

Institution: University of Chester
Unit of Assessment: B12 Engineering
1. Unit context and structure, research and impact strategy

1.1 Context

This is the first REF submission that the University of Chester has made under Engineering. We are therefore one of the youngest Units in the UK to become research active in this area and this statement is based on progress made in the first seven years of activity. 14 FTEs are included in the return:

Name	Status
Professor John Brammer	Professor
Professor Steve Wilkinson	Head of Department
Dr Yousef Faraj	Senior Lecturer
Professor Joseph Howe	Director, Thornton Energy Centre
Dr Yanting Hu	Senior Lecturer
Dr Bin Yang	Associate Professor
Dr Amar Behera	Senior Lecturer
Miss Alice Gillett	Lecturer
Professor Yu Shi	Professor
Dr Andy Williams	Senior Lecturer
Dr Mayo Osundeko	Senior Experimental Office
Dr Gerard Edwards	Acting Head of Department
Professor Julieanna Powell-Turner	Director, Centre for Research in Environmental Science & Technology
Dr Carolina Font Palma	Senior Lecturer

The Engineering Unit of Assessment is formed from staff from the Departments of Chemical Engineering; Mechanical Engineering; and Computer Science, Electronics & Electrical Engineering in the Faculty of Science and Engineering at the University of Chester. The Faculty is based at Thornton Science Park, a unique location where industry, academia and commerce are co-located for mutual benefit. The Science Park is eight miles from the Parkgate Road campus and the city of Chester, and enjoys excellent access to North Wales, the Wirral, Cheshire, the Midlands and the North West conurbations of Liverpool and Manchester. Thornton Science Park forms part of the Cheshire Science Corridor and is a key player in the Northern Powerhouse initiative. In addition to the Faculty, the science park hosts around 40 companies working in the strategic areas of Energy, Automotive, Environment, and Advanced Manufacturing.

The Faculty of Science and Engineering was founded in 2013 with the objective of contributing to the University's strategic aim to further develop its STEM (Science, Technology, Engineering and Mathematics) provision, broaden the curriculum and extend the range of its activities into engineering and the physical sciences. Key to its success was the award of a HEFCE/STEM Capital grant of £7.1M, of which approximately £1.2M was used, together with the acquisition of legacy equipment from Shell Research Ltd (the former operators of the site), to equip laboratories with near state-of-the-art and industry standard facilities. Development of the science park has subsequently benefitted from ERDF, LEP and other funding to a total of >£30M, funding or co-funding initiatives such as the High Growth Centre, the Innovation-to-Commercialisation (I2C) facility, and the Thornton Energy Centre. Engineering is a core activity of the Faculty, and is fully aligned with the strategic areas of the science park and the University's research strategy. Consequently, engineering research was one of the first areas to be established within the new Faculty structure.

The University of Chester Corporate Plan – Vision 2015-2020 – contains an explicit commitment to supporting an expanding and innovative University research environment that ensures high quality

research and innovative practices that help influence the development and improvement of society. The strategy of the Engineering Unit of Assessment is fully aligned with this aspiration and is primarily built around a number of energy related themes. These are focussed on bioenergy (Brammer, Osundeko, Wilkinson), and on low-carbon and carbon-capture technologies (Howe, Font Palma). These are supported by activities in materials science and engineering (Shi, Gillett, Yang), robotics & advanced manufacturing (Behera), quantum electronics (Edwards) and applied thermodynamics (Williams).

These research themes benefit from the proximity of companies on the science park for collaboration and industrial participation, and from the cross-fertilization of ideas and expertise from the associated Mathematics, Physics and Chemistry groups within the Faculty. The Energy theme benefits particularly from close proximity to the Thornton Science Park Energy Centre, a facility to promote growth and acceleration in the development and exploitation of technologies for the energy market. Among the facilities present, this offers access to test bays for a range of technologies, and to an intelligent multi-vector micro-grid allowing cost-effective evaluation and demonstration of novel energy equipment in complex real-world scenarios. The theme also benefits from close links with the HyNET project which aims to reduce carbon emissions from industry, homes and transport and to support economic growth in the North West of England through promotion and development of hydrogen energy and carbon capture, use and storage. This work was specifically earmarked for funding boost in the March 2020 Budget.

Overall, the future strategic aim of the Engineering Unit is to build on and strengthen its core activities through collaboration within and beyond the Faculty of Science and Engineering. The primary focus will remain on Energy & Environment, closely aligned with the University Core Theme of Sustainability and the Environment. Supporting areas will be focussed on this core theme, with impact on the related Regional Economy Core Theme of the University Research Strategy.

1.2 Structure

The Engineering Unit is cross-departmental, with contributions from the Departments of Mechanical Engineering, Chemical Engineering, and Computer Science, Electronics and Electrical Engineering. There is frequent collaborative working with members of the Department of Mathematical and Physical Sciences.

1.3 Research and Impact Strategy

The research and impact strategy of the Unit is closely aligned with the strategic aims of the University articulated through the Institutional Environment statement and cascaded via the Senior Executive Team and University Research Committee. Our focus within the Unit is on developing critical mass, and building strength and depth within the core themes. We recognise that the Unit is relatively small, but is already developing and benefitting from close academic-industrial working collaborations. The strategic aims will be achieved through expanding the collaboration and interdisciplinary working across the Engineering, Mathematics, Physics, Chemistry and Computer Science disciplines within the Faculty, and externally both nationally and internationally with private and public sector bodies.

Bioenergy

The Unit has a growing activity in the area of energy from biomass and wastes. This is focused mainly on gasification and pyrolysis, and is carried out in close collaboration with external business partners. Current projects include the gasification of low value high ash biomass residues (Biogen Systems Ltd.), the high-temperature steam gasification of plastic wastes to produce hydrogen (PowerHouse Energy Group plc), the pyrolysis of biomass from Sub-Saharan Africa to produce biochar and electrical power (PyroGenesys Ltd), and the pyrolysis of end-of-life tyres to produce chemical intermediates (Big Atom Ltd) (**Brammer**).

In addition, the unit works on the production of methane through anaerobic digestion. The main objective is to achieve steady-state operation and improve the efficiency of biomethane production as a sustainable alternative to fossil fuel. A novel strategy for a pilot scale mesophilic anaerobic digestion with internal inoculums is being used to evaluate the operational parameters of anaerobic

Unit-level environment template (REF5b)

digester including the feed concentration, temperature and headspace pressure. Another aspect of the study includes methane upgrading and hydrogen gas production by the use of microalgae. (**Osundeko, Wilkinson, Faraj**).

In all cases, the work is being carried out as a partnership between academia and industry, resulting in a strong practical and commercial focus, commonly involving access to pilot-scale and full-scale test units located on site. Each of these research activities includes a clear and explicit focus on the environmental performance of the process, including both fossil carbon emission reduction potential and the minimisation or re-use of waste materials and the consequent mitigation of disposal issues.

Low carbon technologies

The unit's research activities in carbon capture, utilisation and storage (CCUS) have developed through modelling and experimental work led by Dr Carolina **Font Palma** with the close involvement of Professor Joseph **Howe**. The focus is around low temperature carbon capture: feasibility studies to assess a novel cryogenic carbon capture process by developing process simulation models, funded by Innovate UK Catalyst 4. Coupled with this, proof-of-concept work has been carried out through the construction of a purposely built cryogenic rig, with one PhD student sponsored by the collaborative ERDF Eco-Innovation project. Fundamental studies of CO₂ frost formation and desublimation have been carried out and the application of industrial tomography as a visualisation tool at cryogenic conditions evaluated using UKCCSRC Flexible funding. Overall, this work has involved International collaboration, including multiple research visits to institutions such as the University of Liege (funded by Santander Universities) for modelling work on CO₂ utilisation, and the University of Alberta and National Institute of Electricity and Clean Energy (INEEL) for modelling work on simulation of post-combustion carbon capture funded by UKCCSRC.

Multifunctional composite materials and structures

The Chester Smart Composite Group (CSCG), founded and led by Professor Yu **Shi**, has currently 8 PhD students (one joint PhD funded by CSC, China) and 1 MEng student in the team under his supervision. Funding for two Innovate UK projects has been secured; with a battery technology Small or Medium size Enterprise (SME) and a wind turbine blade Other Equipment Manufacturer (OEM) in China and in automotive monitoring with OEMs such as McLaren/RL Automotive. The total budget of £2.05M includes university income of £342.5k as PI since 2018. The CSCG is also acting as academic lead for other funders' projects, e.g. industry funded PhD, DASA and Horizon 2020 leading to a University income of £394.4k. Since it was set up, the CSCG team has published 36 peer-reviewed journal publications and 13 international conference publications one of which was awarded "best research" at the Power Generation and Energy Conversion (PowerMEMS) conference 2019. Further, one patent has been registered with SME RL Automotive in year 2019. International research collaborations include 3 international labs with Nanjing University of Aeronautics and Astronautics (NUAA) on advanced hybrid thermoplastic composites; Xi'dian University (Advanced multifunctional electronic equipment) and Xi'an Jiaotong University (Smart composites and advanced sensing system), together with journal publications and postgraduate student exchange and joint-supervision. Co-applications have been made for EPSRC-JSPS funding with two Universities in Japan for 5 years, and assistance given to Japanese partners in securing funding from JSPS in Japan. Research on multifunctional composites has enabled Yu Shi and his CSCG group to access and work with 30 home and international universities and over 50 companies and 4 Catapults in the UK. Overall, the group has contributed around 50 peer-reviewed journal publications, book chapters and international conferences in total since its foundation. The CSCG was a finalist at the Educate North Awards for "Innovation Award" and "International Partnership Award".

Supporting Technologies

Through Bin **Yang**'s work, the Unit has been developing the science of Materials Characterisation in the Microwave (GHz) and THz region of the electromagnetic spectrum, which has been demonstrated in three industrial sectors. This has resulted in advances in non-destructive detection to monitor roll-to-roll quality of flexible printing in large area electronics printing applications (funded by EPSRC Large Area Electronic Innovation Centre, £62,500). Applications in improved inspection efficiency for illicit postage by combining mm-wave large throughput penetrated scanning ability with

artificial intelligence algorithm are under investigation (funded by the UK Government's Border Force Agency, £48,250). Further developments in materials characterisation include using THz radiation to investigate intrinsic lattice level vibrations in bio-protein's chiral rotations, particle size related energy storage materials, and functional ceramics, through EPSRC Teranet Seed-corn funding (£12,000). Access to the FELIX (Free-Electron Lasers for Infrared eXperiments; Nijmegen, the Netherlands) facility to explore induced changes of polar structures in ferroelectrics by high intensity and ultrafast THz fields has been obtained through the EPSRC FLUENCE (**Felix Light for the UK: Exploiting Novel Characteristics and Expertise**) project. These research activities operate in cooperation with industrial partners to solve the technical requirement fronted in the engineering practices. Partners include Nano Products Ltd, VisionMetric Ltd; Morgan Advanced Materials Ltd and Deregallera Ltd. 22 journal articles have been published during this REF period, including in journals such as Nature Communications, Advanced Electronic Materials (cover page article), Nano Energy and Advanced Energy Materials.

In other Supporting Technology areas, **Gillett** works closely with the Chemistry Unit on laser modification of surface properties for enhanced energy and environmental performance. This has led to four interdisciplinary MRes projects including one co-sponsored by Camcoat Ltd on prevention of biofouling on marine components and one in a collaboration with Pilkington Glass on increasing the efficiency of energy collection in photovoltaics, developed from work published in the International Journal of Photoenergy (2018), **Hu** is active in developing high performance control systems for energy applications with currently one PhD student and results presented at the Liverpool conference on Developments in Power System Protection (2020), **Behera**, having recently joined the unit, is building on previous work at Queens University Belfast to explore crowd behaviour of robotic drones with an aim of using AI in search-and-rescue applications, **Williams** is active in energy systems and thermodynamics with recent publications in diverse areas ranging from the properties of cryogenic fluids in superheated immiscible liquids (International Journal of Heat & Mass Transfer, 2019) to the prediction of critical heat flux in pool boiling (International Journal of Multiphase Flow, 2018), and currently supervises an MRes student in this field. **Edwards** works on computational modelling of the fundamentals of next-generation computational devices for integrated circuits, co-supervising two PhD students within Engineering and one MRes student across the Engineering and Chemistry Units of Assessment. His Computational Condensed Matter and Nanoelectronics research group currently has two PhD students working on quantum dot cellular automata, one of whom is the chief technology officer of the Saudi Electronic Materials Company, two further PhD students on a visiting basis, and an MRes student modelling electron transport in single molecule junctions.

The Engineering Unit works with the Centre for Environmental Science and Technology (CREST), based at the University Centre Shrewsbury and led by Professor Julieanna **Powell-Turner** with 5 PhD students and 1 MRes student under her supervision. In 2019, the Centre secured an Innovate UK SMART grant with Panacea Global for PM2020 – Emission Reduction Engine Technology in Marine Applications, value to CREST £48,000. This was followed in 2020 by two further grants from the Innovate UK – Smart Grants call: Flox-box in collaboration with the University of Bristol, and deep-tech venture capital investors Flox, Acequai Capital, AI Seed Fund, and Speed Invest. The second Innovate UK - NetFLOX was in response to Covid-19 under the Sustainable Innovation Fund. Partners include a large poultry farm in addition to those above. Projects will deep dive into data-driven productivity for poultry, and emission reductions for the ecosystem. Total income £173,862 over 12 months. Related to this, CREST will carry out analysis of ammonia and nitrogen to provide an evidence base to inform government policy. The Centre has secured two University part-funded Sustainability Futures PhD Studentship Grants in collaboration with industry bodies Panacea Global and Severn Wye Energy Agency (£26,900 from sponsors and £90,000 from Chester). Since its inception in 2017, CREST has worked with 10 UK universities, over 130 SME's and 2 Catapults in the UK. In December 2020, CREST was successful in applying for a Business Fellow under the Connected Places Catapult's Wave 2 of Business Fellows Network. This is the first Business Fellow awarded under Catapult for the University of Chester. CREST have contributed to approximately 15 peer-reviewed journal publications, book chapters and international conferences in total since 2016.

2. People

The unit is relatively small and therefore, where possible, staff are recruited to strengthen and consolidate current areas of strategic importance. The emphasis is on aligning the Unit priorities, as outlined above, the ambitions of Thornton Science Park, the strategy of the Faculty of Science and Engineering, and the broader Institutional strategy. Staff are cross-disciplinary and come from a variety of backgrounds, some of which (for example, physics or chemistry) may have been outside the traditional Engineering route. This enriches the experience and diversity of the Unit, as well as solidifying its resilience and sustainability. Staff development is partly through self-development, for example by participation in conferences, journal reviewing and editorship, and membership of professional organisations, for example the IChemE (Institution of Chemical Engineers), the IET (Institute of Engineering Technology) and the SAE (Society of Automotive Engineers). Staff also make use of the University's comprehensive professional development schemes, including in supervision of PGR students and in grant writing and management. Time is made available in the Workload Allocation Management System for these activities, and their value to the Institution is recognised. During the establishment of the Faculty of Science and Engineering, and this Unit of Assessment, staff were recruited from a mix of industrial research and academic backgrounds. This diversity of experience enables us to approach research from a range of perspectives, and has given a very broad network of academic and industrial/commercial experts from which information and support are drawn.

During the period of this review the Unit has grown organically. One member of staff, **Jia**, moved to Aston University in early 2019 with the vacancy then being successfully filled by **Behera** (Robotics & Mechatronics). To facilitate expansion, **Williams** (Thermodynamics) was appointed in 2017.

During the 2014 – 2021 REF period **Shi** was promoted to a Research Professor position in Smart Composites; **Edwards** to Deputy Head of Computer Science, Electronics and Electrical Engineering and subsequently Acting Head for Electronics and Electrical Engineering; **Yang** to an Associate Professor position; and **Gillett** was appointed to a permanent faculty position following periods on temporary/fixed term contracts. **Powell-Turner** was appointed to Director of CREST and **Howe** to Director of the Thornton Energy Centre.

The Faculty and the Unit encourage & promote equality and diversity. We are proud that the University has successfully renewed its Athena Swan Bronze award, holds the HR Excellence in Research award, and in 2014 was one of only 5 HEIs to be awarded the Gender Charter Mark Bronze award. The percentage of BAME PGR students in the Unit is higher than the University average and we are conscious that this needs to be reflected in our staff profile. We have adopted a policy whereby all staff recruitment interview panels have at least one female member, where possible. The Faculty of Science and Engineering has become an Organisational Member of the Association for Black and Minority Ethnic Engineers AFBE-UK. We are also conscious of the need to attract a higher proportion of female participation in our undergraduate and postgraduate research student body. This is addressed through an ongoing series of public lectures by well-known female science representatives, for example celebrating International Women's Day, our traditional Christmas lecture series, the RAF, and school events. These events are organised by our educated OFFA-funded STEM Outreach Coordinator.

The Thornton Science Park offers good access to people with disabilities. Reserved car parking spaces are close to the entrance of most buildings and there is also a wheelchair accessible minibus that operates a shuttle service between the different University campuses. Many doors into buildings will open at the touch of a button located at wheelchair height, and there are lifts in the buildings where access is needed to a second floor. We have also incorporated some aspects of supporting disabilities into our research, and have developed a virtual environment that allows people to practice driving a powered wheelchair. Across the University, disabled staff are invited to join the Disabled Staff Support Group. This group discusses and finds possible solutions to the various issues relating to disability and making a positive impact to the working lives of disabled staff. For example, they have put together a set of leaflets on a number of disabilities which contain support information for managers and staff, addressing autism, dyslexia, epilepsy, hearing impairment, Meniere's disease,

mobility, and visual impairment. There is a dedicated quiet room at the Thornton campus designed specifically for people with Asperger's syndrome and other autism spectrum disorders. The University also employs a dedicated Assistive Technologist who provides support on the use of assistive technology. We have been awarded the Disability Two Ticks Symbol by Jobcentre Plus, which acknowledges those employers who make certain commitments regarding the recruitment, training, retention, consultation and awareness of disabled people and disability in general.

The University prides itself on its inclusive policies. It has established a support network for staff who identify as Lesbian, Gay, Bisexual or Trans, and holds the Navajo Merseyside and Cheshire LGBTIQA Charter Mark, an indication of good practice, commitment and knowledge of the specific needs, issues and barriers experienced by this community.

The University holds an annual Diversity Festival that is also open to members of the public, and provides a focus through which the University actively promotes, challenges and develops an understanding of equality, diversity and multiculturalism. Throughout the year, staff can participate on several different equality and diversity discussion boards. The University's Equality Forum takes place on a quarterly basis and all staff are welcome to attend.

Progress of research-active staff is considered as part of the annual Personal Development Review (PDR) process. The Unit and its contributing departments are keen to recognise and reward excellence in all fields of academic endeavour, including research. Consequently, promotion is based on research record and on contribution to the wider University community.

The Engineering UoA hosts a small but active PGR community. These students are supported by a first and second supervisor, with the Faculty Senior PGR tutor maintaining oversight of their well-being and progress. All PGR students are subject to a rigorous supervision and monitoring regime which includes 6-monthly progress reviews, and an MPhil to PhD progression review at 12-18 months with independent reviewers. There is also a PGR student society which offers a further range of support and networking activities.

PGR students participate in the annual Institutional PGR Conference and the Research Festival. All Thornton-based PGR students take part in an active seminar series, and are required to present their work at the end of the project (for MRes and PhD) and on transfer from MPhil to PhD registration. The seminar series includes presentations from more senior members of staff and external speakers, and is attended not only by University Alumni but also representatives from commercial companies based on the Science Park. Typically, seminars run every two weeks during term time, with a lower frequency over the summer.

Since the Faculty was founded in 2014, the Engineering Unit has had 2 PhD students who have successfully submitted theses and had their degrees awarded, 2 further PhD students are in the final stages of submission, 14 students are awaiting transfer from MPhil to PhD (or have recently transferred), and we also have 12 MRes students. This is supplemented by 5 PhD students and 1 MRes student based at CREST (University Centre Shrewsbury) The Unit has grown the PGR student population through engagement with the Faculty-wide EU funded P4 Eco-Innovation project. This is an ERDF project which co-funds studentships with SMEs working on the research leading to carbon footprint reductions. The Unit has also engaged with the University-wide Sustainability Scholarship scheme, with one PhD and one MRes currently funded through this route. Both these mechanisms align well with the Unit's Energy & Environment theme, and the research strategy's Sustainability and Environment core theme. Further steps to increase the research intensity include applications in progress through the UK Carbon Capture and Sequestration Research Centre (**Font Palma**), the EPSRC (**Yang, Shi, Font Palma, Behera**), the Carbon Recycling Network (CCnet) of the BBSRC (**Osundeko, Wilkinson**), Innovate UK (**Shi, Yang**), Ministry of Defence (**Shi**) and EU Horizon 2020 (**Shi**) among others, and through Faculty fee-waiver arrangements. Professor Shi has explored international collaborations to joint-supervise PhD students funded by universities in China and the Chinese Scholarship Council (CSC) for 6 months and 2 years, respectively. Two postgraduates from Xi'an Jiaotong University visited for 6 months and contributed one co-authored journal publication in Composite Part B, and two international conference papers (ICCM 2019). The

Unit-level environment template (REF5b)

other joint-supervised PhD student has contributed one publication in Composite Structures and another review paper has been submitted to Composite Part A. In addition, Professor Shi has developed international collaborations with Tohoku and Waseda Universities in Japan, where they have co-authored a review in Advanced Materials on their expertise of piezoelectric sensors applied to Covid-19 virus detection. Professor Shi also worked within an international team including Politechnika Wroclawska, Energytudosnanyi Kutatkozpont, Tohoku University, Tsinghua University, Waseda University and the University of Nottingham Ningbo which has won Horizon 2020 funds for a 4 year collaboration.

Several of the unit's staff members hold, or have held, nationally strategic positions, many with substantial international influence.

Howe is globally recognised as being at the academic forefront of the emerging Net Zero and energy transition agenda. He was co-author of the position paper that the Government adopted as the UK's Industrial Decarbonisation Challenge. In 2019 he was the academic host of the UN Mission Innovation IC8 conference. Current projects and proposals include being Co-Investigator on three UKRI Initiatives/proposals: NW Net Zero Cluster Plan; HyNet Industrial Decarbonisation Deployment; and North West academic lead for the UK Industrial Decarbonisation Research and Innovation Centre. He is the academic lead on numerous engagement activities including: the UK Decarbonised of Gas Alliance; National Grid Future of Gas and Stakeholder User Groups; Energy Estate: Hydrogen Investor Series. He is a member of the Storengy Responsible Business Board and chairs both the UK Engineering Constructions Industry Qualifications and Awards Committee, and the NW Hydrogen Alliance. Recently, he has become an Expert Reviewer for the UK Government's Intergovernmental Panel on Climate Change (IPCC) submission and a member of the Advisory Board of the UK Carbon Capture and Storage Research Consortium.

Powell-Turner has acted as expert consultant and research partner to the UK Ministry of Defence's (MOD's) Defence Equipment & Support organisation in 2014, Defence Concepts & Doctrine Centre in 2017, and Defence Science and Technology Laboratory (DSTL) since 2014. She has engaged widely with diverse industrial fields including environmental management and acquisition (UK MOD, DSTL and Qinetiq 2014-2109), poultry welfare and ammonia control (Flox, Acequai Capital 2020), marine biofuels (Panacea Global 2019, 2020, 2021) and renewables as sustainability expert advisor (Cavendish Nuclear 2020, 2021 Menchine & Bentley farmers 2020, 2021). She is the UK Chair for several International Organisation for Standardisation (ISO) Technical Committees including ISO TC 207 SC3 Environmental Labels and Declarations, and ISO 14063 SES/1/4 BS Environmental Communication, as well as advisor to ISO 14034 SES/1/4/BS Environmental Technology Verification and Performance Evaluation through BSI.

Williams is a member of the management team of the Science and Technology Facilities Council (STFC) Air Quality Network, an ad-hoc member of the Department for Environment, Food and Rural Affairs (DEFRA) Air Quality Expert Group, and co-leader of the UK Fluids Networks Special Interest Group in Particulate Matter Filtration Flows. He was formerly on the Expert Panel for the Strategic Priorities Fund Clean Air Networks as well as the Expert Steering Committee for the UK Government's evidence statement on Electric Vehicles and the Strategy Action Group for the Energy Technology Institute's Heavy-Duty Vehicles Programme. He has also acted as session organiser for the 2017, 18 and 19 SAE World Congresses.

Yang has a wide network of collaborators in THz science and technology including Queen Mary University (Donnan, Yan), Nottingham Trent University (Stevens) and the University of Kent (Gibson). He served on the Technical Programme Committee for the 2020 Conference on Robotics and Automations for Industry 4.0, and on the Technical Committee for the 12th UK-China Workshop on Millimetre-wave and Terahertz Technologies.

Unit-level environment template (REF5b)

Shi is a professional member of the Institute of Materials, Minerals and Mining and is currently working towards accreditation as a Professional Body assessor for composite technician apprenticeships. He has formed partnerships with the University of Manchester and Aston University for research collaboration, and has a wide network within the Research Catapult community for example the National Composite Centre (NCC), Advanced Manufacturing Research Centre (AMRC), LMC Automotive and Warwick Manufacturing Group (WMG). He is a member of UK-China Society of Automotive Engineers (UKCSAE) and UK-China Society of Materials. He has won the chair of the international conference POWERmems 2022 in the UK.

3. Income, infrastructure and facilities

The table below gives a summary of key grants awarded to the Unit during the REF period:

Income Summary

Grant Holder	Sponsor	Net grant to Chester £k	Start Date
Shi	MOD	63.4	Jul 20
Shi	RL Automotive	60.3	Oct 20
Font Palma	Innovate UK	22.9	Oct 17
Font Palma	UK CCSRC	22.5	Jun 20
Shi	MOD	139.8	Apr 20
Fort Palma	Leverhulme Trust	50.9	Sept 20
Yang	SBRI (Innovate UK)	24.9	May 19
Shi	Innovate UK	150.0	Mar 18
Shi	Horizon 2020	172.0	Oct 20
Shi	RL Automotive	5.0	Mar 19
Shi	RL Automotive	125.0	Feb 20
Yang	EPSRC Teranet Seedcorn	12.0	Jan 16, Sept 16, Sept 17
Wilkinson	RAE	29.2	Sept 17
Howe	Costain	58.1	May 18
Yang	EPSRC	62.5	Jan 17
Powell-Turner	Innovate UK	173.9	Aug 20
Powel-Turner	MOD	98.0	Mar 18
Powell-Turner	Panacea Global	48.0	Sept 2019
Howe	Innovate UK	2.7	Apr 20
Howe	Costain Group	3.2	Dec 17
	Totals:	£1,324.3k	

Infrastructure and Facilities

The Engineering Unit is well equipped to support research in the areas of strategic focus and its specialised facilities are briefly summarised below:

Energy Centre

The Energy Centre is a state-of-the-art facility designed to promote sustainable growth and acceleration in the development and exploitation of technologies for the energy market. The centre provides a flexible place where industry and academia can come together to innovate, develop and demonstrate new intelligent energy technologies. Key features of the centre include ground floor high-ceiling test bays, high quality office and laboratory space, and a 3 phase 300 KVA fully instrumented variable voltage electrical microgrid comprising a) a 25 kW electrical / 60 kW thermal Combined Heat and Power (CHP) unit b) a 10 kW / 75 kWh 3 phase vanadium flow cell c) a 300 kVA variable reactivity load bank, and d) 16 additional microgrid connection nodes.

The Energy Centre has facilities for the testing and development of:

- New types of photovoltaic solar cells

Unit-level environment template (REF5b)

- Innovative electrical energy storage solutions
- Developments in low power motor drives
- Advanced software to control and manage multiple renewable energy sources connected to the same power network
- New thermal systems based on stored and pumped heat
- Fuel Cell and Redox Battery technologies

I2C (Innovation to Commercialisation) Centre

Facilities include

- Dual mode CO₂ / Fibre Laser cutter system.
- GOM 3D scanner system.
- Extensive CAD software (ANSYS / SpaceClaim / AutoCAD / SolidWorks / LabView)
- 3D printing in C-Fibre / FDM (fused deposition modelling) technologies.
- Keyence 3000 confocal optical profilometer.

Engineering Laboratories and Workshop

- Extensive range of mechanical engineering facilities including welding, manual and CNC turning and milling, casting, sectioning and preparation.
- Automotive turbocharger test rig
- Electric supercharger test rig
- Internal flow heat transfer test rig

Smart Composites Laboratory

- University of Chester / Xi'an Jiaotong University international joint research laboratory on smart composites and advanced sensing systems, with input from Xidian University. Wide range of equipment and facilities including curing oven, hot-press, vacuum assisted resin transfer moulding, advanced inkjet materials printer, infrared system for curing and welding, and associated power supplies and consumables for composites manufacturing. The laboratory is supplemented through finite element modelling software (Comsol dynamic module from Innovate UK).
- Vibration lab with a range of facilities for advanced vibrational simulation and analysis, including resistance decade box, digital storage oscilloscope, shaker, power supply, power amplifier, function generator, spectrum analyser and digital dual display multimeter.

Design Suite

- 3D printing (Formlabs, Raise Pro 2Plus, Ultimaker)
- Zing programmable laser machining
- 3D scanning

Laser Materials Laboratory:

- 60W CO₂ laser, 300 W fibre laser 1032 nm, picosecond ultra-short pulse laser 1032 nm, 850 mJ Nd/YAG laser + characterisation facilities including UV-vis spectroscopy, optical microscope, carbon coater for coupling layers.

Materials Testing, Preparation and Characterisation Laboratories:

- Tensile testing, hardness testing, metallography, tribology testing
- Spin-coating, polishing, sectioning, grinding, deposition by vacuum evaporation or sputter coating, ball mill, ultra-microtome, vacuum oven, furnace.
- X-ray diffraction (XRD), scanning and transmission electron microscopy with energy-dispersive X-ray analysis (SEM-EDX, TEM), X-ray photoelectron spectroscopy (XPS), scanned probe microscopy by atomic force or tunnelling (AFM/STM), optical microscopy (polarisation, DIC, phase, fluorescence), profilometry, surface energy (sessile drop, wetting balance)

Microwave and Terahertz Material Characterisation (MTCC) Centre

- The centre is equipped with a Terahertz Time domain Spectroscopy system, unique in UK THz community in including all transmission, reflection and ATR modes; a 100 GHz imaging camera and broadband THz detector. In the microwave range, the centre has an open-ended coaxial probe and resonator characterisation systems, driven by a vector network analyser from 2 MHz up to 6 GHz.

The Unit also has access to the **Analytical Centre**. This is a dedicated analytical chemistry facility that exists to provide a modern analytical service for the benefit of teaching, research, and commercial customers. Its facilities include elemental analysis by ICP-MS and combustion (CHONS) techniques, Fourier transform infra-red spectroscopy (FT-IR), gas chromatography-mass spectrometry analysis (GC-MS), time-of-flight mass spectrometry (ToF-MS), high performance liquid chromatography (HPLC), bench-top SEM and a number of further minor items

Theoretical and computational work can be carried out in part using the University's **high-performance computing cluster** which consists of a combined processor power of 312 cores. Intel Xeon E5 series @ 2.5GHz CPUs are incorporated adding up to 530 GB of memory in total. Cores are divided among 17 computer nodes linked via high-speed infiniband interconnects.

Members of staff have access to a wide range of external facilities. For example, within the assessment period, Bin Yang was twice awarded time with Europe's FELIX Free Electron Laser beam, supported by the EPSRC FLUENCE Project, whilst working on "Exploring induced change of polar structures in different ferroelectrics by high intensity and ultrafast THz fields", Feb 2018 to July 2018 and Feb 2019 to July 2019.

Members of staff are supported internally through a small grants scheme, which provides pump-priming funds for projects expected to lead to future grant applications.

4. Collaboration and contribution to the research base, economy and society
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The Engineering Unit strongly believes in the power of networks and collaboration to build, strengthen and sustain research impact and reach. Our collaborations are cross-disciplinary, multi-national, and focussed around our key themes. We work with Universities, research institutions, local authorities, and commercial enterprises to maximise the contribution of our skills and expertise for economic and social good.

The Engineering Unit is based at the Thornton Science Park, which is at the centre of one of the most active manufacturing regions and most vibrant energy clusters in the country. As a result of the research within the Unit, the University has been able to attract 40 tenant companies to base their R&D activities at Thornton, and thus provide a nexus for inward investment into the region. As such there is a strong (and strengthening) interface between the research undertaken in the Unit and the needs of our partners on the campus and in the region. This is reflected in the nationally recognised hydrogen cluster which is transforming the region and the Unit's research through investment and industrial activity including major players such as Peel, Innovyn, Engie, Urenco, and ABB among others

The Unit, through the Faculty and the Science Park, has hosted conferences and related scientific/industrial activities throughout the assessment period. Typical examples include:

- Society for Chemical Industry (SCI: several early-evening meetings co-hosted by the local branch)
- 1st Terahertz and Materials" workshop at Thornton Science Park on 26th of April 2017, sponsored by EPSRC Teranet grant. (B Yang)
- 2nd Terahertz and Materials workshop at Thornton Science Park, sponsored by EPSRC FLUENCE project and IET, on 21 March 2018. (B Yang)
- Several meetings with the Halton Chamber of Commerce co-hosted by the Commercial Services department of the University

- Institute of Mechanical Engineers (I.Mech.E: several early evening meetings co-hosted by the local branch)
- UK Fluids Networks Particulate Matter Special Interest Group Conference 2018

Contributions to the Economy

The presence of the Faculty of Science and Engineering on Thornton Science Park presents a unique value proposition for companies that may wish to co-locate. The consequent interaction between academia and commercial enterprises has resulted in a substantial increase in the quality and number of placement opportunities for students of the Faculty, and has allowed joint usage of facilities at Thornton such as the Innovation-to-Commercialisation centre and the High Growth Centre (both originally ERDF funded), with subsequent job creation and boost to the local economy. A particular example to note is the ERDF P4 funded Eco Innovation programme that has supported 26 SMEs in Cheshire and Warrington regions in their low carbon innovation journey through our PhD and Master of Research routes. Research activity sponsored through this collaborative programme has included carbon capture, waste to energy, improving machine efficiency through machine learning, remediation of waste, improving energy generation from wind turbines, improving heating efficiency for homes and offices, and many other green innovations. In several cases our SMEs partners have gone to market with their new innovations from this Eco-innovation programme

The Engineering Unit has supported the local economy through provision of access to expertise and facilities either on a commercial or collaborative basis. This includes student placements and internships together with access to facilities such as the engineering and materials characterisation laboratories. These have been supplemented by provision of upskilling to SMEs through Masterclasses in Unit research areas and areas of expertise such as 3D printing, and control & automation.

The immediate environment around Thornton Science Parks hosts a Nationally important cohort of SMEs focused in the area of hydrogen and Low Carbon energy. Through the work of Howe in coordinating research within Unit, this is crystallising Government investment in H₂ facilities at the adjacent ESSAR refinery site and linking to the Nationally important Hynet project.

Contributions to Society

The Unit contributes to society through the dissemination and application of its research output, engagement with local companies, and engagement in the wider public domain.

The Unit's research directly benefits society as a consequence of the research focus on energy and sustainability. In many cases this has involved direct engagement with the SMEs in the local and regional economy, giving rise to new business and employment opportunities. The overall thrust of work towards greener, cleaner energy and materials is directly aimed at societal and economic benefits.

- Reduction in plastic waste / plastic waste recycling through collaborative work with Waste2Energy Ltd and with PowerHouse Energy which has led to a pilot at the Thornton Energy Centre and subsequently leading to full scale facility on the adjacent Protos industry park.
- Yu Shi was funded by Innovate UK for £1.55 million to work with SMEs and McLaren, Scania to develop autonomous monitoring of wheel alignment to reduce the emissions from misaligned wheels of road vehicles. The project aims to achieve net-zero emissions to avoid pollution from tyre consumption.
- Yu Shi has collaborated with H2O Renewables Ltd to develop clean energy from onshore wind to heat family homes. This will be a novel avenue to lower the emissions from fuel heating in the UK.
- Working with local Cheshire company Avia Technology Ltd to use solar panels in improving wastewater disinfection. One MRes student is jointly supervised by Avia and B Yang.
- Work by Yu Shi and his group on development of smart self-monitoring wind turbine blades will enable substantial savings to be made on the cost of using offshore wind energy.

Unit-level environment template (REF5b)

- The ERDF P4 funded Eco-Innovation project has led to a number of significant societal benefits, in addition to those to the local and regional economy. The project has supported 6 PhD and 19 MRes studentships in partnership with regional SMEs. Of these, 4 PhDs and 13 MRes fall within the scope of the Engineering Unit. The final report from the Eco-Innovation project is not yet complete, but initial indications are that the product and process improvements identified by research in the Engineering unit have led to a CO₂ reduction of 425 tonnes equivalent so far with a likely additional reduction of approximately 2200 tonnes by the end of the project in May 2021.

The Unit has engaged with society in the wider public domain through a broad range of STEM Outreach activities, drawing on our research as examples with which to inspire and motivate future generations of science and engineering students. In addition to visits to local schools and colleges, these activities have included A-level revision events, public lectures including a series of Christmas lectures by well-known and popular speakers, support to International Women's Day events, and participation in Formula Student and associated projects.

The work of Professor Joe Howe (see section 2 above) involves extensive engagement with the emerging Net Zero and energy transition agenda, at nationally significant levels. This work will result in major societal benefits in terms of environment quality and CO₂ reduction.

Recently, the Engineering Unit of Assessment has devoted its manufacturing capability to amelioration of the local shortfall in PPE as a result of the first onset of the coronavirus pandemic. Visors were produced using additive manufacturing (3D printing). Chemical engineering facilities were re-purposed for the production of hand sanitiser. Assistance was given to a local brewer to convert to sanitiser manufacture. All outputs from this activity along with substantial amounts of PPE (facemasks, lab coats, etc) were donated to local hospitals and care homes.