

Institution: University of Bedfordshire
Unit of Assessment: 12
<p>1. Unit context and structure, research and impact strategy</p> <p>The University of Bedfordshire's submissions to UoA12 are mainly outputs from the Smart Cities Research Institute (SCRI) that brings together advances in knowledge and innovation around the core area of renewable and sustainable energy.</p> <p>Within the research institute, there are three main research centres: the Centre for Sustainable Materials and Nanotechnology (SMNT), the Centre for Renewable Energy (CRE) and the Centre for Clean Air and Water Technology (CAWT). These three research centres provide the pillars upon which the research strategy for the institute is built. It has specially developed a partner relationship with TWI Ltd Cambridge's Renewable Energy Technology Centre for enhancing research on solar energy and wind energy.</p> <p>In the SCRI, the three centres share the same vision of being a world-leading/recognised institute of excellence in i) green energy technology, smart materials and manufacture, and ii) clean environment through sustainability-focused, cross-disciplinary research. The strategic aims for research and impact in the three centres include:</p> <ol style="list-style-type: none"> 1) To create smart materials production and manufacture methods that can support the rapid development of green energy and the digital world; 2) To develop sustainable energy technologies for high energy efficiency and low emissions, or non-emissions, to accelerate the process of 'green industry revolution'; 3) To integrate electronic engineering, energy engineering, environmental engineering and manufacture engineering for achieving clean air and water environments; 4) To enhance innovative applications of sustainable technologies. <p>Each centre has a specific emphasis on one or more of the following objectives:</p> <ul style="list-style-type: none"> • SMNT focuses on objectives 1) and 4) concerning advanced material technologies, including the production and manufacture of nanomaterials and composite materials; • CRE focuses on objectives 2) and 4) in regard to solar energy, wind energy, biofuel and biomass; • CAWT focuses on objectives 3) and 4) in low emission technology and monitoring systems. <p>Our achievements in meeting these objectives are below:</p> <ol style="list-style-type: none"> 1) Developed advanced material production and manufacturing technologies: <ul style="list-style-type: none"> • In the university laboratory, we used a biaxially-oriented polypropylene (BOPP) film and an external magnetic field in a magnetic force microscope (MFM) system for cleaning contaminated magnetic probe tips. The scanning electron microscope (SEM) images developed by this SMNT in 2017 have shown the method is very effective and can greatly improve the quality of magnetic imaging, prolong the service life of magnetic probes and reduce the experimental costs in many MFM applications.

- Sensitive and highly efficient polarisation controlled, three-beam interference set-up has been developed to capture multiple cells. Simulations on the influence of the polarisation angle upon the intensity distribution and the laser gradient force change with different polarisation angles, have been carried out, based on the theory of superposition of three beams.
- Developed a one-step lithography method, based on a super lens, to fabricate diffraction-unlimited metallic patterns. By controlling the material parameters and the distribution of the impinging energy, various phenomena, such as periodic nanonetworks, ultrathin nanowires (sub-50-nm feature size), and variable-sized nanoparticles (ranging from sub-10nm to several hundreds of nanometres), are fabricated using a 1,064-nm nanosecond laser. The dewetting process of metallic films explains the evolution pathway of such phenomena. The direct-writing performance of a transparent material with a super lens is studied, and the maximum etching depth of Si gratings can reach 2 μm under a single laser pulse, with fine profiles.
- Fabrication of hierarchical moth-eye structures with durable superhydrophobic property for ultra-broadband visual and mid-infrared applications.
- Designed asymmetrical three-beam laser interference lithography for fabricating micro- and nano-structures.
- Algorithm design for compression, enhancement, rendering and processing of multimedia signals, particularly the signals associated with images, videos and three-dimensional videos; applicable signal processing algorithm design for signals acquired by sensors and design of machine learning algorithms for detection of events-of-interest in the captured signals.

2) Studied and designed sustainable energy technologies for high energy efficiency and low emissions, or non-emissions, to accelerate the process of the 'green industrial revolution':

- Optimised battery-less Radio Frequency (RF) energy harvesting system performance with a hybrid storage solution that uses an adaptive learning algorithm to predict the amount of available ambient energy and dynamically switches between two capacitors, depending on the environment.
- Designed and optimised a compact RF energy harvesting device for smart applications.
- Studied history-assisted, energy-efficient spectrum sensing for infrastructure-based cognitive radio networks.
- Developed a solar PVT (PV-Thermal) system for improving PV's conversion efficiency and providing heat supply.
- Developed Internet of Things (IoT) localisation and energy harvesting with applications in intelligent transportation and mobile health applications, in particular, applying machine learning and RF-sensing methods to human activity recognition and localisation in various environments.

3) Integrated electronic engineering, energy engineering, environmental engineering and manufacture engineering to achieve clean air and water environments:

- Developed and optimised mechanical-relating technologies to enhance and upgrade powertrain performances of various ground vehicles and water vessels. By applying advanced combustion, flows and Carbon Capture and Storage (CCS) into conventional combustion engines, this research has improved vehicles' fuel economy and energy efficiency, thereby reducing fuel consumption and emissions. A main objective of this research is to eliminate harmful emissions from the exhaust gases of vehicles.

- Studied and developed required technologies, combined with internal flows of fuel cells, to explore the integration of fuel cell applications in heavy-duty vehicles. The research involves replacing combustion engines with fuel cells to achieve zero emissions during the vehicle's operation. These vehicles have an operational range that exceeds that of a battery-powered vehicle and comes close to that of a combustion engine-powered vehicle.
- Investigated sustainable energy technologies for enhancing their energy output and life cycle efficiency. Relevant investigations include applying advanced thermodynamic, heat transfer and advanced materials and structures technologies to implement combined solar PV-thermal, thereby increasing the total system efficiency.
- Developed nano-antenna arrays combining enhancement and beam control for fluorescence-based sensing applications to water quality monitoring.
- Developed and applied knowledge and solutions based on sensors, wireless communications and signal processing for smart homes, building and city paradigms. Novel integrative solutions with the support of artificial intelligence (AI) have been created for energy harvesting and saving, green technologies, water quality monitoring and management.

4) Enhanced applications of sustainable technology:

- Managed energy systems to reduce early handover to save energy in Long Term Evolution (LTE) networks.
- Studied energy detection-based spectrum sensing over two-wave with diffuse power fading channels.
- Developed a sustainable μ ECM machining process with indicators and assessment by considering pulse signal features and EDL capacitance.

UoA12-related SCRI research will build upon the established research and impact aims/goals that have currently been achieved to become a world-leader through:

- Generating new cross-disciplinary research areas in response to the global challenges of health and security;
- Disseminating high-quality research outcomes to targeted audiences in engineering areas;
- Engaging with societies, communities and industry to understand their needs and identify the research to meet those needs;
- Developing expertise across staff members and post-graduate (PGR) students.

SCRI has initiated new, cross-disciplinary research to those technologies relating to the 'green industrial revolution'. The research institute has engaged increasingly with EU and UK research councils and EU organisations, for example, EPSRC, Innovate UK, Horizon 2020 and Horizon Europe for support that enhances our research. Most of that research has been or will be carried out by collaborations with international and/or industrial partners.

2. People

SCRI has succeeded in creating an equitable and supportive environment for all its members, including those submitted with this unit, evidenced in our approach to recruiting, retaining and nurturing research staff.

Recruitment: the recruitment of staff members in this unit happens via two channels. One is the university's School of Computer Science and Technology (CST), to which almost all SCRI members belong. Staff recruited through this channel mainly have a permanent teaching & research contract with the university. The other route is through externally funded projects. Staff members recruited through these projects have fixed-term, research-only contracts. Recruitment

has been in line with the university's policy, in particular, equality and diversity. Increasing the proportion of female staff in the research institute has been a long-standing priority. Among the staff with significant research responsibility in the unit, three out of 10 are female. People recruited through either channel who have significant research responsibility have been successful in bidding for external research funding and have produced excellent research outcomes.

Retention: SCRI encourages staff promotion. In this REF period, one professor and two readers were promoted in the institute, relating to UoA12. Working with CST, SCRI ensures staff members who have significant research responsibility have 25% of their annual workload assigned to research.

Nurturing: All newly recruited staff have been assigned with a mentor (for permanent contract holders) or a supervisor (for fixed-term contract holders) to help them make headway with their research and to establish a research profile. Along with the university's three-month review for staff in their first year in post, the mentors and supervisors help the new staff members identify any training requirements. The university's Innovation & Enterprises Department provides staff, especially new recruits, with information about funding opportunities, and support with bid development and project management. SCRI offers individualised advice to new members of staff through the director of SCRI and through the centre leaders. It also provides financial support, in conjunction with CST's staff development fund, to help staff disseminate their research and develop research networks. SCRI has a strong track record of nurturing staff to fulfil their potential either at UoB or, in some cases, in leading roles elsewhere. Dr Yue Zhang, for example, is now leading communication research at the University of Leicester. SCRI has the following special programmes in skill development for researchers:

- **Quality Research (QR):** During this REF period, SCRI has received £600k in QR funding to support research and researcher development.
- **Conference funding:** Through QR funding, SCRI has supported up to two staff members each year to participate in top-tier, national and international conferences that facilitate effective dissemination of findings, ensure targeted impact, form new collaborations and develop existing relationships. This fund is in addition to the support available from externally funded projects.
- **UoB Conference:** SCRI researchers of all levels produce posters and research presentations.
- **Visiting researchers:** SCRI has attracted one visiting professor who is a distinguished, top-tier researcher and three other visiting research fellows. This helps staff and student development in SCRI by providing opportunities for close interaction with these visitors. Faculty members also visit top-tier research institutes nationally and internationally, assisting staff development and bringing new knowledge back to the research institute.
- **Funding bid preparation workshop:** UoB runs regular workshops on how to write successful bids for specific funding bodies. These sessions cover aspects including, selection of the right funding schemes and how to make a bid, how to use the full economic costing, reviewing previous bids for lessons learnt and best practice. The workshops use live bids to demonstrate the process. Prof Li, Prof Peng and Dr Ajmal, who together have more than 11 successful Research Council or EU bids, regularly share their bid development expertise.
- **Research student supervision preparation:** Every year all early career research staff without supervision experience are included in teams as a way to upskill them.
- **Research Fellows and Progression:** SCRI has RFs recruited under externally funded research grants. At the end of their contracts, RFs frequently take up challenging roles in top organisations.

- **Early Career Researchers (ECR):** SCRI has five academics who began their lecturing careers during this assessment period. SCRI supports all ECRs by providing mentors, encouraging collaborative research through bids and outputs and supporting their teaching workload. The recruitment and development of ECRs is paramount to our strategy as it brings vitality to the research environment and ensures sustainable growth.

UoA12-related SCRI values the development of PGR students, i.e. PhD and MSc by research students, to become young researchers and engineers. In this REF period, the unit has awarded PhDs to 21 students. They continue their research and technical development in universities and in industry. Some excellent examples include:

- Faisal Qureshi - completed in 2014 and is currently the managing director and consultant at Express Communication Services Limited;
- Eleftherios Chatziantoniou - completed his PhD in 2015 and is now a research scientist at Cobham Aerospace Connectivity, UK;
- Christopher Hahne - completed in 2017 and is now a researcher at BASF, Germany.

This UoA nurtures PGR students with the following foci:

- Research and technical development capabilities through supervision, PGR fund, workshops/seminars, and participation in staff exchange programmes:
 - Supervision - Each PGR student has a supervisory team of two supervisors, at least one of whom must have successfully led a student to completion. Where appropriate, students may also have an external expert from industry or other universities as the third supervisor. The supervisory teams provide the students with suggestions on research direction and detailed research tasks every month.
 - PGR fund – Each PGR student is allocated a specific allowance (£1800 in 2019-2020 academic year) to support their research, including facilities (computers, lab equipment, software, etc.) and activities (research visits and conference presentations).
 - Workshops and seminars – At least two workshops per term on various topics have been organised for the PGR students to help them make headway with their research, focusing on the literature review.
 - Participation in international conferences - Our PhD students are given free access to conferences hosted by research centres, such as the IEEE Multimedia Signal Processing (MMSP) 2017, (<https://www.beds.ac.uk/mmmsp2017/>) and the IEEE International Conference on Multimedia and Expo (ICME) 2020, co-hosted with Queen Mary University of London.
- Entrepreneurship via collaboration with industry:
 - Collaboration with Industry – In recent years, SCRI has developed extensive connections with local and regional industry, including those through the EU H2020 projects, Innovation Bridge and ICT Escalator, to help industry develop digital business. Together with their supervisors, some PGR students have been involved in a collaboration to develop customer-oriented technologies.

Within SCRI, there are a range of platforms that enable the PGR student voice to be heard. A PGR student representative collects students' opinions on research management and reports them to the SCRI's board meetings every three months. Supervisors are the first contact point for PGR students for matters relating to research management and students' registration.

3. Income, infrastructure and facilities

SCRI-related UoA12 is proactive and successful in bidding for funds to support research and expertise development. The unit values research income as recognition of our research. We have led and participated in six EU-funded projects, four projects funded by national funding bodies, including the EPSRC, and three regional and local projects. These projects have brought us £845K in research income in this REF cycle. In addition, the unit also received approximately £600k QR funding during the same period.

SCRI research has benefited from the new STEM (Science, Technology, Engineering and Mathematics) building, built in 2018 with £40m investment from the university. Led by the university RDC (Research Development Committee) and other relevant committees who drive the university's strategy in research and business development, the IES (Innovation and Enterprise Service) has also directly supported SCRI to secure funding and industry collaboration. It has also helped build the partner relationship with TWI Ltd Cambridge to develop research collaboration on renewable energy technology.

The director of SCRI manages infrastructure and dedicated administrative staff (20% FTE). The research institute has the following facilities across three research centres - Centre for Sustainable Materials and NanoTechnology (SMNT), Centre for Renewable Energy (CRE), and Centre for Clean Air and Water Technology (CAWT).

- The CRE research centre has hosted the co-funded Rohde and Schwarz telecommunications laboratory and electronics workshop that offers state-of-the-art facilities for design, prototyping, construction and testing of analogue and digital circuits, antennas and wireless communication systems. It also hosts an optics laboratory with systems of heterogeneous cameras (visual, omnidirectional, infrared and time-of-flight) for experimental facilities in 3D and heterogeneous camera video processing, as well as plenoptic imaging.
- CAWT's research facilities include two engine testbeds used for optimising engine combustion to reduce CO₂ emissions and harmful emissions. Combustion analysis equipment has been installed on both testbeds. Carbon capture and storage (CCS) has been fitted on one engine testbed to implement zero emissions of combustion engines. High-speed imaging equipment is also available for this research. CAWT also has two fuel cell test rigs - one is fitted with a 2 kW PEMFC (Proton Exchange Membrane Fuel Cell) stack, and another has an 800 W DMFC (Direct Methanol Fuel Cell) system. Meanwhile, a high-performance computer cluster is available for making advanced numerical simulation. CAWT also has wide access to R&D resources from their industry partners, such as powertrain experimental equipment and numerical simulation hardware and software.
- Recent financial support for CAWT Research Centre's research includes grants from the EU, Innovate UK, and local Industry. In the last three years alone, (2017-2020), the total research budget provided from external sources has been around £500k.

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

SCRI, which mainly contributes to UoA12, has developed a wide range of collaborations with academics, industry, local authorities and the UK government and contributed to research and society through these relationships. It has specially developed a partner relationship with TWI Ltd Cambridge's Renewable Energy Technology Centre for enhancing research on solar energy and wind energy.

- Staff from CRE hosted the IEEE Multimedia Signal Processing (MMSP) Conference 2017 at the UoB (<https://www.beds.ac.uk/mmmsp2017/>). It was chaired by a senior staff member from the centre. This annual IEEE event was organised by the Signal Processing Society / Multimedia Signal Processing group, bringing together around 150 leading researchers from 31 countries worldwide, with every continent represented. Our PhD students received free access to all events across the three days, with 10 of them attending more than one day.

- The CRE co-hosted the IEEE International Conference on Multimedia and Expo (ICME) 2020 with Queen Mary University of London, offering free access to both events to research students in the School.
- Several staff from SCRI have worked and continue to work as associate editors for a number of IEEE, IET and Elsevier journals and as chairs for leading international conferences. One of the members is an affiliate member of the IEEE SPS MMSP Technical Committee and also chair of the IEEE ComSoc MMTC Interest Group on 3D Processing and Communications.
- A colleague from the CRE has completed relevant research and produced the following publications jointly with the University of Cambridge and the University of Oxford in 2017: An active radio-frequency-identification-system capable of identifying co-locations and social-structure: Validation with a wild free-ranging animal (authors: Stephen A. Ellwood, Chris Newman, Robert A. Montgomery, Vincenzo Nicosia, Christina D. Buesching, Andrew Markham, Cecilia Mascolo, Niki Trigoni, Bence Pasztor, Vladimir Dyo, Vito Latora, Sandra E. Baker, David W. Macdonald; Journal: Methods in Ecology and Evolution; Publisher: John Wiley & Sons).
- CAWT has had substantial collaborations with several international partners, such as Beihang University, Tianjin University, the University of the Ryukyus, and industry partners, such as AVL Powertrain UK, Cleancarb Luxemburg, DST – Germany, ECE – Germany, etc. All of those partners have worked with CAWT for granted research projects. This collaborative research has contributed to reduced greenhouse gas emissions, reduced harmful emissions and improved air quality. The developed technologies of mechanical engineering and sustainable energy have enhanced the quality of relevant industry products, thereby increasing each company's income and employment.
- CAWT also has comprehensive access to R&D resources from their industry partners (such as AVL Powertrain UK Ltd, Syselek Ltd, Select Solar Ltd, etc.), including powertrain experimental equipment and numerical simulation hardware and software.
- KTP: Colleagues from the CRE have just completed one KTP project by collaborating with Harrod Sports UK and working on another KTP with Deckpro Pumps-Uptime Systems.