear

Disruptive Technologies (Robotics and AI)

- Decommissioning of fission and fusion technologies.
- Manipulation of materials inside glove boxes including; optimisation of manipulator workspace, dextrous manipulation and tactile sensing.
- Human-robotic interactions including; user-centric design, teleoperation in extreme environments, haptic interfaces, and trustworthy autonomous systems.
- Nuclear forensics including radiation mapping and hotspots using aerial and ground-based robotics for site survey.
- Digital engineering, digital twins and surrogate modelling.
- Artificial intelligence techniques to enhance materials characterisation, device design and modelling.

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Policy and Regulation

Ensuring we have the correct mechanisms for encouraging, enabling and enforcing our move to Net Zero in a fair and efficient way will be vital to achieving our 2050 target and the broader ambitions of the Paris Agreement. This will require coordination and agreement across national and international boundaries to develop and enforce the required policies and regulations to deliver and embed Net Zero technologies and practices throughout the global economy. Additionally, this will ensure fair and effective mitigation and adaptation activities are delivered both locally, and across the globe as our environment changes due to the impacts of historic and ongoing emissions.

Mitigation, Adaptation and Loss

More information

Governance

More information

Global Challenges

More information

Policy and Regulation

Mitigation, Adaptation and Loss

- Greenhouse Gas Removal and negative emissions
- Fuel poverty policy including insulation and housing retrofit policy to improve energy efficiency
- Drivers and Barriers for retrofitting activities at local/regional levels
- De-growth and alternative economic systems
- Loss and damage including climate reparations
- Empowerment and working on ways to deal with climate anxiety and loss

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Policy and Regulation

Governance

- Accountability including sophisticated carbon accounting throughout the supply chain across different scopes (1, 2, 3)
- Assurance of greenhouse gas emission data
- Science based targets and carbon budgets including the role of corporate-level targets aligned with the Paris agreement
- Climate change modelling to ensure correct alignment of targets and policies
- Business regulation for enabling and enforcing a move to Net Zero including corporate governance mechanisms (board/committee structures, remuneration)

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Policy and Regulation

Governance

- Indicators for enhanced evaluation of environmental management performance in service industries
- Deliberative democracy for Net Zero
- Ownership models and financial instruments for Net Zero
- The role of alternative organisations including co-ops and B-corps
- Community engagement and participation to accelerate and enable transition
- Social value measures for Net Zero

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Policy and Regulation

Global Challenges

- Sustainable development and trade law
- Political ontology of Net Zero
- International legal responses to the climate crisis
- Climate justice in international environmental law
- International development, global policy making, and the global political economy
- Global governance of climate change to ensure justice is embedded in decision making

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Policy and Regulation

Global Challenges

- Impact and relationship of the UKs Net Zero shortages to global achievement of climate goals
- The role of global financial institutions including:
  - Corporate loan securitization to shed climate transition risk
  - The impact of central bank stress tests on lending choices and therefore the transition to a low-carbon economy
  - How partnerships of banks and non-banks facilitate the transition of corporations to the Net Zero economy based on their competitive advantages/disadvantages

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Sustainable Aviation

The aerospace industry has been identified as one of the most challenging sectors to decarbonise. Ultra-efficient aircraft design, climate optimal routing and zero-carbon emission propulsion systems must all be developed alongside international regulation and ground-side infrastructure and training to make zero emissions flying a reality.

Cleaner Aviation

More information

Quieter Aviation

More information

Smarter Aviation

More information

Sustainability through Behavioural Change

More information

Sustainable Aviation

Cleaner Aviation

- **Lower drag:** Creating new aircraft designs with lower drag and therefore fuel burn by optimising their aerodynamic design. Developing sophisticated analysis tools which capture the complex, multi-physics interactions between aerodynamics, structures, propulsion and actuation. Developing promising new adaptive solutions which work with the air instead of fighting against it. Using extensive wind tunnel testing capabilities to validate new concepts and analysis models.

- **Lighter weight:** Pioneering new composite materials, structures, and manufacturing technologies that enable designs unconstrained by traditional approaches. Improved structural performance leads to lower mass, directly reducing fuel burn, but it also allows for entirely new design architectures with new capabilities.

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Sustainable Aviation

Cleaner Aviation

- **Sustainable fuels:** Developing technologies to help replace fossil fuels in aviation, such as novel nanoporous materials and ultra-low temperature capable composite materials for hydrogen fuel storage.
- **Electric and hybrid propulsion:** Developing innovations to distribute and power electric propulsors, ensuring they are both lightweight and energy efficient. Focusing on the electrical power conversion technologies, electric actuation and energy systems while also developing aerodynamic performance improvements for electric propulsions.

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Sustainable Aviation

Quieter Aviation

- **Physics of noise:** Better fundamental understanding of the physics of noise generation from the different aircraft components, including propulsion systems, airframes, and high lift systems. Developing novel passive and active methods to directly reduce noise at its source.
- **Experimental testing:** Extensive aeroacoustic wind tunnel testing of solutions from academia and industry in our bespoke and uniquely capable National Wind Tunnel and Pressure Neutral Aeroacoustic Facilities.
- **Modelling:** Supporting design and development of quieter solutions with a suite of low to high fidelity computational aeroacoustic codes, with validation against wind tunnel experiments. Whole vehicle, noise focused design and testing to minimise noise propagation impact on communities.

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Sustainable Aviation

Smarter Aviation

- **Flying today's aircraft smarter:** Developing climate optimised routing approaches by incorporating into flight planning an understanding of the location and time dependent impact of emissions and contrails on climate forcing. Investigating formation flying to reduce drag and fuel burn with current aircraft.
- **Better understanding of climate impact:** Developing new approaches to emissions modelling, sensing and automation to understand the full climate impact of different aviation fuel sources, also considering NOx and other non-CO2 emissions.
- **Better control:** Developing the flight dynamics and control techniques needed to make formation flight, contrail mitigation, and aerial refuelling a possibility. Exploring robust, non-traditional approaches to de-risk the next generation of new aircraft concepts.

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Sustainable Aviation

Sustainability through Behavioural Change

- Effective integration of aviation with the wider transport and energy systems to increase resilience and enable decarbonisation
- Systems approaches to transport to enable improvements that prioritise, encourage and enable alternatives to aviation
- Changing attitudes and approaches to aviation to reduce demand
- Development of UAMs and UAVs as a means to decarbonise last mile delivery

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Electrical Systems and Devices

Accelerating the electrification of the UK energy system will be critical to the UK's plans for decarbonisation, with ambitions to see full electrification of new cars and vans by 2035 and bans on new gas boilers as early as 2025. These efforts, alongside the decarbonisation of manufacturing, will drive an electrification of current processes and will require our existing electrical machines to become significantly lighter and more efficient to meet our growing demands.

Electrical Systems and Devices

Power Electronics and Energy Management

Focus is on exploiting advancements in wide band gap power semiconductor devices in power electronic and power conversion applications including:

- Gate Driving and switching profiling to reduce losses and electromagnetic emissions, losses, EMI and additional filtering
- Characterisation and application of GaN and other emergent semiconductor materials including increasing efficiency by switching power devices safely at ultra-high slew rates, improving reliability by sensing junction temperature and device health
- Ultra-high efficiency power electronics including the miniaturisation of power conversion, enabled by the reduction of power loss to below 1%

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Electrical Systems and Devices

Power Electronics and Energy Management

- High voltage and grid-level power electronics. Characterisation of high voltage SiC devices and efficient, multi-level and robust grid-tied inverter architectures.
- Ultra-high Voltage power electronics applications (2-3kV)
- High Bandwidth measurement making visible high-frequency features in the current and voltage waveforms of SiC and GaN converters
- Gallium Oxide and its heterogeneous integration with other materials
- Diamond as a power electronics material and its integration with other materials
- Growth and growth development of power electronics materials

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Motors and Drives

- Research into compact, energy efficienct electrical machine formats and working with our industry partners delivering full scale test validation prototypes of these concepts
- Working on a range of solutions to improve the efficiency and robustness of aircraft generation and propulsion technologies
- Electrodynamic actuator technology encompassing the electro-mechanical actuator, power electronic driving circuitry and control strategies covering a wide range of mechatronic and dynamic control applications
- Exploiting superconducting electrical machines

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Electrical Systems and Devices

Digital Design, Manufacture and Testing

- Computationally efficient tools and methods for holistic electrical, thermal and mechanical design and integration
- Advanced digital manufacture tool chains, including additive manufacturing, applied to electrical machine drives and their thermal management
- Fabrication and manufacturing of devices
- Post-manufacture finishing processes, surface treatments and metrology
- Advanced electrical insulation systems, reliability and operational life assessment

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Electrical Systems and Devices

Digital Design, Manufacture and Testing

- Tool chain validation and calibration through forensic component and sub-assembly test
- Electrical testing of components and their reliability
- Advanced packaging of power electronics components

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Electrical Systems and Devices

Energy Storage

- Novel materials for supercapacitors and metal-air batteries through to development of novel components and devices
- Improved battery modelling systems to help determine cell performance under different thermal and cycling parameters
- Whole systems integration of renewable energy generation and storage, including hydrogen generation and alternative energy vectors

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Energy Systems and Design

Energy networks are crucial enablers of the wider energy sector and a pivotal infrastructure across UK society. As we move towards Net Zero these networks will become increasingly important as we seek greater efficiencies and stability while maintaining affordability and resilience of supply to all UK communities. A whole systems approach to appropriately design and integrate new technologies and energy vectors into our everyday lives in an efficient and effective way will be essential to us reaching this target. Energy systems design and operation practices must be revisited so that the challenges created by decarbonisation and climate change can be overcome in a Net Zero future.

Energy Systems
More information

Systems Design
More information

Energy Systems and Design

Energy Systems

- Multi-vector and whole systems analysis and simulation, including development of whole-system models and control regimes for transition and integration of energy systems
- Multi-vector and whole systems planning and operations, including integration of gases, heat, electricity networks and transport networks
- Examining interactions and interdependencies at local, regional and national levels, while accounting for required climate change mitigation and adaptation, within and across related systems.

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Systems Design

- Digital twins and Smart cyber-physical infrastructure to explore the impacts of integrating various aspects of the energy system, virtually and with live feedback from the physical energy system, using real world data in a way that is safe and secure from cyberattack
- Identification of impacts of various different interventions as part of a whole system before they are made, enabling effective prioritisation of the most important and impactful changes over the medium to long-term
- Efficient design, inspection and maintenance of interdependent energy systems infrastructure, including through multi-agent systems and swarm robotics

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