Institution: Newcastle University

Unit of Assessment: Engineering (12)

1. Unit context and structure, research and impact strategy

Overview

The School of Engineering at Newcastle University has a long history. Founded in 1871 (as Armstrong College), we remain committed to the vision of our eponymous founder, namely interdisciplinary research to meet contemporary global challenges. Those challenges have evolved over the past 150 years and so have we.

In 2017, we created an integrated School of Engineering recognising that the challenges we face today are not the province of any single engineering discipline. Our community is committed to an ambitious research agenda, designed to address Global Research Themes (GRTs, Figure 1) by capturing the synergies between disciplines. Working together alongside industry and other partners, the disciplines are providing research excellence at every scale from the nano, micro (and microbial), through urban, industrial and marine assets, and from all the sciences (physical, biological and social) to meet the GRTs.

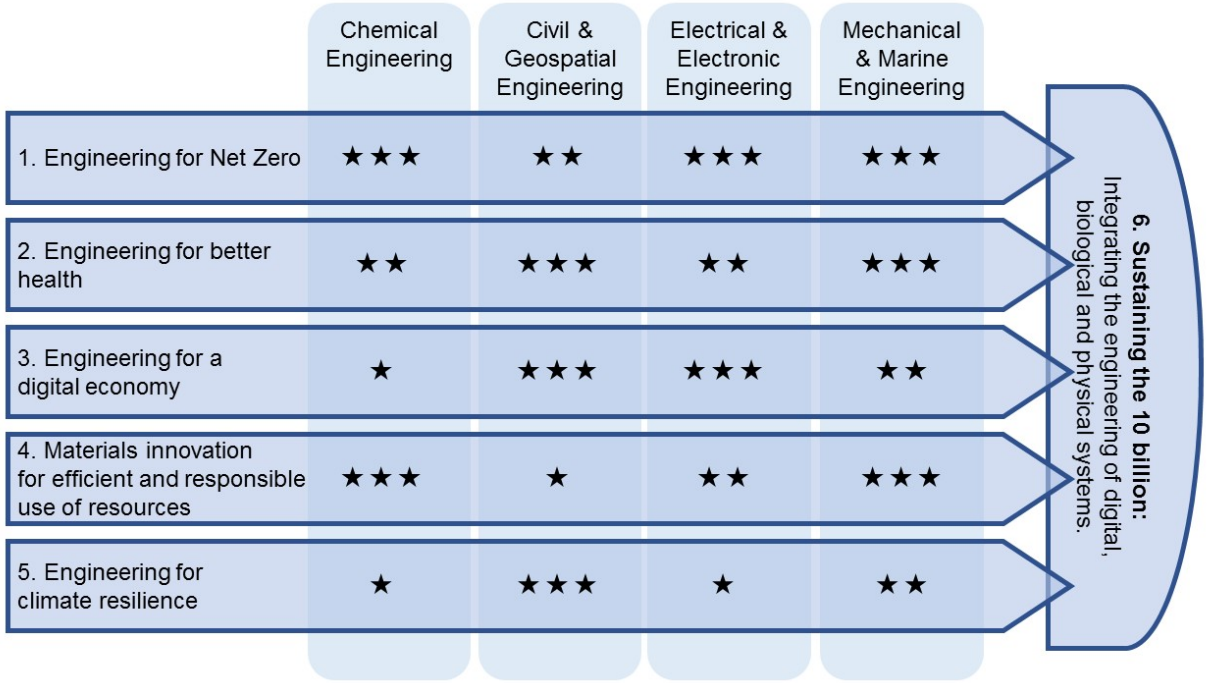

Figure 1. Global Research Themes integrate across our disciplines. □indicates proportion of discipline engaged in each theme.

Disciplinary excellence, the bedrock for our interdisciplinary vision, is provided through our 4 Disciplines and 16 Groups (Table 1). Colleagues are empowered to cross disciplinary boundaries to address GRTs supported by a vibrant and ambitious research culture (Figure 1). Collaborations occur at all levels from shared students to multi-million pound grants with partnerships that are local, national and international.

Table 1. Research outputs by group 2014-2020. Research income assigned to group of PI. PhD/EngD completions Jan 2014 to July 2020. ᐞDenotes new group since REF2014.

Discipline	Group	Returned Staff (FTE)	PhD/ EngDs completed	Research spend (2014-2020)	Journal Papers	Impact case studies
Chemical Engineering	Advanced Materials & Electrochemical Engineering$^{\Delta}$	9.3	46	£4.59M	197	
	Materials, Concepts and Reaction Engineering$^{\Delta}$	5	13	£5.08M	55	
	Process Intensification	9.9	64	£5.33M	168	
Civil and Geospatial Engineering	Environmental Engineering	11.4	56	£9.27M	199	[10]
	Future Mobility$^{\Delta}$	11.4	30	£7.96M	126	[4]
	Geospatial Engineering	11.2	23	£10.44M	146	[7]
	Geotechnics and Structures	15.6	27	£8.63M	155	[7]
	Water	16.2	31	£22.02M	180	[7], [8]
Electrical and electronic Engineering	Electrical Power	13.2	77	£31.60M	167	[2], [9]
	Emerging Technology and Materials	9.6	24	£3.83M	178	
	Intelligent Sensing & Communications	11	80	£4.65M	248	[5]
	Microsystems	6	37	£3.26M	63	[1]
Mechanical Engineering and Marine Technology	Bioengineering	8	24	£1.57M	144	[3]
	Design Manufacture and Materials	10	34	£5.12M	171	
	Fluid Dynamics and Thermal Systems	5	8	£1.57M (+£5.25M computing time)	184	
	Marine, Offshore and Subsea Technology	14.9	36	£3.21M	213	[6]
	Total	167.7	610	£128.1M	2594	

No single metric can capture the breadth of our ambition, and our vision is far from complete, yet since 2014 we have:

- Generated over £110M in new research awards and £24M in consultancy from more than 800 different projects
- Published over 2500 papers in refereed journals
- Published papers with authors from 1208 different institutions in 87 countries
- Invested more than £130M in infrastructure projects
- Increased contracted-researchers from 55 to 152
- Received more than 20 major awards (Fellowships and prestigious prizes)
- Worked hard on our journey to improve diversity, e.g. in the last four years our proportion of female professors increased from 7.8 to 12.5%

Vision & Research Strategy

Our School vision is "*to transform our world through developing and applying multi-disciplinary engineering knowledge for global societal benefit*".

The School of Engineering was formed from the realisation that the ambitions implicit in our disciplinary UoAs for REF2014 could not be met by those units alone. We needed a creative, inclusive, interdisciplinary and globally impactful approach to engineering research.

The creation of this new integrated School has benefited from NU's five guiding principles for **Research for Discovery and Impact**:

1. **Working together.** There are two simple truths at the heart of our vision: our people are the source of our excellence and by working together we can transcend our individual limitations and so rise to meet our global challenges to create an institution that is truly outstanding. We aim to embed equality, diversity and inclusion values to enable equal and inclusive access to decision making, development and opportunity. We promote integration and interdisciplinary work to create the synergies between ourselves and our disciplines. This promotion is both formal and strategic (through institutional initiatives such as Newcastle University Centres of Research Excellence (NUCoREs) and strategic industrial partnerships) and informal and serendipitous (through seminars, sandpits, charity fund raising and social events). Both approaches work and both are necessary.

2. **Excellence in infrastructure.** Excellent people deserve excellent facilities and our £130M investment has three strands: (i) The flagship refurbishment of the Stephenson Building will create a world class working environment that enables inclusivity and fosters interdisciplinarity with cross-disciplinary research hubs in areas such as bioengineering and digital manufacturing. (ii) Other investments support our disciplinary bedrock including, for example, geotechnical facilities, fluids testing, battery and drive chain analysis facilities and many modest, but vital, career enhancing investments in new staff. (iii) Partnerships with key stakeholders and UKRIC are developing a unique suite of testbeds that streamline the innovation cycle and accelerate impact. These include large marine facilities (with cavitation tunnel) at the Port of Blyth; Driving the Electric Revolution North East Industrialisation Centre close to Nissan's Electric Vehicle factory; BE:WISE, a Northumbrian Water pilot treatment facility at Birtley; the UKCRIC National Green Infrastructure Facility; the Urban Observatory and smart energy systems and storage facilities within the Urban Sciences Building with support from Siemens, Newcastle City Council, Northumbrian Water and Northern Powergrid.

3. **Visibly leading.** We lead nationally and internationally. A significant number of Engineering colleagues have driven research and policy to help realise our global challenges during the REF period e.g. Chief Scientific Advisor for the Department of Transport (Blythe); WHO (Graham), Committee on Climate Change (Dawson); Intergovernmental Panel on Climate Change (Fowler); National Infrastructure Commission Technical Expert Panel (Dawson); EPSRC Advisory Council (Taylor); EPSRC Strategic Advisory Team (Chakraborty); Royal Society report on Hydrogen (Metcalfe); FREng (current Blythe, Bull, Mecrow, Metcalfe, Postlethwaite, Yakovlev, and emeritus Braiden, Johnson, Morris, O'Connell, Page); RAEng Chair (Metcalfe).

4. **Integrity and ethics.** We hold ourselves to the highest standards of professional conduct, openness, fairness, and honesty. This reflects our engineering ideals and the institutional imperative of EDI to act fairly and honestly, as discussed in section 2. PhDs and new researchers are trained in the principles of Responsible Research and Innovation. We promote rigour, integrity and honesty during preparation and peer review of papers and proposals, fully acknowledging contributions from colleagues and collaborators, and we resolve cases of misconduct through application of the University code of practice (www.ncl.ac.uk/research/researchgovernance/goodpractice/). Ethical issues are

systematically reviewed during the costing and proposal approval process and the School Ethics Committee (Chair: Prof. Degenaar) considers all cases where issues have been raised (following the University's Policy and Procedure). Research data and publications are open access unless there are overriding commercial or ethical reasons not to be.

5. **Responding to current and future global challenges.** Focusing our research around GRTs enables us to be more responsive, interdisciplinary and strategic. They are more than just themes to describe what we do, they present ongoing challenges that are leading to significant research success and impact (as summarised below), and will inform our research strategy for the next REF period.

GRT 1: Engineering for Net Zero. This theme looks to deliver a thriving, low-carbon economy by 2050, resulting from rapid and coordinated action at scale, across sectors. Underpinned by flagship awards, including RAEng Chair in low carbon technologies, leadership of UKRI Driving the Electric Revolution Industrialisation Centres programme, EPSRC's National Centre for Energy Systems Integration and EPSRC's CDT in Sustainable Electric Propulsion our research is developing efficient engines for air, road, rail, shipping transport; batteries for electric vehicles; renewable energy technologies, especially hydrogen; carbon capture & storage; and smart grid technologies. Over the next REF period our emphasis will be on integrating across these systems to enable households to achieve net zero living.

GRT 2: Engineering for better health. Health engineering has a 70 year history at NU. With the £5.6M EPSRC Frontiers award, we have engineered biological systems for advanced wastewater treatment and pollution remediation. Advanced new materials, precision manufacturing techniques, and neural engineering are helping to restore human mobility e.g. Controlling Abnormal Network Dynamics with Optogenetics, £10M Wellcome/EPSRC grant; and our sensors and home modification technologies enable aging populations to maintain independence for longer. Over the REF period, expansion in Bioengineering and investments in the Stephenson biomedical facilities will help us to develop devices with smart sensors to improve further quality of life.

GRT 3: Engineering for a digital economy. Engineering is a core member of the Turing Institute and hosts Turing Fellows and projects. We are developing fundamental new technologies, from sensors, geospatial data acquisition and processing, smart transport and energy systems, enabled by microprocessors designed and optimised for AI calculations. These have enabled us to pioneer a "digital twin" of a water system, an industry first. Our flagship £8M Urban Observatory, the world's largest set of publicly available real time urban data, is being replicated in Bristol, Manchester, Sheffield, and Birmingham through our role as lead of the UKCRIC Observatories programme. Over the next REF period we will exploit the full potential of real-time data to develop new mechanisms to leverage data science and simulation and build, for example, the foundations for an Urban Digital Twin.

GRT 4: Materials innovation for efficient and responsible use of resources. Our research is underpinning the nation's future competitiveness and creativity through successful development and innovation of new materials and manufacturing techniques. Applications range from the nanoscale, through 3D printing, artificial limbs, up to construction of the built environment. We draw inspiration from biological systems that have led to lighter, self-healing, more sustainable materials. Major grants include the £1.8M EPSRC North East Centre for Energy Materials, and most recently exploratory work on biological construction through the

university's £8M Hub for Biotechnology in the Built Environment (HBBE). Activities in the next REF period will see growth in bio-construction, bio-fabrication and bio-inspired materials.

GRT 5: Engineering for climate resilience. To help protect people and the economy it is crucial to enhance the resilience of infrastructure and the built environment. We have pioneered the production of climate information for engineering design, use of geomatic data to characterise engineering performance and monitor extreme events, and methods to assess climate risks to infrastructure systems. Leadership of flagship initiatives such as the £2.3M NERC OnePlanet DTP, £17M GCRF Water Security Hub, £9.7M UKCRIC National Green Infrastructure Facility (NGIF), and roles on the UK's Climate Change Committee and Intergovernmental Panel on Climate Change means we are uniquely placed to have a major impact in this GRT. Over the next REF period we will focus on the use of big data and AI in climate adaptation, as well as characterising the engineering performance of nature-based solutions.

GRT 6: Sustaining the 10 billion. This overarching theme recognises that engineers must take a holistic approach to reconfiguring complex systems, such as cities, to support a projected global population of 10 billion within the 21st Century. Just as engineering at NU was founded in 1871 to meet the challenges and opportunities of the 2nd Industrial Revolution, *integration of our expertise in the engineering of digital, biological and physical systems makes us uniquely placed to contribute to delivery of the 4th IR.*

Group research profiles and future strategies

Groups are the engines for research activity, they set their own research strategy, which is reviewed annually with the School Executive Board, complementing the individual Performance, Development and Review process and including EDI impact assessment. Directors of Discipline (DoDs) provide strategic leadership, facilitate coordination between groups and ensure, with the School Director of Research, that research is integrated across the School.

Chemical Engineering (DoD Professor Biggs)

The underlying philosophy of Chemical Engineering is to **develop world-class, blue skies research and apply it to industrial challenges in the fine chemical, energy, pharmaceutical and food sectors**. By drawing on a range of expertise, the discipline achieves innovation in materials and manufacturing to realise **responsible consumption and production** and **clean growth**.

Advanced Materials and Electrochemical Engineering: Professor Siller (Head), 11 academics, 14 RAs and 25 PhDs

The group rationale is the development and application of new materials where both structural and functional performance are important, particularly using electrochemical methods. It is known for synthesis and modelling of nanostructured porous materials (the largest UK group

working on aerogels), electrochemical processes in fuel production, hydrogen fuel cells and batteries, surface engineering and high-resolution characterisation.

Building on the REF2014 strategy of improving sustainability and enhancing industrial competitiveness, the group was formed by merging two to create critical mass for work in two areas: energy and healthcare materials. The current grant portfolio contains significant funding: EPSRC NECEM grant (EP/R021503), Earth abundant metal air batteries (EP/R020744) and Next generation anion exchange membranes (EP/T00939); Faraday Institution funded Battery degradation and recycling and reuse start up grants; as well as other income from UK Government and industry. Work in healthcare materials has been strengthened by two appointments: Geoghegan (the Group's second Cookson chair), working on soft matter surfaces, and Peeters working on biosensors.

The group has had major involvement with Supergen on fuel cells and renewable energy (EP/H019596, EP/H019489, EP/K013319 and winner of institutional EDI award for commitment to diversity in engineering), and is a significant partner in the RENU CDT. Work on the decommissioning of lithium ion batteries has resulted in emerging impact through interactions with fire officers and local authorities. We work closely with industry to transfer technologies we develop to the marketplace e.g. spin out company, Dragonfly Insulation Ltd, to exploit our novel low cost aerogel product patent. The group plans to extend work on energy materials and smart materials, developing improved characterisation techniques and smart materials for wearable textiles. An increasing focus on the sustainable use and reuse of materials will be important over the next REF period in line with our GRTs.

Materials, Concepts and Reaction Engineering (MatCoRE): Professor Metcalfe (Head), 5 academics, 4 RAs and 10 PhDs

This is a relatively small but distinctive group delivering innovative concepts, materials, devices and chemical engineering solutions which impact upon technological challenges facing mankind. MatCore's interests lie in bridging the gap between material science and chemical and electrochemical reaction engineering. It studies the connection between structural and compositional properties of materials, and their physico-chemical properties, in order to discover, design and optimise materials for end applications. Application areas include catalysis, emissions control and energy conversion and storage; and all are of national and international strategic importance. The group excel at characterisation and have pioneered several cutting-edge techniques.

The group was formed in August 2017 with the recruitment of Papaioannou, Hu and Pramana to work alongside Metcalfe, who holds an RAEng Chair in Emerging Technologies, in order to provide critical mass in an area of significant strength. The group has been very successful, notably being awarded EPSRC Programme Grant (EP/M01486), ERC Advanced Grant, and RAEng Research Fellowship (Mutch).

The Matcore strategy is to seek problems, which others have regarded as being of extreme difficulty, and to supply transformative discipline-leading solutions. (i) *Membranes:* We are developing single crystal-hosted membranes for the optical and spectroscopic investigation of membrane transport processes. This is improving performance for difficult separations of permanent gases including oxygen, carbon dioxide, NOx and SOx. We are also designing high

temperature membranes that rely upon the co-permeation of species allowing one species to 'pump' the other to higher chemical potentials on separation such as humidity-driven carbon dioxide separation. This is leading to new processes where ambient sources of energy are used to drive carbon capture processes. (ii) *Reactor and materials design:* To overcome reaction equilibrium limitations and achieve close to 100% conversion whilst producing multiple pure products separately in a single unit operation (e.g. synthesis gas to dry hydrogen and pure carbon dioxide from a single reactor at high temperature). This allows us to operate much simplified processes for e.g. hydrogen production. There is considerable interest in this area and Newcastle holds relevant process patents. Metcalfe's RAEng chair in emerging technologies is supporting efforts to scale-up.
(iii) *Catalytic processes*: We are bridging surface science and chemical engineering by understanding and controlling segregation in materials. This includes the development of highly active catalysts with 'infinite' lifetimes. We have used metal exsolution from the support to produce 'anchored' catalyst nanoparticles that cannot participate in sintering processes. We are now working on robust catalyst systems for methane reforming where a large number of potential applications exist, not least in hydrogen production. MatCore will continue its ground-breaking research to provide the underpinning chemical engineering to realise our GRTs.

Process Intensification: Professor Harvey (Head), 12 academics, 5 RAs and 50 PhDs

Process Intensification (PI) involves the development and application of new technologies and techniques for process industries that produce our chemicals, materials, pharmaceuticals, biochemicals and food. Specifically the techniques reduce the size of process technology by at least an order of magnitude. This significantly reduces capital and running costs, environmental impact and process risk.

Arguably the largest PI research group in the world in terms of group size, it is world-leading in the development of rotating process technologies, heat pipe technologies, oscillatory baffled reactors and has significant research in process modelling, plasma processing, microfluidics/flow chemistry, and microfluidised beds. Key applications include biofuel processing, biomass processing more widely and CO_2 sequestration. Harvey and Reay authored the main textbook on Process Intensification. The Group manages the "Process Intensification Network" which has run an international symposium every year since 1999.

Since 2014 the group strategy has been to increase the range of technologies and applications of PI. For example, "Intensified by Design" an €11M EU project involving 22 partners focussed on the intensification of solids processing. This led to development of a Heat Pipe Screw Dryer for efficient drying of ceramic materials, a Taylor-Couette device for particle classification at Newcastle and a review paper in Chem. Eng. Process. (2017), which was the first journal paper to discuss the application of PI in solids handling processes. From 2015-2019, ***Harvey*** led the £5.6M EPSRC BBTC EngD Centre, which produced 45 graduates, all embedded in the bio/pharmaceutical industry.

Targeted appointments were made over the REF period: Zivkovic (particle characterisation), Law (thermal design) and McDonough (additive layer manufacturing of reactors). Over the next 5 years, the PI group will apply its skills to tackle new compact reactor research areas, such as plasma reactor engineering, 3D printing of chemical reactors, CO_2 sequestration and wastewater treatment.

Civil and Geospatial Engineering (DoD Professor Kilsby)

Civil and Geospatial Engineering has an outstanding record of research achievement, ranked 2nd by Research Fortnight for Power in REF2014. Their vision is to develop new scientific understanding, engineering analysis and design, and apply it to enhance the future resilience of infrastructure networks, cities and river basins in the face of global change. With strong emphasis on sustainability, underpinned by powerful new data sensing, analytics and simulation they are setting the agenda in the digital transformation of the discipline.

Environmental Engineering: Professor Curtis (Head), 13 academics, 19 RAs and 38 PhDs

Environmental Engineering has excelled since the 1940s with a vibrant mix of fundamental engineering science (including engineering biology, novel iron chemistry and microbial electrochemistry), problem solving and policy (in areas such as mine-water pollution, anti-microbial resistance, solar disinfection and the circular economy). Its activities have garnered an enviable international reputation and network of collaborators in 26 countries. Since 2014, approximately 65% of its 400 publications have international co-authors. This international outlook has not been at the expense of the local community and industry where the group is firmly embedded. For example, there are collaborations with Newcastle Council on air pollution and an ongoing strategic partnership with Northumbrian Water.

The group has broken new ground with a mixture of sustained funding, new blood, a highly multidisciplinary ethos and an actively managed culture of creativity (with 3 EPSRC “Bright Ideas” awards). Engineering biology is one example of strength, with over £7M research income and an interdisciplinary team ethos, from which we have developed new strategies for modelling and measuring engineered microbial communities through 13 orders of magnitude in scale from a single cell to a pilot wastewater treatment plant. A corollary of our pre-eminence in molecular microbial ecology is global leadership in determining the role of environmental engineering in emerging antimicrobial resistance. This has delivered headline making findings in studies from the arctic to the tropics, and a strategic advisory role for Graham with the World Health Organisation and leading NU activities on detecting COVID in wastewater. Sustained funding from industry has supported the development of impressive full-scale treatment systems for mine-water pollution and hydrocarbon polluted sediments and world leading contributions to the regulation of new pollutants.

Since REF2014 we have attracted 4 academics and new research fellows who have strengthened the group with their diverse skills and research successes: e.g. developing clay minerals as a previously unsuspected source of disinfectants and catalysts, providing powerful insights into the real limits in our anticipated circular economy, searching out new frontiers in microbial modelling, developing strategies on the scourge of air pollution and generating new local and international collaborations.

Our strategy is to extend this record of achievement by sustaining our vibrant and collegiate culture. The vision is to embrace every facet of environmental engineering from computer simulations to biology to clay chemistry to find responsible and real world solutions to protect the health of the environment and the people in it.

Future Mobility: Professor Robinson (Head), 12 academics, 12 RAs and 10 PhDs

The Future Mobility (FM) group was formed in 2017 to provide a coherent, interdisciplinary group for multi-modal passenger and freight transport by merging TORG, the Transport Operations Research Group, with NewRail, the Newcastle Centre for Railway Research.

FM brings together complementary expertise to address the challenge of how technology can transform transport systems of the future whilst tackling the key challenge of decarbonisation and putting the user at the heart of future transport systems. We are working with alternative propulsion systems for decarbonisation purposes, one of which is hydrogen but there are others, electrification of rail and new traction sources. We are researching how we can influence travellers to make more sustainable choices. To this end, since REF 2014 we have made 2 key appointments in behaviour and environment so that we can research the impact of technologies on individuals and their environment. For example, with UKRI support (ES/5006885/1) we are exploring the role autonomous electric vehicles and shared mobility services have on travel behaviour, user acceptance and the environment.

FM is strong on consumers and technological competencies and has an extensive multi-modal, multi-disciplinary research portfolio. There is a wide range of expertise in interconnected areas of technology, behaviour, electrification of transport freight logistics, safety and security. It is strongly linked to other Engineering groups (e.g. Marine Technology, Design Manufacture and Materials) and University centres such as the National Innovation Centre for Data, National innovation Centre for Ageing, CESI, UKRRIN and UKCRIC. The UKRRIN contract provides £10M research funding to investigate rail vehicle innovations.

FM has strong links with policy, consumer behaviour, safety, social acceptance, and standards of transport that lead to research advances and impact. Over the coming years, the group will focus on autonomous vehicles, decarbonisation, freight, logistics, and mobility as a service. This will capitalise on the national agenda and the UK's *future of mobility* grand challenge.

Geospatial Engineering: Professor Clarke (Head), 13 academics, 13 RAs and 19 PhDs

The group conducts research across the spectrum of geospatial engineering, from underpinning basic physical/information science through to engineering applications. It encompasses three intertwined strands: (i) *Geodesy*: precise static and kinematic GPS/GNSS positioning, satellite laser ranging and orbital modelling, reference frames, Earth's changing gravity field, surface mass loading modelling, inland/ocean altimetric remote sensing, InSAR/GB-SAR deformation monitoring and precision agriculture; (ii) *Earth Observation ("NEO-Lab")*: multi-temporal, multi-modal modelling/monitoring, including terrestrial/airborne laser scanning, mobile mapping, InSAR/GB-SAR, photogrammetry, optical remote sensing, computer vision, early warning systems; and (iii) *Geospatial Data Analytics and Modelling*: spatial analytics, visualisation, heterogeneous sensor networks, geospatial data fusion, integration and development of geospatial information and decision support systems.

We excel in the geodetic measurement of cryospheric change and other geohazards (multiple NERC and ESA grants), the use of laser scanning and other remote sensing techniques for urban and heritage monitoring, flood prevention and the development and use of multi-sensor networks (e.g. leadership of the UKCRIC Urban Observatories programme). Our leadership in

these areas has been recognised by the award of the EPSRC CDT in Geospatial Systems (PI: Mills) which forms the basis of many of our multidisciplinary collaborations.

Our research vision builds on our internationally leading status (e.g. International GNSS Service and NERC COMET+ operations) in our three themes. We will advance geodetic science using forthcoming satellite missions and apply this to regional- and local-scale engineering responses to geohazards. We will increase the fusion of data from satellite, mobile terrestrial, airborne (including UAV) and seagoing robotic sensors to provide the geospatial input needed to address geohazards and engineering-societal-environmental problems. Through our geospatial CDT we will train a new generation of students able to design and develop solutions for the capture, management, analysis and modelling of geospatial data that enable a wider range of complex engineering-societal-environmental problems to be addressed in a systems-based manner. We will achieve this by developing the next generation of 'big data' geospatial data management systems.

Geotechnics and Structures: **Professor Utili (Head)**, **14 academics, 5RAs and 12 PhDs**

The group combines the traditional disciplines of Structural and Geotechnical Engineering to work on the grand challenge themes of sustainability in construction and climate change effects in civil engineering. A particular strength is developing resilient infrastructure systems under extreme conditions and natural hazards (e.g. landslides, earthquakes, flooding, climate change). The group leads (or has led) the flagship ACHILLES Programme Grant (£4.9M, EP/R034575), iSMART (£2.5M, EP/K027050/1), and Understanding transient response to climate change in coupled hydro-eco-geomorphic landscapes (NERC). We are/have been significant partners in CACTUS (£1.8M, EP/R005834), HERCULES (€2M, EU H2020 RISE), and Realtime assessments of wind related damage to electricity infrastructure (NERC).

This work is complemented by research at the material scale, looking at long-term degradation processes (DURACOMP, £1.4M EP/K026925/1), the development of novel sustainable cement (Engineering Microbial-Induced Carbonate Precipitation via Meso-Scale Simulations £0.6M, EP/S013997/1), and transforming soils through synthetic biology (Computational colloids P/N005791/1 & Thinking soils £0.6M EP/R003629/1). Our research has also necessitated the development of multi-scale numerical tools for application to the landslides, infrastructure networks and novel construction materials embedded in these programmes. Our work on deterioration and performance of materials and infrastructure systems has helped shape practice and European Standards (CEN248 & CEN250 for technical textiles).

There is a distinctive focus on full-scale observation, experimentation and demonstration through continued leadership of the BIONICS full-scale embankment test facility, construction of the Key (a novel sustainable fabric structure; newcastlehelix.com/about/the-key) and joint leadership of £9.7M UKCRIC National Green Infrastructure Facility and £8M UKCRIC Urban Observatory.

Following staff departures, our strategy has been to recruit new leadership (Utili) as well as ECRs and research fellows that support our broad strategy and take us into new and exciting directions: Bruno (hydromechanical modelling of geo-materials); Dunn (catastrophe modelling of infrastructure networks); Masoero (chemo-mechanics of porous materials); Mofidi (bio-based composites & rehabilitation); Nadimi (urban geothermal heat), and Fellows: Milledge (landslides

assessment and mitigation); Theodoridou (biological processes for structural repair) and Stirling (climate-vegetation-soil interactions).

The future strategy is to grow further our work on sustainable, resilient infrastructure systems with an increased focus on integration of digital technologies, and to contribute to the School's GRTs by pioneering biotechnology for the built environment, understanding long-term interactions between the natural and built environments in a changing climate, and decarbonising heating and cooling using geothermal energy.

Water: Dr Parkin (Head), 16.4 academics, 19 RAs and 14 PhDs

Water research at Newcastle University marked its 70th anniversary in January 2020. The Water Group is internationally renowned for its work on (i) Blue-Green Cities and Resilient Infrastructure; (ii) Catchment and Water Management (e.g. Advise Nile Basin Initiative, our SHETRAN hydrological model used to develop water management plans in >100 catchments worldwide especially in India, South America and Africa); (iii) Climate Impacts and Adaptation; (iv) Flood Risk Management.

Since 2014, the group has reinforced its internationally leading position. NU holds (as PI) 20% of all EPSRC university research classified by sector as 'water', (£33.9M, not including grants on which we are CoIs), more than any other UK institution (from grants on web: April 2019). The group leads multiple flagship programmes including the £9.7M UKCRIC National Green Infrastructure Facility, the £7M NERC ONE Planet DTP, and the £18M GCRF Water Security and Sustainable Development Hub. The group is also a partner in other major programmes including the EPSRC Water Infrastructure and Resilience CDT, the Twenty65 Water Grand Challenge programme, the GCRF Living Deltas Hub, and the ITRC and MISTRAL Infrastructure Programme Grants. The group also has a robust NERC and EU funding record.

Following two retirements (O'Connell, Bathurst) and one death (Kutija) our recruitment strategy has been to recruit new academics in exciting emerging research areas, especially with expertise in AI and big data analytics. This has been bolstered by a £1M investment in additional staff from the University's Research Innovation Fund in recognition of the group's sustained successes.

Four priority challenges for the coming years that build on recent grant successes and new appointments are: (i) Big data and digitisation, supported by NERC Flood-PREPARED (NE/P017134/1), Urban Observatory, Dawson as Turing Research Fellow, Parkin and Quinn's innovation in citizen science in UK and Ethiopia, and appointment of Smith as Lecturer in Data-Centric Civil Engineering. (ii) Delivering SDG6 and global water security, supported by substantial success in GCRF, reflecting the group's international links and profile, and live projects in all continents apart from Antarctica, funded by a range of UKRI, DFID and GCRF successes including EPSRC urban green Dams (EP/S005862/1), NERC Resilience to pluvial floods (NE/S005994/1), NERC Indonesia Rainfall (NE/S003274/1) as well as the GCRF Water Security Hub which we lead. Work in this area is enhanced by new academic appointments Walker and Lewis (iii) Delivering engineering design standards through scientific understanding of green infrastructure and nature-based solutions supported by unique NGIF laboratory and

appointments of Hewett and Walsh. (iv) Climate Ready Cities supported by One Planet DTP, EPSRC Blue-Green Cities (EP/K013661/1) and appointment of Fellows Forsythe and Guerreiro.

Electrical and Electronic Engineering: DoD Professor Pickert

EEE expertise ranges from high power applications such as electric propulsion for aircraft to ultra-low power applications such as implementing microsystems into the brain. It is known for its impact generating inter-disciplinary research in information technology, human health, energy systems and sustainability. They lead several major Centres in the area, including EPSRC CDT in Sustainable Electric Propulsion, EPSRC National Centre for Energy System Integration and the Dyson Research Centre.

Electrical Power: Dr Atkinson (Head), 16 academics, 37 RAs and 52 PhDs

Electrical power is key to a more electrified world driven by global environmental, political and technical challenges. The group is one of the strongest power groups in the UK and is renowned for its research impact. It leads the agenda on:

(i) Electric Drives, especially for transport applications
(ii) Energy Storage, especially on recycling
(iii) Smart Distribution Grids, especially on buildings offering services to the grid

In REF2014, the strategy of EP was to grow in two key areas: electric drives/motors and energy/smart grids whilst maintaining the success of others. We have recruited three new Lecturers, one in Electric Drives and two in Energy/Smart Grids who have helped to grow activity significantly in both areas. Grants, each of value in excess of £750K, in these areas include:

Electric drives/motors:

- Hoganas Technical Centre (from 2014, £180K per year)
- EPSRC Future Electrical Machines Manufacturing Hub (2019, EP/S018034, £10.4M)
- Goodrich Actuation System: Flap Actuation System (2019, £792K)
- EPSRC CDT in Sustainable Electric Propulsion (2019, EP/S024069/1, £5.4M)

Energy/smart grids:

- EPSRC CESI- Centre for Energy Systems Integration (2016, WP/P001173, £5.4M)
- Faraday Institution Recycling of Lithium Ion Batteries (2017, £7M)
- EPSRC The Active Building Centre (2018, EP/S016627/1, £35M)
- Innovate UK E4Futures V2G (2018, £9.8M)
- EPSRC Supergen Energy Networks Hub (2018, EP/S00078X/1, £3.8M)
- Goodrich Actuation System: Flap Actuation System (2019, £792K)

EP has been awarded 147 research projects funded by the EU, UKRI or directly from industry over the REF period.

Although a number of senior research staff have left since 2014, the group has recruited new academics and grown in size from 13 to 15 while the number of research associates has more

than doubled to 35. We will grow our leadership in power-related electrification and our goal is to lead the electric revolution in the areas of electric drives/motors and energy/smart-grids. With its current staff, EP has the critical mass to continue to lead in electric drives/motors and energy/smart-grids but also to contribute to new emerging areas such as electrification of biomedical devices and superconductivity. Our plans are to advance in the following four areas:

(i) Electric drives from milli watts to mega watts
(ii) Battery safety research & training
(iii) Electric transportation
(iv) Electrical energy use

These ambitions are greatly assisted by NU's leadership of the £30M Driving the Electric Revolution consortium which will see the creation of four industrialisation centres to enable faster collaborative research and development of electric machines for cars, planes and ships. The group is appointing a new Professor of Electric Drives to lead DER NE Industrialisation Centre. We are extending our research facilities as part of the Stephenson development on campus, and our impact through innovation centres e.g. the InTEGRel partnership with Northern Gas Networks and DER.

Emerging Technology and Materials: Dr Healy (Head), 10 academics, 9 RAs and 19 PhDs

ETM has an all-encompassing research programme with an atoms-to-applications philosophy. Its research covers all aspects of the technology development cycle from computational materials discovery, through materials development and characterisation, to optical and electrical devices. It has agenda defining research in:

- Semiconductor device technologies for extreme environments, e.g. SiC devices.
- Quantum mechanical in-silico materials discovery; we are home to the AimPro density functional theory program, used by hundreds of groups across the world.
- Materials development; in particular, new energy, low-dimensional and photonics materials.
- Bioelectronic devices; the development of implantable electronics devices used for in-vivo neural control.

As part of a University strategy to re-establish a Department of Physics, there have been 5 appointments in the ETM group since REF2014. This has brought expertise in material's discovery, optical devices and device physics, which complement existing semiconductor physics/device expertise. This has enhanced the scope and reach of ETM with fundamental research translating directly into engineering applications e.g. defect studies at the quantum mechanical level have explained hidden optical transitions in diamond, Fe^{+} contamination of silicon components, and the effects of morphology in SiC devices.

The nature of ETM gives it the ability to push the boundaries of engineering at a fundamental level, while simultaneously being multidisciplinary. Key collaborative activities include:

- CANDO (NS/A000026/1, £10M). A multi-site, cross-disciplinary project to develop a cortical implant for optogenetic neural control.
- TeamTao, the only UK team to reach the grand final of the Ocean XPRIZE, winning the Moonshot (innovation) Prize.
- EPSRC CDT in Diamond Science and Technology.
- EPSRC CDT in Sustainable Electric Propulsion.

In the future the group is uniquely placed to bridge fundamental research in physics with electrical engineering innovation in optoelectronics and healthcare.

Intelligent Sensing and Communications: Dr Tsimenedis (Head), 11 academics, 10 RAs and 26 PhDs

ISC conducts world-leading research and delivers impact across a spectrum of communications and digital signal processing from underpinning theories through to applications. Its research comprises two interconnected strands: 1) Intelligent Sensing for limb prosthetics, biometrics, ultrasound imaging and non-destructive testing (NDT) and; 2) Communications, including wireless and underwater acoustics.

In REF2014, the group strategy was to invest in biomedical engineering and underwater communications, whilst maintaining success in other areas of communication. With support from Newcastle University's Research Investment Fund (£0.75M) and two appointments in biomedical engineering (Nazarpour and Dyson) there has been significant growth in this area, which is now supported by funding of £2.8M from EPSRC and NIHR, including an EPSRC Healthcare Technology Challenge Award of £1.28M (EP/R004242/1). Research in wireless and underwater communications received EPSRC and EU funding of £2.15M, including the EPSRC project USMART to develop smart dust for large scale underwater wireless sensing (£1.58M FEC, EP/P017975/1). NDT research has attracted EPSRC and EU funding of £1.95M, including the EPSRC project NEWTON to develop novel sensing networks for intelligent monitoring (£1.47M FEC, EP/J012343/1). At the time of submission, the value of active EPSRC grants is £5.55M.

In the next few years, ISC will broaden its industrial base and expand into emerging areas of wireless communications for 6G and beyond, machine learning and artificial intelligence, internet of things, security and surveillance, Agritech, bioelectronics medicine and healthcare.

Microsystems: Professor Yakovlev (Head), 6 academics, 4 RAs and 20 PhDs

Microsystems is world leading in asynchronous and low power circuits and systems and is highly successful at translational research in formal design and verification methods. Following the REF2014 strategy, the group has expanded into *(i) Power modulated computing:* Energy-driven, real-power computing for future autonomous electronics in its trillions of devices. *(ii) Biomedical more than Moore:* Combining industrially fabbed MEMS and CMOS architectures into advanced implantable microsystems for neuroprosthetics and electroceuticals. *(iii) Design productivity:* Analogue-mixed signal design automation and asynchronous-analogue co-design for complex electronics to improve design productivity.

It contributes to a large portfolio of grants, including PRiME (EPSRC £5.6M), POETS (EPSRC £5M), OptoNeuro (FP7 €2.1M), CANDO (Wellcome £10M), and has expanded its expertise with a new Lecturer bringing opportunities in computing with functional materials (photonics, meta-materials), MEMS/More than Moore, Energy modulated computing and 5G comms. Microsystems will continue to exploit its strong links with industry, which have generated considerable impact over the REF period e.g. with Dialog, Impact Case Study 1.

The strategy is (i) to build on its leadership in design methods and tools for energy-constrained and power-efficient electronics (Impact Case Study 1) through a wider range of industrial applications involving analogue, digital and mixed-signal systems and radically new forms of

computing, involving meta-materials and electromagnetic waves; and (ii) to establish international leadership in developing system design platforms for explainable artificial intelligence with on-site real-time and real-power learning capabilities, thereby enabling routes towards applications in biomedical engineering (e.g. bionic eye, on-site disease diagnostics) and internet of things (e.g. self-power environmental monitoring and industrial predictive maintenance).

Mechanical and Marine Engineering: DoD Dr Palacin

The research strategy of Mechanical and Marine Engineering is to acquire fundamental knowledge and translate it into applied interventions, together with our partners, to deliver net zero road, rail and marine transportation systems, and bioengineering healthcare systems. Central to our approach is the interdisciplinary nature of engineering creativity, reflected in the range of expertise of our teams and anchored in design principles. Following on from the REF2014 strategy of developing sustainability research and supporting industrial competitiveness we have focussed on industrial design (particularly in the transport sector) and healthcare research.

Bioengineering: Professor Joyce (Head), 8 academics, 2 RAs and 26 PhDs

Bioengineering has two main themes: medical devices and their regulation, and biomaterials. Medical device research is focussed on the development and assessment of new devices for knee, hip and spinal implants, including biotribology and the adverse effects of wear debris; previous work on developing new shoulder implants has had significant impact (Impact Case Study 3). Research has informed national and international policy development on the regulation of hip implants and juvenile scoliosis spinal implants. Biomaterials research covers the development of novel bulk biomaterials for cancer treatment, retinal and musculoskeletal applications; and surface functionalisation using peptides and proteins to enhance the performance of medical devices. Research is clinically informed by partners from Newcastle's Medical School and the wider clinical community and involves significant collaboration with industry (DePuy-Synthes; Zimmer-Biomet, Invibio).

The strategy is to undertake fundamental research into new materials and devices, whilst working with interdisciplinary teams to address Healthcare challenges. New biomaterials for the treatment of osteoporosis is an emerging focus, with research funded by Horizon 2020 (GIOTTO: *Active aGeIng and Osteoporosis, The next challenge for smarT nanobiOmaterials and 3D Technologies*), and research on medical devices will address surface coating of orthopaedic implants through a new award from Orthpaedic Research UK in collaboration with Zimmer-Biomet.

Building larger interdisciplinary teams to tackle healthcare device reliability will be pursued through existing external collaborations and two NUCoREs: Regulatory Science (established in 2019, Joyce co-lead) and Biomedical Engineering (in planning). We are appointing a new Professor in Bioengineering to provide leadership. Close collaboration with the Design, Manufacture and Materials Group will continue blending new materials synthesis techniques with new materials processing techniques in the development of novel medical devices.

Design Manufacture and Materials: Professor Dalgarno (Head), 10 academics, 9 RAs and 26 PhDs

DMM focusses on (i) understanding material microstructures and their mechanical properties arising from their manufacture and optimising them for engineering application, and (ii) developing new manufacturing processes and associated best practices for design for manufacture. Materials modelling, additive manufacture and biofabrication and precision machining are key research topics, and the application focus for the group is primarily gears and power transmission, and medical devices and tissue engineering (in collaboration with the Bioengineering Group).

Our funded research portfolio includes the EPSRC Centre for Innovative Manufacture in Medical Devices; the Arthritis Research UK Tissue Engineering Centre, the EPSRC CDT in Additive Manufacture; the Innovate UK Materials, Manufacturing and Oils Technologies for High Power Gearbox Systems programme. Collaboration is an important element of all of these flagship national programmes, and the group collaborates widely with companies ranging in size from SMEs to multinationals, and with Universities across the UK and internationally.

The group strategy has two strands: (a) to grow collaboration with industry where we have established and distinctive expertise (e.g. large scale facilities in our UKRRIN laboratories), and (b) to support basic research into understanding and developing new materials, design approaches and manufacturing processes in order to underpin future industrial collaboration e.g. design of electric vehicle transmission systems through an Advanced Propulsion Centre project.

The strategy for the next REF period is to enhance the group's reputation as an international centre for applied research in design, manufacture and materials in the areas of biofabrication and mechanical power transmission. We will do this by expanding the infrastructure (through the new Stephenson Building and new dedicated facility at Walker for large scale research into gears and power transmission), continuing to publish discipline leading papers, maximising impact through industrial engagement, and engaging in national and international collaborative research programmes.

Fluid Dynamics and Thermal Systems: Professor Chakraborty (Head), 5 academics, 15 RAs and 29 PhDs

The group is renowned for its leading research in:

(i) Advanced Computational Fluid Dynamics simulations of turbulent reacting flows with direct relevance to the utilisation of energy resources, development of reliable fire and explosion safety measures and reduction of environmental impact of combustion processes.

(ii) CFD analysis of heat transfer involving complex non-Newtonian fluids with direct applications to chemical processing, nuclear and cosmetic industries.

(iii) Applied thermodynamic investigations related to energy generation, storage and refrigeration with direct relevance to climate change, energy security and sustainable energy solutions.

(iv) Heat and mass transfer in fuel cells and lithium-ion batteries.

Since 2014, the group has developed these areas in line with the University's 'Sustainability' theme and now the School's GRTs. The group has strategically focussed on collaboration with internationally renowned colleagues from leading UK and international organisations, and has attracted funding from Newton (e.g. NRCP 1516/ 4/67), UK-Institutional Link British Council (e.g. IL4279134267) and UKRI. This includes strategically important projects utilising high performance computing (e.g., EP/K025163/1 and EP/V003534/1 from EPSRC) and networks

such as UK Consortium on Turbulent Reacting Flows (EP/R029369); UKRI Thermal Energy Challenge Network (EP/P005667/2); EPSRC network for hydrogen-fuelled transportation (Network-H2) (EP/S032134/1)); EPSRC CCSInSupply (EP/N024567/2).

Three new appointments in the REF period have enhanced the group's expertise in combustion, CFD modelling and thermal engineering. The future strategy lies in reinforcing fundamental research capabilities in turbulent flow analysis in the areas of turbulent reacting flows, heat transfer and wall-bounded flows, and applying the physical insights obtained from fundamental research to industrial applications. The group will grow experimental combustion research especially in the areas of hydrogen and biofuel combustion in order to complement the current strength in numerical modelling.

Marine, Offshore and Subsea Technology: Dr Murphy (Head), 16 academics, 5 RAs and 32 PhDs

MOST researchers cover a diverse range of expertise focussed on global challenges associated with sustainability in marine and offshore environments. Key strategies, since REF2014, have been to create a centre of excellence in marine propulsion, established with investments of £3M at the Port of Blyth, and to recruit world-leading staff to build on our strengths: Lloyds Register Professor of Offshore Engineering (Hu), Professor in Marine Hydrodynamics (Liu) and Lecturers in Marine Structures, Marine Economics, Marine Engineering & Ship Design. The marine propulsion lab incorporates the upgraded Emerson Cavitation Tunnel, a flume for artificially aging coatings for performance assessment and slime farm (growing fouling under controlled conditions), funded by Akzo-Nobel (£1M), and we have a research vessel. Research on mitigating environmental interactions and impacts of marine structures on the environment includes:

- Performance of protective coatings and bio-fouling (collaborating with marine biologists), supported by grants: Underwater radiated Noise EU SONIC (€4M) and SEAFRONT (€11M).
- Ship propulsion, energy management and structural performance modelling and monitoring, supported by projects and equipment investments from Royston (£1.5M, including KTPs, Innovate UK and direct industry funding); Impact Case Study 6.
- RNLI research for future design of search and rescue craft (£600K); EPSRC MUltiphase Flow-induced Fluid-flexible structure InteractioN in Subsea applications (MUFFINS, EP/P0331418/1, £575K).
- Research with the US ONR for structural performance of Naval vessels, including four PhDs (£500K) and the development of structural design code now incorporated into commercial ship design software, Maestro Marine.

The group has a significant body of EPSRC, EU and other funding to support marine transport's decarbonisation towards Net Zero and reduce other harmful airborne pollutants. This includes working with the UK DfT and others supported by funding from EPSRC Shipping in Changing Climates (EP/K039253, £3.5M), EPSRC Network Plus, EU Clean Inland Shipping (€8M), EU SusTunTech (€3M). The work has developed to include all parts of the marine infrastructure including Smart Ports in projects continuing beyond the assessment period. The forward strategy revolves around the imperative for net zero carbon energy, one of our GRTs, with key aims of reducing emissions from marine transport, exploiting the ocean for production of renewable energy and embedding digital, data and autonomous systems into maritime systems.

2. People

People Strategy

Our people strategy is simple: to recruit outstanding colleagues in fair and inclusive processes, place them in an excellent, inclusive and supportive environment, and thereby encourage the highest standards within their discipline. Our people form the disciplinary 'bedrock' for our excellence and the foundation for our interdisciplinary success. The strategy drives our EDI-informed appointments process: building capacity in emerging research areas and maintaining excellence in our existing strengths. Female professors have increased from 7.8 to 12.5% of our staff in the last four years.

The group is the primary "home" for colleagues and an excellent environment is created through the coordinated actions and policies of the groups, disciplines and School's Global Research Themes.

Academic Appointments

We have recruited 73 lecturers, 17 SLs, 9 readers and 14 professors and invested in 10 ECR fellowships (5 NU Research Fellows and 5 NUAcTs) in this REF period. The increase in academics (from 133 in 2014 to 151 in 2020) has helped increase time for research and facilitated a more effective sabbatical policy. This has been accompanied by an increase in BAME colleagues from 11% to 22% of our total.

Training & Development

Career development is critical for all colleagues. However, we pay particular attention to our new lecturers and fellows. We use a blend of careful workload management, mentoring, targeted training and "start-up" packages, with coaching along the first steps as independent researchers. Mentoring by RAEng Chairs Metcalfe and Krasnogor led to an RAEng Fellowship for Mutch and we have a track record of recruiting promising ECRs and transforming them into world leaders (e.g. Fowler and Blythe).

There are multiple avenues and opportunities for development, both formal and informal, offered by the University and the School.

Formal processes include a thorough implementation of the *Concordat to Support the Career Development of Researchers,* the *Career Pathways Framework Programme* and the *Performance and Development Review* (PDR) process. The continuous PDR process includes an annual review meeting to reflect on the previous year, to agree objectives for the coming 12 months and to ensure that everyone has access to the resources and opportunities they need to succeed.

Chief amongst those resources is the *Organisational Development Team.* There are courses for every career stage ranging from generic (e.g. time-management) development, to specific aspects of research (*e.g.* intellectual property), or career progression (*e.g.* networking and collaboration). First time grant winners can benefit from a *PI Development Programme*. All new lecturers undertake the *Certificate in Advanced Studies in Academic Practice*, which covers research, teaching and management. More experienced academic staff are prepared for leadership roles by the *Academic Leadership Programme*, that develops high level leadership, strategy and team management skills. 64% of staff (half Female) have taken advantage of such opportunities.

Obtaining funding is often an art so our specialist Faculty Research Funding Development Team deliver support around this; including training for grant writing and management for new appointees, and as a refresher for established colleagues. Particular help is offered to applicants

for fellowships or large grants with internal reviews and mock panels. New starters are guided through their "New Investigator" applications, and benefit from similar processes. 100% new and 60% existing colleagues have used these facilities in the REF period with a 15% increase in grant applications and successes.

In addition, the school offers a comprehensive induction, mentoring and events programme (e.g. ECR showcasing events). We have good links with all Engineering Professional Institutions (e.g. to assist with staff gaining CEng status) and are members of key engineering networks (e.g. WES, EPC, etc.). Groups offer a less formal, but more frequent framework for support and development. These small collegiate teams support each other on the "nitty-gritty" of academic life from informal peer review, individual and team mentoring, and learning from inevitable disappointments.

Workload

Time, not money, is our most important resource. The School contribution model records the activities of all colleagues under the headings of Teaching, Research, Management and Other. The model draws heavily on the Athena Forum report of 2018 on workload allocation models and provides a profile of all contributions as well as employment position and special circumstances. Full-time equivalent values are shown next to actual values for part-time colleagues to ensure appropriate planning and consideration. The profiles are used to support individual's career plans, whilst maintaining a work-life balance, and to help managers allocate and balance workloads, review achievements, and plan strategically and inclusively. We routinely reduce the FTE for staff approaching retirement to enable a managed transition.

Promotions

The School academic and research promotions process ensures that all those eligible are considered by the Head of School, not just those who put themselves forward.

Colleagues are developed and prepared for promotion through the PDR process, mentorship and training schemes (e.g. leadership development) enhanced by local mentoring and coaching systems in the School. Over the REF period, 5 colleagues were promoted to Chair, 14 to Reader, 25 to SL and 31 to Lecturer G. The success rate for applications, regardless of gender, is 61% over all grades.

Rewards

We recognise significant contributions of colleagues through the University rewards scheme (promotions, accelerated increments and bonuses). Additionally, we have made 44 prize payments to individuals or teams since REF 2014 for things including the promotion of gender diversity in engineering, improvements in sustainability and exceptional student support. We coordinate nominations to WES or Professional Institution recognition schemes and oversee submissions to informal initiatives, which may lead to public acknowledgement. Colleagues' achievements and resulting good practice or learning are shared via regular newsletters and at School meetings.

Sabbatical policy

Academic colleagues are eligible for one semester of sabbatical leave every six semesters. Engineering has actively promoted this to good effect, reviewing and supporting sabbatical plans to maximise impact on research and minimising impact on group colleagues who cover other areas of work during this time, utilising our contribution model to enable this.

Technical Support Teams
Technical Support was reorganised in 2017 and is managed by the Faculty. It encompasses around 150 colleagues, with a broad skill base, and has an effective reporting structure to School and Faculty. Technical teams work in collaboration with academics but are line managed and mentored by a member of professional staff. Technicians across the University have formed NUTechNet, an internal network of technicians "by technicians for technicians" which arranges activities from regular events to task and finish groups on topics of interest. NUTechNet provided the impetus for NU to host the 2020 Technician Partnership Conference, a joint venture with the National Technician Development Centre and the N8 group of Northern Universities.

As part of our commitment to development, we have appointed a Faculty Technical Trainee and Training Co-ordinator who manages a training, development, and apprenticeship programme, linking to professional registration, where appropriate.

EDI in the School
We believe that embedding EDI values in the School is both a moral imperative and a pre-requisite for excellence. Our GRTs encourage everyone, and all engineering disciplines, to work together. It is essential that colleagues have equal and inclusive access to decision making, development and opportunity and that we can attract and retain exceptional people. We have therefore placed EDI at the heart of the new School's vision and put in place robust procedures to underpin our long term plans.

% Female T&R colleagues in the School of Engineering

	31-Jul-17	31-Jul-18	31-Jul-19	31-Jul-20	01-Feb-21
All colleagues	16.9%	18.2%	18.4%	17.1%	18.0%
Professors	7.8%	8.7%	13.0%	12.5%	12.5%

% BAME T&R colleagues in the School of Engineering

	31-Jul-17	31-Jul-18	31-Jul-19	31-Jul-20	01-Feb-21
British only	6.4%	6.7%	8.4%	12.9%	11.1%
All colleagues	10.8%	21.4%	19.0%	21.1%	22.0%

EDI strategy and progress is overseen by a diverse committee that includes senior leadership (Chair, Deputy Head of School), PGRs and RAs, CDT leaders and NUAcT representatives, who are all committed to be beacons of EDI excellence. Professor Geoghegan, the School Athena Swan Champion, Chairs the Athena Swan SAT that reports to the EDI committee. The School has Athena Swan bronze and will apply for silver in 2023. EDI is a standing item on the School Executive agenda and issues from debate feed directly into the appropriate Faculty and University committees. The Faculty EDI champions in disability and race are both members of the School, as is the Faculty Deputy Director of EDI. We work closely with our student union societies and ensure we understand and support their initiatives and plans.

We embed EDI in all our processes, visibly championing diversity and inclusivity by wearing rainbow lanyards and other badges of support, and other initiatives like:

- As a minimum, all members of Executive Board, EDI committees and REF decision makers have completed EDI training, all recruitment panels complete unconscious bias training, and all staff are introduced to EDI as part of their induction.
- The School engaged the support of Diversity by Design to improve its recruitment process. The new approach better reflects the importance of dissemination of job adverts, gender neutral language in adverts, commitment (signposting) to EDI, reasonable application deadlines, diverse selection and interview panels, and recruitment based upon competencies.
- Any policy or procedural change is accompanied by an EDI impact assessment.
- School priorities in 2020, which directly inform individual PDR objectives, included 'to treat everyone with dignity and respect in accordance with University EDI principles'.
- Images and text for webpages or materials are selected to give a true sense of the School while demonstrating and enabling inclusivity.
- Providing financial and other support to peer support networks in the School, including the EDI award winning NU Women in Engineering group and the PGR group.
- Maximising access to School life by holding meetings in core times (9.30am to 3pm) and considering school holidays.
- Enabling flexible and part-time working; for instance, colleagues with caring responsibilities after maternity.
- Recognising key dates in the calendar with events, information and/or media content and signposting (Pride, Black History Month, World Engineering Day, International Women's Day, etc)
- Introducing a scheme to fund maternity leave for PGR students when sponsors don't provide this.
- "Decolonising" not just our teaching but also our research, and in particular equitable partnerships for research collaboration. Through leadership of the Water Security and Sustainable Development Hub we are considering best practice in safeguarding, decolonisation, and research inclusion into the University's Global Challenges Academy and School. This has already led to a change in University financial policy for paying developing world partners.
- Focussing on addressing the BAME achievement gap (which is notable in engineering as a discipline) through interactions with staff role models.

Our staff are increasingly recognised as EDI advocates, for example Dawson was invited to speak at the RAEng event on Engineering Change in March 2021.

Postgraduate Research (PGR) Students

An outstanding cadre of doctoral researchers is central to our research vision and culture. We have graduated over 600 research students in this REF period. We have attracted large numbers of students through CDTs as well as with international scholarships and industrial sponsorships. This ability to attract high quality students attests to our international reputation in PGR supervision and training.

PGR Mentoring and Management

We see our PGRs as future leaders in research, industry and policy. Accordingly we place a strong emphasis on training, mentoring and management to ensure they meet both research and wider objectives.

Recruitment and coordination of research students are managed by the School Postgraduate Studies Director working closely with Faculty on strategic issues like quality and student experience. We believe a good relationship between student and supervisory team is crucial to success. A high level of support is provided during the programme, as defined in an agreement between student and supervisors. Every student is allocated at least 2 academic supervisors who work with them to produce an initial proposal within 3 months and then supervise progress. University policy determines at least 10 formal meetings a year, however, our students are encouraged to meet more frequently. PGRs are important members of groups, to ensure they

are fully integrated into a vibrant research culture and able to obtain informal support from other students, RAs and academics working on related topics; as well as via PGR peer support groups.

The University provides generic research skills training and monitors the courses attended, and the school provides specific technique-based training. Credits are awarded for completion of modules and a minimum score is needed before students proceed to further years. A panel, comprising 2 independent academic colleagues, monitors progress throughout the PhD interviewing the student and reviewing reports.

The School holds an Annual Research Conference organised and led by PGRs. It provides a platform for students to learn about current research in the School and gain experience in technical writing and presentation skills. The event attracts keynote speakers and financial sponsorship from industry. First year students present a poster, whereas students in subsequent years present a technical paper with presentation. Best-student prizes are awarded. Last year, because of COVID, the conference was successfully held on-line.

A Research Student-Staff Committee meets regularly with senior representatives from SEB and every discipline, offering a direct route to raise concerns, or to discuss ideas for improving student experience. Diversity and appropriate representation is ensured, and students from every group are encouraged to participate. The Committee organises inclusive social events and team building activities such as quiz nights. School students are also represented on the Faculty Student-Staff Committee.

PGR Recruitment

PGR recruitment includes self-funded, individual and cohort-based studentships with approximately 60% international and 40% “UK/EU”. Individual students are recruited through application in response to advertised studentships or, for self-funded students, direct application. There are a range of international recruitment activities throughout the year to promote research opportunities. The process is designed to support EDI principles with multiple staff members of different backgrounds involved. We discuss needs with every student and any agreed modifications to working practice or spaces are supported.

For UK recruitment, we believe that cohort-based programmes are important, and we will continue to use our expertise, facilities and training portfolio to lead integrated PhD programmes. Since 2014, we have recruited to 5 major cohort-based PhD programmes:

- EPSRC *Engineering Doctorate in Biopharmaceutical Process Developmen*t, led by Newcastle, 2009 to 2018, all students placed with industrial sponsors.
- IAPETUS where staff contribute to the themes “Global Environmental Change”, “Geodynamics and Earth Resources” and “Hazard, Risk and Resilience”.
- STREAM, the Industrial Doctoral Centre for the Water Sector led by Cranfield University, funded by EPSRC and sponsorship companies, 2009 to 2018.
- EPSRC Centre for Doctoral Training in Diamond Science & Technology, which brought together nine universities and industrialists from more than 30 companies.
- EPSRC Centre for Doctoral Training in Additive Manufacture and 3D Printing. All studentships were CASE-like with an industrial or third sector sponsor.

We lead three ongoing cohort-based programmes:

- Sustainable Electric Propulsion; EPSRC-funded CDT.
- Geospatial Systems; EPSRC-funded CDT.
- One Planet, NERC-funded DTP.

We are a major stakeholder in ongoing externally led cohort-based programmes:

- Renewable Energy Northeast Universities (ReNU), EPSRC CDT led by Northumbria University
- Water resilience for infrastructure and cities, EPSRC CDT led by Cranfield University
- Offshore wind energy and the environment, EPSRC CDT led by Hull University
- IAPETUS 2, NERC DTP. This is a partnership between research universities in England and Scotland, together with British Geological Survey and Centre for Ecology & Hydrology, named after the ancient ocean that closed to bring together the two countries.

With our enhanced mentoring and management of PGRs, graduations have increased over the REF period from 77 per year in 2014-15 to 91 per year in 2019-20. This includes more than 60 industrially funded students who completed during the REF period.

PGR Training
We offer over thirty skills training courses for research students, based on the Vitae Researcher Development Framework, including research skills and techniques, communication skills, networking and team working, and career management. Students are supported in maintaining a personal development programme throughout their degree. All students build up training credits in each year of their study, through skills training, presentations within the University and attending and presenting at conferences. Progress monitoring is through an online "ePortfolio" system, which students update with documents relevant to their progression.

In 2020, the University launched a campus-wide Skills Academy to support career needs, and nurture creativity and innovation in our research students. This has dramatically increased the range of training opportunities available on our CANVAS virtual learning environment.

At the start of the REF period, the University launched a PGR Innovation Fund for groups of students working on projects to improve the PGR student experience, e.g. by increasing attendance at key conferences and networking events. Students are encouraged to take an active role in improving their experience and we involve PGR representatives. We invite participation in the annual HEA PGR Experience Survey and for 2019 94.3% of Engineering respondents were satisfied with their experience.

PGR career breaks
The School has introduced a scheme to fund maternity leave for PGR students when sponsors don't provide this.

PGR employment in research
We are strong in supporting the journey to research as a career. Employment of our PhD graduates as researchers is strong with at least 95 (17% of all PGRs) in the last five years: 65 (PDRAs at Newcastle); 30 external.

3. Income, infrastructure and facilities

Income
The strategy has been to diversify funding sources whilst maintaining our research council income. We have set up mentoring systems to increase the number of submissions from early career researchers resulting in a 17% increase over the REF period. In the last four years, two thirds of our research income has come from research councils – often considered the gold standard. A further 20% came from EU and UK government sources, 10% from industry and 3% from charities. The REF period has seen substantial growth in RCUK funding (three year average annual spends up from £8.3M in 2015 to £12.3M in 2019). Total research spend over the REF period is over £121M, the three year average annual spend rising from £17.4M in 2015 to £19.4M in 2019. In addition, we have received over £0.5M in-kind income during the REF period for facilities time at Diamond (23%), ESRF (40%), ISIS (21%) and GNSS (15%).

Going forward, success in new research initiatives already gives us secured funding of more than £25M over the next 7 years with a dramatic increase in charity and government funding. Our success in winning three CDTs and being key participants in four others has helped alongside our strategy to prioritise long term initiatives. Research income is anticipated to grow in the coming years as new academic colleagues and early career researchers become established in their fields. Senior academics will be encouraged to lead longer, larger collaborative research projects. We will also encourage networking nationally (e.g. Achilles and CeSI), industrial partnerships (e.g. Dyson, Hoganas and Goodrich) and international partnerships (e.g. GRCF water hub). We have key technicians supporting work across the School with specialisms that cover our major research infrastructure. This includes running analytical and characterisation facilities, manufacture of samples and test rigs and providing routine testing services e.g. manufacture and test of gears to industrial standards.

Consultancy income over the REF period is £23.4M, including contracts from large multinational organisations e.g. Rolls Royce and Siemens, and with smaller companies e.g. Peratech.

Infrastructure strategy

Since 2014, the School has been addressing the problem of cramped, overcrowded engineering buildings on the main campus to provide unique facilities and creative spaces that provide the dynamic research environment to realise our GRTs. Three key elements to our infrastructure strategy are:

- *Investing in new infrastructure.* To invest in growth areas and build a new flagship building for the new School of Engineering. At the heart of this is a redeveloped Stephenson Building (Figure 2), conducting world-leading research and innovative teaching, generating partnerships with industry and addressing skills shortages in key areas. This £65M project, which started in 2020, will provide new state of the art facilities to upscale and accelerate our research in bioengineering, digital manufacturing and propulsion.
- *Co-locating large facilities with industry:* To maximise impact by moving large facilities offsite where they can be co-located with industry e.g. purpose-built sites at Blyth, Walker, Sunderland.
- *Refurbishing and enhancing existing facilities:* To meet the research requirements of our GRTs, including development of the One Planet facilities in the Drummond Building.

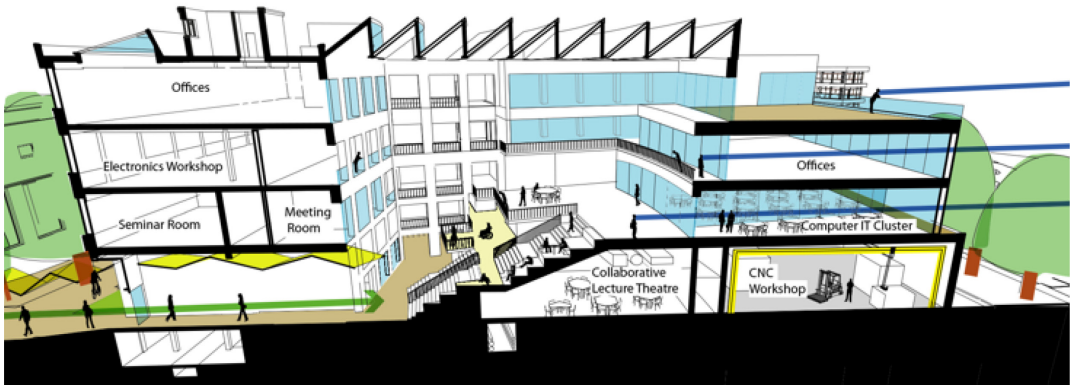

Figure 2. Concept design for interior space of new Stephenson Building

New and Refurbished Buildings

Major infrastructure investments that started in the REF period include:

- Stephenson Building (£68.7m). Redevelopment of existing mechanical engineering building to create a focus for multi-disciplinary engineering research and teaching.
- Urban Sciences Building (USB) (£58m). State-of-the art flagship development on the £350M Newcastle Helix regeneration site in the heart of the city. Part of a demonstrator to create a full-scale demonstration of urban innovation; “a living laboratory” underpinning research to make urban centres more sustainable for future generations.
- The Key (£1m). A fabric-roofed structure on the Helix site; the first in the UK to use such a structure as office space.
- National Innovation Centre for Data (£44.4m). The Catalyst building in Newcastle is the home for two National Innovation Centres: Ageing and Data. It is a dynamic community of ambitious businesses and research specialists working collaboratively to develop products and services.
- Port of Blythe (£2.5m). The Emerson Cavitation Tunnel and specialist flume were moved to a purpose-built facility for hydrodynamic research on propellers, turbines, foils, bluff bodies and their coatings and innovations with an extensive range of instrumentation.
- Tyne Subsea (£2m). A hyperbaric testing and research facility located on the north bank of the Tyne including a 4.5m long and 2.5m diameter hyperbaric chamber; the largest commercially available chamber of its type in the world.
- One Planet, Drummond Building Refurbishment (£2m). With strengths in water research, organic geochemistry and analytical environmental chemistry we are creating a unique scientific environment to help us contribute to our GRT challenges.
- Advanced Engineering Hub, to co-locate industry facing colleagues in a purpose-built facility, in close proximity to industry and our Tyne Subsea facility. Specialist research and industrial testing facility for power transmission systems, including materials testing, metrology, failure analysis and a climatic chamber simulating extreme environments. It will be the new home for the Design Unit and the UKRINN facilities when completed in the next year.

Projects in early-stage development:

- The School is establishing the DER North East Industrialisation Centre (part of a £30M national project led by Newcastle) on the International Advanced Manufacturing Park, Sunderland, an £18m investment from Sunderland City Council next to Nissan’s electric vehicle factory.
- The InTEGRel site run by Northern Gas Networks, with partners from other utilities and industry, will house research covering hydrogen supply developments in the north east. Installation of pilot-scale research facilities by the School is in the planning stage.

Unique facilities

We invest in facilities that support our current and future research portfolio and new facilities to meet the needs of emergent research. All groups have access to their own specialist facilities and are supported by cross-cutting facilities across the campus. External specialist facilities are used, as needed.

New major facilities since 2014, with significant external and University investment include:

- The UK Rail Research and Innovation Network (UKRRIN). Newcastle has been appointed Centre of Excellence for Rolling Stock resulting in a £2m investment in testing facilities. Industry has committed £64m to UKRRIN projects 2020-2028 and we will work with stakeholders to take advantage of this.
- A Smart Grid laboratory with £0.5M from Siemens and matching University investment. This combines distribution network devices, monitoring and control equipment with field trial data and computer models to test advanced network management techniques.
- Driving the Electric Revolution. NU leads a £30M national network of four Industrialisation Centres across the UK, to enable faster collaborative research and

development of electric machines, including cars, planes and ships. NU is establishing the DER North East Industrialisation Centre in Sunderland close to Nissan, and the School has recently won £9M new manufacturing and testing equipment for electric vehicles.

- InTEGRel, led by Northern Gas Networks and in partnership with Northern Powergrid and NU is a new integrated energy facility in Gateshead. It is helping to tackle the UK's energy challenges with teams of academics and engineers working to deliver breakthroughs in the decarbonisation of heat, energy storage and transport, to identify the most affordable and practical solutions for moving customers onto low carbon, low-cost energy.
- BEWISe, the "Biological Engineering: Wastewater Innovation at Scale" facility has been developed at Northumbrian Water's sewage treatment plant at Birtley. It is the first of its type in Europe for large-scale wastewater treatment research using bacteria. It is playing a key role in improving how sewage is treated by speeding up the transition from existing energy-intensive treatment processes to low carbon alternatives with lower running costs.
- We are founding partners of UKCRIC (UK Collaboratorium for Research in Infrastructure and Cities, and have lead roles in all three strands:
    - £10M investment into the National Green Infrastructure Facility (NGIF), a unique full-scale space for research in soil-vegetation-atmosphere interaction in the urban environment. NGIF is a 'living laboratory', underpinning research into sustainable drainage systems and green infrastructure to make urban centres more resilient and sustainable for future generations.
    - £8M investment into our Urban Observatory, a ground-breaking project to monitor Newcastle. It has become a major provider of open source data from a network of sensors around Newcastle since REF 2014. This offers unique scale and data resolution that aids modelling the effects of the environment and urban planning decision making. Through UKCRIC we lead the National Observatories programme which includes Birmingham, Bristol, Manchester, Sheffield and Cranfield.
    - Partners in the £8M DAFNI programme (Data & Analytics Facility for National Infrastructure) and have a key role on its Governance and Executive Board.

Previously established specialist facilities, which have been further developed and were available over the REF period, include:

- An investment of £3.5m (£2.3m EPSRC; £1.2m University) in equipment for interface engineering and characterisation. This purchased a He-ion microscope with analytical capability (a UK first) and a Time-of-Flight Secondary Ion Mass Spectrometer, and new atomic layer deposition and additive layer manufacture equipment, which will be used to create new interfaces and gradient structures.
- Tyne Subsea (£2M from the University with a further £5M from HEFCE and industry) offering nationally leading large scale hyperbaric and environmental test facilities capable of testing at temperatures and pressures equivalent to deep ocean conditions.
- The Advanced Chemical and Materials Analysis Service provides a range of analytical techniques, including scanning electron microscopy; x-ray powder diffraction; inductively coupled plasma optical emission spectroscopy; FT infrared spectroscopy; structural mass spectrometry; and carbon, hydrogen, nitrogen combustion analysis.
- The UK National Gear Metrology Laboratory (NGML) is accredited by the UK Accreditation Service (UKAS) for the measurement and calibration of gears, gear artefacts and gear measuring instruments, and is linked to primary calibration facilities at the NPL (UK) and Physikalisch-Technisch Bundersanstalt (Germany). It maintains and develops the UK reference calibration objects to establish and disseminate traceability to industry throughout the UK.
- The marine research labs: (i) The Emerson Cavitation Tunnel, used to study marine propulsion cavitation; (ii) The Jones Marine Engineering Laboratory, which features a diesel engine test bed which has been adapted to operate using novel fuels; (iii) the

Hydrodynamics laboratory which features a wave, wind, and tidal facility for renewable energy research and (iv) a towing tank for calm water, wave resistance and sea-keeping experiments.

- Dedicated facilities for electric drives. Modern, specialist equipment includes 13 dynamometers, worth £1.5M, spanning powers of up to 500kW and speeds up to 100,000 rpm. We also have an environmental chamber, new instrumentation including DC and variable frequency AC supplies up to 60KVA, totalling more than £1M. In addition to 800 m^2 of laboratories on the main campus, we have gained 200 m^2 of space in the new USB building. This space is dedicated to energy management, where we have acquired bespoke source and load emulators all connected to an 11kV test ring. In our energy, power and transport laboratory, we do battery recycling and battery degradation research work sponsored by the Faraday Institution and we conduct tests on electric vehicle charging technologies.
- Microelectronic fabrication facilities including two class 1000 clean rooms with end-to-end fabrication capability, housing a 200 mm cluster tool for atomic layer deposition, sputter deposition, chemical stations, rapid thermal processing, special tools for SiC processing, lithography, coating and device bonding, together with metrology tools such as an ellipsometer and microscopes. In addition, we also have access to a 400 m^2 class 100 clean-room for device fabrication, packaging and evaluation on campus.
- The Thermofluids lab has specialised experimental facilities (particle image velocimetry, laser doppler velocimetry, micro-PIV, wind tunnel and water tunnel, high pressure fuel spray and combustion, vortex rig, emissions testing) which have been co-located in a new lab since REF2014.
- We make significant use of the N8 super-computer (>5000 cores) and the £43M national super-computer, ARCHER (>118,000 cores).
- Environmental researchers benefit from molecular microbiology capacity that is unique in the UK (*e.g.* Ion Torrent DNA sequencing system with dedicated bioinformatics clusters, pipelines and support, qPCR instrumentation, DNA purification and liquid-handling robots, flow cytometer and epifluorescence microscopy), analytical chemistry (*e.g.* Liquid Chromatography MS- ion trap and triple-quad; ICP-OES and ICP-MS for metals analysis; Mössbauer spectrometer) and pilot plant facilities (multi-instrumented data-logged replicate lab-scale reactors).
- Geospatial Engineering researchers benefit from field equipment and processing facilities, housed in a dedicated laboratory, including the 'MORP' IGS station (part of the NERC BIGF, EUREF and IGS networks), the 'MORG' Leica SmartNet reference station and the 'MORO' Ordnance Survey fundamental GeoNet station. GE also operates the 'NSLG' GNSS receiver at North Shields in the UK Tide Gauge and IGS 'TIGA' networks, and hosts a Topcon NRTK reference station 'NCLV' and the Ordnance Survey national GPS network 'NCAS' station. Operation of the IGS Global Network Associate Analysis Centre (GNAAC) and Associate Analysis Centre of the International Laser Ranging Service contribute to international state of the art geodetic analyses underpinning the development and evolution of the International Terrestrial Reference Frame.
- Earth Systems Laboratories are a unique platform for inter-disciplinary systems scale research, fusing theory with large scale experimentation and demonstration, comprising:
    - The BIONICS national facility, a densely instrumented full-scale section of infrastructure embankment with climate control capability.
    - An experimental groundwater borehole array at Cockle Park Research Farm.
    - The Eden CHASM / Demonstration Test Catchment (DTC) containing ~ £1M worth of instrumentation and is a UNESCO designated HELP basin. The site is a Defra flagship addressing sustainable farming and mitigating sediment and nutrient pollution. The DTC site hosts the NERC Environmental Virtual Observatory Pilot.
    - The Belford Catchment Flood Solution Project was one of the first full-scale natural flood management projects to be created in the UK.
    - The Tyne and Wear 'Urban Traffic Management Control' (UTMC) System funded by DfT and Local Authorities.

- Our Sensing Labs are high-quality, purpose-built research facilities, including: (1) 100m^2 Intelligent Sensing laboratory with £300k worth of FDA- and CE-marked electrophysiology sensing, imaging and fast prototyping equipment, (2) a Communications Systems laboratory equipped with a £150K massive MIMO base station for 5G research, (3) an anechoic RF chamber (£0.5M) for EMI-free RF and antenna characterisation over a wide range of frequencies (300MHz – 8.9GHz) (4) a Sensors, Electromagnetics and Acoustics laboratory (SEALAB) equipped with a £1M anechoic acoustic tank to enable wet testing of underwater modems, (5) a Sensors and NDT laboratory (£1M) equipped with eddy current pulsed thermograph (6) laser sciences and photonics facilties (£300K).
- A dedicated Biofabrication lab with bioprinting technologies and cell culture facilities supporting research into the fabrication of a range of artificial tissues for drug testing and tissue engineering was created for the DMM group (£500K).

4. Collaboration and contribution to the research base, economy and society

Our research and its outputs are highly collaborative, and end-user focussed. This is evidenced by our current EPSRC research portfolio where, of 28 grants, 24 are collaborative with 65 different UK and international universities and research organisations. There are 143 other unique partners (by EPSRC definition of providing a financial contribution) on these grants, constituting an active end-user community (Source: EPSRC Grants on the Web, accessed 10 December 2020). Published research shows the interdisciplinary and collaborative nature of our work, with School authors contributing some 2,600 ISI cited papers in the period 2014-2020 co-authored with a total of around 4,500 institutions, with around 3,500 of these based overseas. Furthermore, ~25% of the co-authors are “end-users” (e.g. industry or government departments) rather than from research institutions (Source: Web of Science, December 2020).

Research collaborations are supported by our leadership and membership of national/international networks (we have published papers with 106 other UK Universities), embedding companies within the School, our Industrial Advisory Groups, encouraging visiting professorial exchanges, and participation in the N8 research partnership.

Interdisciplinary, collaborative research programmes and linkages with industry have been supported in various ways, e.g.:

- NU invested £0.5M in developing interdisciplinary research networks in sustainability, ageing and social inclusion.
- Funding for travel in the development of research proposals, including a specific fund for meetings related to the development of EC proposals.

Exemplars of Key collaborations

Our research grants demonstrate commitment to collaborative working with other universities and key partners. For example, the Water group in collaboration with UEA, Bristol University, the Centre for Ecology and Hydrology, and the Science and Technology Facilities Council are partners in the Open CLimate IMpacts modelling framework (OpenCLIM) to provide the next generation of modelling tools to assess the risks of climate change. The £2M programme (£800K to Newcastle) is funded by the UK Climate Resilience Programme and will underpin the UK’s 4th Climate Change Risk Assessment scheduled by parliament to report in 2027. The Fluids group and collaborators from Cambridge University, Imperial college, University of Edinburgh and Daresbury Laboratory have attracted £3.8M research council funding on research areas

dealing with different aspects of energy efficiency and environmental friendliness for both power generation and propulsion sectors.

The REF outputs give an indication of our main academic collaborators. These include jointly authored papers reporting collaborations with:

- Allied Healthcare, Biology, Chemistry, Civil Engineering, Electrical Engineering, Mathematics, Medicine and Physics disciplines.
- Birmingham, Brunel, Cambridge, Cardiff, Cranfield, Durham, Edinburgh, Imperial College, Kings College London, Leeds, Liverpool, Loughborough, Oxford, Sheffield, St Andrews, Strathclyde, Surrey, Ulster and UCL universities.
- International collaborators based in Australia, China, the Czech Republic, Georgia, Germany, Greece, India, Iran, Israel, Italy, Japan, Korea, Libya, Malaysia, the Netherlands, Norway, Singapore, Spain, Sweden, Switzerland, Thailand, Turkey, and USA.
- Industry e.g. GSK, Shell, Ricardo, Roche, Riken, Novartis, Astra Zenica, Sanofi, Dyson, Rolls Royce, Proctor and Gamble and Dialog.

We seek to maximise **engagement and impact** through these relationships with academic and industrial end-users. This involves direct collaboration, consultancy and CPD provision for industry and other commercial users of technology e.g. offshore survey and precision agriculture.

We work closely with end users and partners through a number of mechanisms to maximise the utility and impact of our research on our GRTs:

- Research networks and centres.
- Establishment of strategic priorities with existing industrial collaborators to build long-term relationships (e.g. with International Paint, now Akzo-Nobel, for over 30 years and have lasting links with Dyson, Rolls Royce and Northumbrian water).
- Institutional strategic partnerships (e.g. Arup, BAE Systems and Siemens where we are a “Preferred Partner” University, one of only seven in the UK).
- School level strategic partnerships such as with Stadler in the area of rolling stock development.
- Industrial Advisory Boards to support Disciplines and research projects.
- External advisory boards and committees e.g. Director of National Microelectronics Institute (now Techworks); a forum for >250 UK electronics systems businesses; the only director from academia is in Engineering (O’Neill).
- The appointment of Professors of Practice from Industry (e.g. Drury who was elected FREng in 2020 and supports our electric drives research, Boyle who is the National Executive Chair for DER (Driving the Electrical Revolution) and Herron, Managing Director of Zero Carbon Futures).

Working with industry

We have strong industry links e.g. with: Dyson (Impact Case Study 2), Siemens, Hoganas, Northern Power Grid and Jaguar Land Rover in Electrical Power Engineering. The links with Dyson recently led to an EPSRC Prosperity Partnership award worth £5m; Dyson contributing half the funds. Work in the electric vehicles area in collaboration with Jaguar Land Rover, initially funded through innovate UK projects and the Advanced Propulsion Centre resulted in the generation of a successful spinout company.

We drive strategically important long term links with relationship managers tasked with generating collaborative funding. We have used our partnership with Siemens to develop research in the energy area, particularly in the CESI project. Research is expanding into open

data in collaboration with Newcastle Computer scientists because Siemens views the UK work ahead of that in Germany where the company is headquartered. New opportunities include the Innovate UK GCRF project RESONATE (Water Reuse Innovation for Sustainable Households, Communities and Cities) and the North of Tyne Advancing Circular Economy demonstrator project (Neumann) with P&G.

We have a number of Visiting Professors of Practice. These are senior colleagues, generally from Industry, who offer advice and stimulate sustained research collaboration: David Hetherington (Global Water Research Manager, Arup); Chris Jones (Director of R&D, Northumbrian Water) and Matt Boyle OBE, Executive Chair of the national DER project.

Our industrial links are evident in part from the REF outputs, which include industrial co-authors from over 450 companies. However, many industrial links have led to important research outputs without joint publication over the REF period.

NU acquired **Zero Carbon Futures UK (ZCF)** in November 2020, a company that provides insight into low carbon vehicles and associated technologies enabling the development of strategies to reduce carbon emissions from transport. ZCF will enhance our recent success in DER allowing us to operationalise electric drives to meet the Government's net zero targets.

Working with UK Local and National Governments

Several research areas impinge directly on Government actions. For instance, in Future Mobility, Blythe is Chief Scientific Adviser to the Department for Transport and it is no surprise that transport is back as a key EPSRC area after an absence of 10 years. The DfT initiative, **Future of Mobility,** is driven by our position**,** one of 4 Grand Challenges established in the Industrial Strategy to improve people's lives, increase the country's productivity and put the UK at the forefront of future industries.

Open data supplied by the Urban Observatory programme is valuable in helping Government understand mobility changes during the COVID-19 pandemic. Our ongoing support to DfT's Science Advisory Council and the Transport Research Innovation Board was acknowledged by Grant Schapps, Secretary of State for Transport, September 2020.

In Geotechnics and Structures, Utili was seconded to the Science and Technology Committee of the House of Commons as Academic Parliamentary Fellow, March 2018 to February 2019.

CityCAT flood modelling has been used by Newcastle City Council, Antwerp and New York local authorities, amongst others, for flood risk resilience design. Fowler and PDRA Chan contributed to the development of the new UK Climate Projections. Quinn was appointed Special Advisor to the EFRA Select Committee flood inquiry.

The city of Newcastle was named global climate leader for its efforts to become carbon neutral by 2030 through its Net Zero Task Force co-chaired by Fowler with Council Leader, Nick Forbes.

Working with National Organisations

We have given advice to the National Fire Chiefs Council on electric vehicle crashworthiness and damage to rechargeable batteries. Christensen peer reviewed
the fire service's National Operational Guidance (on board all fire tenders) on rechargeable batteries and is on BEIS working group defining UK FRS response.

Working with International Organisations

Dawson: advises UN on risks to cities and leads the Urban Resilience theme of Tyndall Centre for Climate Change Research; appointed to Committee on Climate change.

Fowler held a Royal Society Wolfson Fellowship for work on hydrological impacts of climate change; contributing author on two chapters of IPCC 6th Assessment WGI Report (Ch. 8 Water Cycle and Ch. 11 Extremes); leads the Global Energy and Water Exchanges (GEWEX) Hydroclimate Panel.

We are a longstanding partner of the Willis global research network (https://www.willistowerswatson.com/en-gb/insights/research-programs-and-collaborations/willis-research-network), an award-winning collaboration to improve the understanding and quantification of risk. This has led to research with highly rated institutions (e.g. Princeton, ETHZ, NUS). Since 2009, Kilsby and Serinaldi have been funded as Senior Academic and Research Fellow in the Willis Research Network working on flood risk.

Patents and consultancies

We have made 97 patent applications since 2014 with seven granted supporting start-up companies in electric motors, aerogel insulation and ultrasonic imaging. Other patents have progressed with industry (e.g. Element 6 and Dialog Semiconductor). 145 colleagues (>75%) have had important industrial links/consultancies over the assessment period. The majority of consultancy income is associated with the Design Unit in the area of power transmission systems and gears, increasingly for electric vehicles. Other exemplars include: the development of design software Workcraft for semiconductor manufacturers (Yakovlev, Impact Case Study 1); working with Northumbrian Water on "Biological Engineering: Wastewater Innovation at Scale" (Davenport); a £17m collaboration with Rolls Royce on future aircraft (Baker); a consultancy to act as Japan Government's technical expert in pursuit of a subsidy and countervailing measures suit in WTO, with the shipbuilding industry of South Korea as the defendant (Stott).

Exemplars of Collaborative and Interdisciplinary Research

Significant EPSRC activity in multi-partner collaborative research includes: ACHILLES (EP/R034575/1) on long life transport infrastructure assets (6 University and 11 industry partners); Centre for Energy Systems Integration (EP/P001173/1) with 5 University and 30 industry and government partners; SynFabFun (EP/M01486X/1) on membrane materials with 4 University and 11 industrial partners; the Tissue Engineering and Regenerative Therapies Centre Versus Arthritis (5 University partners). We have major roles in interdisciplinary research facilitated by University NUCoREs: Walker leads Energy; Fowler leads Climate Change and Environmental Resilience; Wright leads a stream in Data; Joyce leads a stream in Regulatory Science. James leads the UKCRIC Urban Observatory network.

Exemplars of Leadership in the Academic Community

UKRI College Members, EPSRC and NERC: 35.

Fellows of the Royal Academy of Engineering: Blythe, Bull, Mecrow, Metcalfe, Postlethwaite, Yakovlev; and Braiden, Johnson, Morris, O'Connell and Page (emeritus).

Leading roles in Societies and Institutions

Chair of UK Consortium on Turbulent Reacting Flows (Chakraborty); Chair of Awards and Professional Standards committee of RSPSoc (Xiao); Vice President Learned Society IChemE (Glassey); President, UK Heat Transfer Society (Reay); Chairman of Barrow Hill Engine Shed

Society (Robinson); Treasurer, Chair of Finance commission and Grants Evaluation Committee for the International Society of Photogrammetry and Remote Sensing council (Mills); 2018-19 Chair of the International Association of Travel Behaviour Research (Cherchi); Vice President of the International Rail Research Board responsible for worldwide academic networks for rail research (Robinson); 2016-2020 Chair of European Conference of Transport Research Institutes (Robinson);Vice President of the IET (Blythe).

Other panel/committee memberships: over 50 individual memberships in the period including: Computational Science Centre for Research Communities (Chakraborty); National Infrastructure Commission, Technical Expert Advisory Group (Dawson); Foreign High-end Expert, Ministry of Foreign Affairs, China (Robinson); Future Earth - Urban Knowledge Action Network – Steering Group (Dawson); Rail Vehicle/Structures Systems Interface Committee (Palacin); Vehicle/Train Energy System Interface Committee (Palacin); Transport Lead, Hydrogen Advisory Council (Blythe); Commissioner – Adaptation Committee, Committee on Climate Change (Dawson); EA/DEFRA working group on understanding AMR fate in wastewater systems (Graham); Royal Society Industrial Fellowship panel expert (Glassey); Chair of the LWEC Infrastructure Report Card working group (Dawson); DSAC independent member (Bull); Future of our national infrastructure programme, Government Office for Science (Dawson); Chair of Commission 1: “Data Acquisition”, EuroSDR (European Spatial Data Research)(Mills); Invited to convene a session at the Inter-governmental Panel Climate Change Conference on Cities in Canada (Walsh); NERC Advisory Network (Clarke); Steering Committee European Association for Research in Transportation (Cherchi); Executive Board of International Association of Travel Behaviour Research (Cherchi); Science Advisory Group for Emergencies SAGE (Blythe); BEIS CCUS Young Professionals Forum (Mutch).

Standards and industry working groups
We contribute to the development and implementation of standards. We house the UK National Gear Metrology Laboratory as part of the UK’s National Measurement System supported by BEIS. We work on various standardisation groups e.g. Neasham is member of DSTL/MoD's CETO working group on the development of underwater communication standards and teamed with two industrial partners to define, validate and demonstrate an underwater acoustic communication standard for data sharing between UK forces and its allies. Dalgarno wrote the BSI White Paper on “The impact and potential for 3D printing and bioprinting in the medical devices industry” BSI Standards Ltd, 2019 and Fowler was a BSI committee member for B/505/21/11 Climate change.

Advisory Boards
Member of Rolls Royce ECSEAB Advisory Board, providing external advice on electrical machines (Mecrow); Member of Advisory Board of government initiative "Driving the Electric Revolution" (Mecrow); Chair, UK Government Transport Research and Innovation Board (Blythe); Network Rail and Highways England Research and Innovation Advisory Boards (Blythe)

Plenary Lectures: [2015] 26th Chinese Process Control Conference (Zhang), IET PEMD conference (Mecrow); Astra-Zeneca Pharmaceuticals in the environment conference (Davenport); Diamond Conference (Goss); [2016] 1st UK-Brazil Workshop on Sustainable Wastewater Treatment (Davenport); [2017] ECMI-SciTech (Boussakta); ICCMR13 (Metcalfe); [2018] CQID (Glassey), UKTC annual meeting (Chakraborty); the International Conference of micro and nano-diagnostics of fossil coals and rocks (Bull); IPCC Cities and Climate Change

Conference and the Global Engineering Congress (Dawson) [2019] Electrochemistry 2019 (Scott, whilst receiving the Castner Medal).

Keynotes: 126 in the REF period e.g. [2014] EC2E2N (Glassey); ICOM (Metcalfe); [2015] Sustainability 2015 (Stirling); BioTech 2015 (Chen); IEEE Transportation and Electrification Conference (Pickert); [2016] ICCE (Liu), International Conference on Embedded Systems (Boussakta), ICIM (Metcalfe), PI for Greener Industry (Boodhoo), BioTech (Chen), Agua (Davenport), Soft Materials for Energy Applications (Geoghegan); [2017] TACT (Bull), GM3 (Rouania), GRC on Oscillation and Dynamic Instabilities in Chemical Systems (Novakovic), IEEE Communications (Haigh); [2018] ICCSIC (Zhang), BIOMIC (Ferrara-Duarte), Modern Railways 8 (Robinson), ICIM (Metcalfe, ITEC (Pickert), MRS (Dagenaar), ARM summit (Yakovlev); Smart and future Cities (James); [2019] International Transport Forum Annual Summit (Mangan), TERMIS (Gentile), CORE (Yang), UKMIC (Stott), Biomaterials (Peeters), PIERS (Tian), ICCSIC (Zhang); MRS (Dagenaar). [2020] Biomaterials (Siller, Novakovic).

Invited Lectures: 449 including invited presentations at overseas institutions, national and international conferences, workshops and discussion meetings. Specific examples where the invite covers policy or industrial issues include: Palacin speaking on digitalisation of urban mobility at H2020 RTR19 International Conference; Haigh speaking at Nokia Bell Labs and Samsung; Walker speaking at Westminster Energy, Environment & Transport Forum.

Major report authorship
We have contributed to reports for national and international governments and NGOs. Exemplars: United Nations Intergovernmental Panel on Climate Change, Lead Author for 6th Assessment Report Chapter 6: Cities, Settlements and Key Infrastructure and Coordinating Lead Author for Cross Chapter Paper: Cities and Settlements by the Sea (Dawson); Lead author of Infrastructure Section: 2nd UK Climate Change Risk Assessment (Dawson); co-writing the Public Policy Brief on AMR mitigation for the UN (Graham); White Paper for NATO on "Assessment of plasma actuator technologies for internal flows" as part of the NATO AVT-254 group (Neasham); Editor of the Engineering and Materials chapter of Exascale Computing Science case commissioned by EPSRC for the HM Treasury (Chakraborty); Contributor to Royal Society position paper on producing low-carbon hydrogen (Metcalfe).

Editorial Boards
106 editorial board positions including the following as editor in chief: IET Power Electronics (Pickert); Thermal Science and Engineering Progress (Reay); Education for Chemical Engineers (Glassey).

Advisory and expert witness support
Expert witness to the US Presidential Council on Antibiotic Resistance Bacteria, Washington DC (Graham); Adviser to the WHO on AMR mitigation via global WASH implementation (Graham); expert witness for healthcare product issues (Joyce); Chief Scientific Adviser DfT (Blythe).

Best paper awards: 24 awards including: Best paper in 2016 in J. Engineering Design (Coates); Frank Kottlowski Memorial Award (Rouainia); B. John Davies Best Paper Prize for papers published in IJAMT 2015 (Huo); High research impact paper award from Chinese Journal of Mechanical Engineering (Tian); Outstanding Paper Award, 12th International Symposium on Linear Drives for Industry Applications (Baker); Best paper award J. Phys. D (2016) (Whalley). J. Flood Risk Management Outstanding paper Award (2019) (Fowler), the Gaydon Prize for the best UK paper in the 36th International Symposium on Combustion by the British Section of

Combustion Institute (2016) (Apsden). International Association of Hydrologic Sciences – Commission on Statistical Hydrology (IAHS-STAHY) 2020 best paper award (Serinaldi). Editor's pick by Physics of Fluids (2018 Chakraborty)

Other Awards/Prizes: 30 awards including**:** [2015] C-SAW (Council for Science and Animal Welfare) AstraZeneca, Global 3Rs Collaboration Award (Davenport); Hind-Rattan award, which is one of the highest awards given to people of Indian origin by the Government of India (Chakraborty); [2018] Netexplo Observatory Award for the hand that sees project, UNESCO (Nazarapour); IET Achievement Award (Yakovlev); UIC Lifetime Achievement Award (Robinson); [2019] Castner Medal from SCI (Scott); X-prize Moonshot award (Team Tao). [2020] Curtis won the International Water Association/International Society for Microbial Ecology Biocluster Awards Grand prize in 2020 recognising his work at the interface of microbial ecology, engineering sciences and water and wastewater treatment.

Fellowships: 30 individual fellowships over the period including: EPSRC Research Fellowships (Nazarpour, Dawson); Parliamentary Academic Fellow at POST, secondment (Utili); EPSRC Healthcare Technologies Impact Fellowship (Novakovic); Faraday Institution Research Fellow (Rajaeifar); Mercator (Visiting Professor) Fellowship, Duisburg University (Chakraborty); Invitation Fellowship of JSPS (Chakraborty); RAEng (Mutch).