Institution: Edinburgh Research Partnership in Engineering – ERPE (Heriot-Watt/Edinburgh)

Unit of Assessment: B15 General Engineering

a. Context

Formed in 2004, the Edinburgh Research Partnership in Engineering (ERPE, www.erpe.ac.uk) encompasses the entirety of Engineering across Heriot-Watt University (HWU) and the University of Edinburgh (UoE). It spans Chemical to Civil and Structural, Electrical and Electronic to Mechanical Engineering with significant scale and strength. Highlights of ERPE's research portfolio are internationally recognised groups in fire safety engineering, carbon capture and storage, laser engineering, offshore renewable energy systems and devices, petroleum engineering, railway engineering and signal processing, all garnering significant industrial engagement. ERPE is organised into four themes: (1) Infrastructure and Environment; (2) Energy and Resource Management; (3) Manufacturing and Materials; and (4) Sensors, Signals and Systems. From its foundation ERPE has focused on the creation and dissemination of knowledge in areas of significant economic and societal benefit, as our impact case studies testify. ERPE employs a variety of approaches to create and transfer knowledge, generating impact within the UK, Europe and internationally. These include: joint industry projects (JIPs) and strategic partnerships (academic, industrial and international); the creation of intellectual property (IP) and know-how; company formation; the issuing and licensing of patents; contribution to the definition of technical standards and regulations; support of product development, new or enhanced service offerings, both by the Universities and commercial partners; and the creation and transfer of knowledge and technologies to pre-existing commercial entities.

b. Approach to impact

Over the REF2014 period ERPE has: spun-out 8 new companies (securing a total £9.7M in funding); won a total of £3.95M in pre-commercialisation research funding; successfully completed licensing negotiation with 106 companies; earned a total of £6.63M in consultancy work with industry; been awarded £39.53M of industrial funding for collaborative research projects; and contributed to the publication of 24 international standards. There follows a description of the formal structures and mechanisms by which ERPE has supported the translation of our research output to global impact. Twenty-one impact case studies are presented in REF3B representing a cross-section of these impacts.

ERPE Advances Industrial Interaction

Multiple mechanisms facilitate ERPE's engagement with industry: high-level strategic partnerships with key companies; direct sponsorship of Chairs and Fellowships by and with companies; focussed links with companies on specific challenges via our JIP mechanism; and annual Industry Days with specific technical foci, e.g. Sensors in 2012 and Sustainable Built Environment in 2013.

ERPE benefits greatly from strategic alliances with major industrial partners, namely Arup, AWE, BP, BAE Systems, BRE, Converteam (now GE), Cairn Energy, EDF, Iberdola, Selex-ES, Renishaw, STMicroelectronics, Shell, Schlumberger and Scottish & Southern Energy (now SSE). These offer partners access to the wealth of technical competence within ERPE and provide an agility in response to technical challenges that is hugely beneficial. For example, the Converteam Advanced Technology Centre benefits from ERPE's research lead in off-shore wind turbine power generation; Michelin profits from access to a unique cold-laboratory to study tyre grip on snow and ice under controlled conditions; the Adsorption Research Industrial Consortium was created to support Exxon-Mobil, Hitachi, Air Products and Air Liquide; and our Innovative Manufacturing Research Centre has had direct funding (£3.7M cash and in-kind support) and collaboration with 35 companies delivering manufacturing solutions and creating IP (see www.jwi.hw.ac.uk/imrc/collaborators.htm). ERPE is also a key participant in several ETI funded projects and is working closely with Rolls-Royce, EDF, E.ON, GL Garrad-Hassan and Alstom.

These relationships also provide direct support for key academic staff through industrially-endowed chairs (Mulgrew, Selex-ES/RAEng Research Chair; Esser, Selex-ES/RAEng Research Chair; Torero, BRE/RAEng Research Chair; Maroto-Valer, Robert M Buchan Chair in Sustainable Energy Engineering; Corbett, Total; Sorbie, Cairn Energy; Bisby, Arup Chair in Fire and Structures; Simeoni, BRE Chair in Fire Safety Engineering, Woodward, Atkins Chair in Railway Engineering) and research fellowships at senior level (Bisby, Arup/RAEng (2008-13); Sefiane,

ExxonMobil/RAEng; Petillot, SeeByte/Royal Society). ERPE's younger RAEng post-doctoral fellows are also actively encouraged to have direct user engagement in their research, e.g. Bridle (Scottish Water), Kersaudy-Kerhoas (with UoE Medicine), and Lucquiaud (Scottish Power, Doosan Power Systems, Howden Group).

ERPE's JIP model of academic and industry partnership facilitates the rapid transfer of knowledge to industry. JIPs combine knowledge of industry research needs with the funding to address them. Typically, the JIP sets out a 3-year programme of applied research to tackle industry-defined challenges. Each sponsoring company contributes a share of the full economic costs of the research, with a 6:1 or higher leverage being common. Our JIPs have attracted an average of £3.5M per year of industry funding. ERPE also generates enhanced impact from the JIPs by using the close relationships generated to inform our graduate training. EngD and PhD students tackle industrially-relevant challenges with financial/material support from our industry partners and are exposed to industry during the biannual JIP steering group meetings. This approach is exemplified by our Industrial Doctoral Centres in Off-shore Renewable Energy (IDCORE, EP/J500847) and in Optics and Photonics Technologies (IDCOPT, EP/G037523, renewed in the 2013 CDT call), research training mechanisms grounded in industrial co-working. Finally, leading industrialists lead our industrial advisory boards to maintain and raise awareness of current and future industry challenges.

ERPE Facilitates Commercial Impact

Three principles underpin our approach to impact: (1) creation of critical mass, (2) delivery of industrial relevance, and (3) enhancement of mechanisms to support impact. Whilst focused on the key themes of specialisation within ERPE, we recognise the parallel need to invest in areas of existing strength and enable opportunistic development in other areas; e.g. in synthetic biology. ERPE's four main research themes (given above) are further subdivided into nineteen research groupings that provide foci for our research. All of our themes exploit the infrastructure we have in place to deliver impact. Support for impact generation is provided by an embedded, five person, full-time Business Development Team (BDT). Colocation of the BDT and the researchers across ERPE creates opportunity for the pro-active identification of KT opportunities. BDT services offered include, but are not limited to: IP management advice; company formation assistance; support for consultancy, including templated research contract agreements for consultancy; engagement in the Initiating Knowledge Transfer Fund (IKTF) and Converge Challenge; access to EPSRC Impact Accelerator Award (IAA) funds totalling £3.78M; facilitation of direct research collaboration with industrial partners; and engagement of industry in all aspects of ERPE activities. The end-points of the BDTs' efforts include licensing to industry, further industrial collaborations and spin-out company formation. This broad range of support is available to all academic staff and researchers. PhD candidates who wish to pursue commercialisation are well supported through LAUNCH and EPIS, the Edinburgh Pre-Incubator Scheme to assist the initiation of their start-up companies through free advice on company law, financial planning and intellectual property rights. ERPE spin-out companies are encouraged to utilise our Technology Transfer Centres which are co-located with the School of Engineering at UoE and at the Research Park at HWU, which facilitates rapid interactions between the academic inventors and early company employees.

Following our runner-up placing in the 2007 EPSRC KT Challenge we employed the awarded monies to form the Initiating Knowledge Transfer Fund (IKTF). The IKTF is a flexible, early-stage, support mechanism providing essential bridging support to promising pre-commercial technologies, at the most effective time for such direct intervention. Since 2008, IKTF funding competitions have provided awards of up to £15k to seventeen projects, helping them emerge from basic research and achieve the first steps toward achieving a commercial outcome. A high percentage of supported technologies have gone on to gain further translational support, and realise impact as improved products or services. To date, two IKTF projects have supported company spin-out activity (pureVLC in visible optical communication and NGenTec for novel direct-drive electric generators, which have subsequently raised £5.8M of investment and grants) with a further four projects receiving substantial follow-on funding from external sources. An additional six awards have led to enhanced industrial engagement including the formal adoption of IP by existing companies: e.g. the transfer of wheelchair IP to CALL Scotland; a wear debris monitor developed with Macom Technologies; the refinement of existing design tools for thermal modelling of synchronous machines with Cummins Generators; and the development of lightweight floors

having optimised structural dynamic characteristics with Powerwall Systems, a provider of lightweight steel framing of walls and floor systems for mid-rise residential and commercial buildings.

ERPE researchers have also actively engaged with the Converge Challenge (CC) business competition and entrepreneurial training programme. Converge Challenge is an action of the Converge Project, a £6.5M joint initiative funded by the European Regional Development Fund, the EPSRC and HWU. Converge Challenge fosters a culture of innovation and entrepreneurship in transferring research to industry by offering the next generation of Scottish technology entrepreneurs access to training, hands-on mentoring, business support and cash prizes up to £35k (total package value £60k). Open to staff, postgraduate and final year students of all Scottish Universities and Research Institutes, and now in its third year, CC has learnt from best practice. In its first two years CC provided training for 80 company founders, attracted 150 business ideas and facilitated their further development leading to 90 funded projects. Converge Challenge alumni have created 25 new companies; three alumni from 2010 have already launched 3 products and received total funding in excess of £3.2M. CC awards have also led to ERPE spin-outs including Sofant Technologies and Hydrason.

ERPE's "Crucible" is a successful, professional leadership and entrepreneurship development programme for experienced post-doctoral researchers and those in their first academic position. Now open to all of Scotland and funded by the Scottish Funding Council, Royal Society of Edinburgh and ERPE's industrial partners (Selex-ES, Edinburgh Instruments, etc), ERPE's Crucible brings together a diverse group of young professionals including scientists, engineers and social scientists in a programme designed to immerse them in alternate modes of working, thinking and creating. The scheme enables 30 talented researchers, 50% of whom are from ERPE, to experience sandpit-style workshops and expand their creative capacity and problem-solving potential in ways that challenge their preconceptions. Our Crucible includes staff from key industrial partners, such as Selex-ES, and benefits from an enhanced commercial perspective and a legacy generated by putting company personnel into intense but social situations with ERPE researchers.

ERPE's Facilities and Organisation Enable Impact in Key Areas

ERPE has a clear collaborative research agenda that establishes critical mass within our strategic priority domains, and avoids dissipation of effort by facilitating the deepening of KT competence within these domains and the generation of a focused industry club within each thematic area. ERPE activities and facilities that support our research and act as vehicles for direct interaction with industry are presented below by theme:

In **Infrastructure and Environment** we host unique laboratories for operational performance testing of silos and shell structures, with applications for the testing of powder cohesion in containers and coal hoppers (UK Coal; Procter & Gamble) as well as advising on the design of the world's largest silo structure (LKAB). Our expertise in Fire Engineering is complemented by the Rushbrook Fire Laboratories and Large Structures Test halls at both UoE and HWU which house bespoke fire testing hardware, including: cone calorimeter, fire propagation apparatus, furniture calorimeter, hot box, smoke room, servo-hydraulic structural testing systems and various materials testing frames and fixtures. In Railway Engineering, our Geo-pavement and Railways Accelerated Fatigue Testing facility (GRAFT) boasts a hydraulic capacity of 200 tonnes, enabling testing of existing and new railway products in realistic railway conditions. The GRAFT facility has been developed to enable the performance of solutions to be quantified and compared with confidence; its utility and novelty attracts diverse users including Balfour-Beatty and Atkins.

In **Energy and Resource Management** ERPE boasts globally-leading groups in Carbon Capture and Storage (CCS), Petroleum Engineering and Marine Renewables, each with a unique set of facilities. The Scottish Carbon Capture and Storage Group is the premier CCS research grouping in the UK. This partnership (with The School of Geosciences in UoE, the British Geological Survey and major companies including BP, Shell, SSE and Iberdrola) offers laboratory facilities that enable post-combustion CO_2 capture testing, provide screening of post-combustion capture solvents and support up-scaling of the most promising options for technology commercialisation. These are complemented by ACTTROM, a transportable advanced laboratory designed for in-situ testing of capture solvents funded by the Department of Energy and Climate Change. Fitted with multiple

circulating loops, the facility exposes capture solvents to real power station flue gases for extended periods of time and provides a more cost-effective approach than pilot-scale testing. ERPE's research in petroleum engineering exploits JIPs as their impact mechanism, with some 40+ companies supporting £13M of research. In addition, we have received in excess of £100M of in-kind support, including >160 concurrent software licenses for each of the reservoir simulators, ECLIPSE, CMG and VIP. This scale of infrastructure, significantly larger than any other university worldwide, enables research beyond the reach of many oil companies. In the marine renewable sector, ERPE has conducted foundational research that underpins the spin-outs Edinburgh Designs Ltd (for commercial and leisure wave tanks), Pelamis Wave Power and Artemis Intelligent Power. ERPE also leads in the proactive design of new test facilities, e.g. our £6M investment in the All-Waters Combined Current and Wave Test Facility to match public investment (EP/I02932X, £6M). All-Waters offers industry partners a globally unique test facility for marine devices and provides an ideal, controlled environment enabling companies to test and develop their next generation equipment in simulated real-sea conditions, uniquely replicating waves and current conditions simultaneously. Our partnership with European Marine Energy Centre (EMEC) enables the renewables industry to carry out seamless testing at multiple scales prior to deployment.

In **Manufacturing and Materials** our James Watt Institute (JWI) addresses major long-term manufacturing challenges through innovative manufacturing research in Photonics, Microsystems and Digital Tools (EP/F02553X, £7.1M) and our EPSRC funded Centre for Innovative Manufacturing in Laser-based Production Processes (EP/K030884, £5.6M). The JWI has stimulated the creation of three spin-out companies: Microstencil; PowerPhotonic; and Totallytextures. JWI researchers have undertaken collaborative research with 35 companies, including key relationships with Renishaw (who have provided equipment of value >£1M) and Selex-ES. The success of the JWI is underpinned by significant interactions with other Centres for Innovative Manufacturing (including Photonics, Additive Manufacturing, and Ultra Precision based at Southampton, Nottingham and Cranfield, respectively). In addition, ERPE's Scottish Microelectronics Centre has continued to provide an incubator to seed company development, giving an essential capability to UK and overseas industry for semiconductor micro-fabrication, device defect assessment and repair, as well as laser micro-machining generating industrial income of £800k per annum. Materials research facilities include a cold room experimental suite (supported by Michelin, £800k) for the fundamental understanding of friction of rubber on ice and snow, and specialised instruments developed to study materials at high pressure (>100kbars).

In **Sensors, Signals and Systems** we were recognised by the Defence Science and Technology Laboratory (DSTL) in 2012 as an internationally leading UK University group in Defence Signal Processing. We have laboratories for audio research, underwater systems, Field-Programmable Gate Array (FPGA) coding and wireless test beds, as well as an optical wireless laboratory. The latter supports the Intelligent Light project, now spun-out as pureVLC (Visible Light Communication with LEDs). The highly successful spin-out SeeByte grew out of our underwater systems laboratory and currently employs over 50 staff. During the last two decades we have demonstrated impact through the growth of highly successful spin-outs with whom we maintain strong collaborations: Wolfson Microelectronics, a 400 employee company leading in HD audio; and Vision Group, now a 100 strong team within STMicroelectronics selling imagers to the major worldwide smartphone and tablet PC manufacturers.

ERPE Promotes a Broad Impact Agenda

ERPE acknowledges the benefits of, as well as its societal responsibility to undertake, public engagement (PE) activities to enable broad access to, and debate around, publically funded engineering research. ERPE employs a dedicated Schools Liaison Officer who delivers more than 350 events in local schools each year (>13,000 children) and a further 30 public events. In addition, professional science communication support is available from FUSION; a case study of FUSION's role can be found at www.scifun.ed.ac.uk/fusion/fusion-case1-CCSI.html.

We actively support training of ERPE researchers to undertake public engagement activities. Most of this training is provided through the Edinburgh Beltane partnership (www.beltanenetwork.org) which provides PE training and support including dialogue techniques, storytelling development, engaging policy makers and even stand-up comedy through the Edinburgh Bright Club (brightclubedinburgh.blogspot.co.uk). A Fellowship scheme has provided successful researchers

dedicated time and support to develop their public engagement activities, and was shortlisted for the 2012 THE Awards in the "Outstanding Support for Early Career Researchers" category. Bespoke PE training, tailored to engineering, has been delivered to ERPE researchers in two programmes funded by the RAEng Ingenious scheme; DEEPER (2008-10, Murray) and Art-full Engagement (2010-11, Elfick).

ERPE researchers have undertaken annual PE events such as at the Edinburgh International Science Festival, Orkney Science Festival, Hebridean Science Festival and Edinburgh Book Festival, and have also held events at the Hong Kong Science Festival (British Council sponsored). ERPE exploits other routes to communicating the nature and impact of our research, such as our work in visible light communications by Haas, whose TED talk has received over 1.36M views online (www.ted.com/talks/harald_haas_wireless_data_from_every_light_bulb.html) and was also presented on CNN's “Make, Create, Innovate” TV program (broadcast 27 September 2012).

c. Strategy and Plans

Our strategy during the REF2014 period has been to undertake high quality research, with a focus on significant engineering problems of national or international importance and a joined-up KT process promoting IP transfer to industry. This will remain our approach for the next assessment period. From ERPE’s strong position in terms of our people, research and KT processes, we will continue to generate significant impact upon UK plc and society. Recent successes reinforce this optimistic position. For example the recent award of an IRC in Healthcare Sensing (EP/K03197X, £9.4M) brings together our photonics and signal processing research in collaboration with chemists and medical faculty; the award of our Centre for Innovative Manufacturing (EP/K030884, £5.6M), with the direct support and engagement of 31 companies, serves to maintain ERPE’s momentum in this theme. ERPE will continue to recruit and develop the highest calibre staff, to encourage and promote interaction with industry, and to facilitate and support transfer of results to industry, either through direct engagement or by company formation.

Recruitment, Development and Motivation of High-Calibre Staff

The purpose of this element of our strategy is clear; excellent individuals who are highly motivated and who work in an appropriate, supportive and enabling environment will achieve excellent results. Of 210 category A staff returned in this submission, 80 have been appointed within the REF2014 period and 52 are early career researchers. This has enabled ERPE to invest in building critical mass in strategic areas with enhanced sustainability through a balance of established and future leaders. Examples of success are the recruitment of Esser, Maroto-Valer, Simeoni and Underhill to industrially-sponsored research Chairs, Reese taking up the Regius Chair, McCann being recruited to a senior management position and Borthwick to the Chair of Applied Hydrodynamics. We have also promoted a number of junior high-calibre staff into research leadership roles. Examples include: Bisby to the Arup/RAEng Chair in Fire and Structures, Elfick to a Chair in Synthetic Biological Engineering, Petillot to a Chair in Signal Processing and Harrison to the Bert Whittington Chair of Electrical Power Engineering. A wide range of professional development training has been created to encourage impact; a year round programme of bespoke workshops is delivered to develop our researcher’s skills in exploiting their knowledge. Both HWU and UoE have recently secured institutional Athena Swan Bronze awards in recognition of good practice in recruiting, retaining and promoting women in engineering.

Deepening and Diversifying Interaction with Industry

The high-level relationships that ERPE enjoys with key companies, often via the development of Strategic Alliances, guarantee that our research is driven by national and international needs. Looking to the future, ERPE will act to maintain a strong industrial interface by:

- promoting existing interactions with key partners through: company membership of academic strategic advisory boards; direct, focussed links with companies on specific problems with mutual benefit through formal involvement of PhD/EngD candidates; and expansion of our annual Industry Day Training;
- continuing the investment in our facilities to enhance both our research and industry engagement;
- building on the great success of Crucible in developing creative problem-solvers;
- coordinating academic participation in the Offshore Renewable Energy Catapult;
- leading the formation and operation of two new Technology and Innovation Centres (TICs)

funded by the SFC in 2013, which will be powerful vehicles to promote our industrial connectivity in the next census period in the Sensors TIC (£10M) and Industrial Biotechnology TIC (£10M);
- advancing the impact of engineering research to medicine via our research in the IRC in Healthcare sensing (EP/K03197X, £9.4M), the IMPACT Programme grant (EP/K034510, £4.3M);
- developing a JIP to gain leverage from the foundational role of ERPE researchers in the recent award of the Synthetic Biology IKC (EP/L011573, £5M); and
- organising industrial road-mapping events (e.g. in laser-based manufacturing) with key partners to promote industrial-academic funding opportunities.

Further Extending ERPE's Support for KT

ERPE is committed to maintaining our dedicated team of five embedded Business Development Executives in the long-term. There is a clear return on investment from these specialists in pre-commercialisation and their full-time work to provide a joined-up pipeline of support. Our BDT will remain responsible for creating value from each University's IP assets: by promoting industrial interaction; by stimulating and critiquing applications to enter into research contracts with established industrial companies; by supporting "Follow-On" and "Proof of Concept" type grant applications; by leading IP protection actions; and so forth.

ERPE will sustain, invest in and develop intervention measures in support of early-stage technologies that have an identified impact potential but are not yet ready for adoption by industry or end-users. In particular, we will build on the success of the IKTF. A variety of funding sources have been employed to replenish the IKTF, including EPSRC funds, windfalls from previous spin-outs, and direct institutional support; providing a total top-up in excess of £1M. Such interventions will be used to encourage academic staff to engage with activity likely to lead to impact; to help form teams around the PI and business development staff; and to facilitate the due diligence required to de-risk the technology to the point it is ready to be adopted by industry.

Our Impact Cases of the Future

Some of ERPE's recently formed and rapidly growing companies are premature to report as Impact Case Studies to REF2014, but will make significant contributions to our overall impact and its sustainability during the next census period. NGenTec (incorporated 2009, £4.5M of investment and grants to date) designs and supplies low/medium speed, direct-drive, permanent magnet generators. pureVLC (incorporated 2011, raised £1.3M in grants and investment and now employing 10 staff) exploits light for wireless data communication; its LiFi technology was quoted in TIME magazine as one of the fifty best inventions of 2011. Hydrason Solutions Ltd (incorporated 2011) are developing next generation bio-inspired sonar for use in both the oil and defence sectors. DSTL have commissioned SEA Ltd to license ERPE software algorithms for implementation within a new low-frequency synthetic aperture radar system that DSTL/SEA are developing. RICAtek was formed in 2010 to exploit IP in reconfigurable architecture for integrated circuit design; [text removed for publication]. ERPE researchers have collaborated with Selex-ES to develop radio frequency (RF) filters that enable radar and communication systems to be tuned so as to prevent interference with other RF technology. Our JIP, "Added value from Intelligent Wells and Field Systems Technologies", has created evaluation models and techniques able to improve oil recovery (soon to be deployed in four intelligent wells for Nexen with a likely improved oil recovery of 6%); these technologies are now integrated in Schlumberger's Eclipse reservoir simulator (2012 release), the industry benchmark.

d. Relationship to Case Studies

ERPE research with the potential for impact has emerged across our four themes and beyond. We have selected twenty-one case studies to highlight how our approach and processes have ensured that impact has been achieved across the full width, breadth and depth of our research portfolio. Ten cases relate to the launch of new SME's, commercialised from our research base, some of which have grown and been acquired by larger companies. A further five relate to cases where we have supplied new technology to existing major companies, typically in the petroleum engineering sector. The final six involve the incorporation of our research advances into engineering standards, design codes and industrial practice where these have demonstrated worldwide reach. In many cases ERPE academic staff have chaired the industry-based committees who confirm and

incorporate these research advances. The research theme of Infrastructure and Environment has contributed six case studies:

- New standards to extend the life of concrete infrastructure using fibre reinforced polymer;
- Effective design and operation of concrete infrastructure;
- Increasing the efficiency of railway track maintenance through ballast reinforcement;
- Improving Public Health: Protecting water-based trap seals for complex & multi-storey buildings;
- Enhanced standards for particulate storage structures and granular solids handling; and
- Fire safety: Transforming building design.

Strong industrial links, and the JIPs, in the Energy and Resource Management theme have enabled seven case studies from this area:

- Low-loss hydraulic power transmission for wind turbines;
- Test protocols for tidal current energy converters;
- Increasing oil recovery by advanced reservoir management;
- Assuring hydrocarbon flow with improved hydrate management;
- Maximising oil recovery through low salinity water flooding;
- Oilfield mineral scale management; and
- Advanced wavemaker designs.

Manufacturing and Materials has contributed a further six case studies:

- Industrial laser technology: Exponential growth of a successful international company;
- Efficient high-quality silicon microdisplays;
- Feature recognition for smart design and manufacture;
- Hand tool vibration monitor improves health and safety of construction workers;
- Creation of a global micro-optics volume supplier; and
- Low-cost electroformed stencil for advanced microelectronics.

The final two case studies originate in research from the Sensors, Signals and Systems theme:

- Smart software for autonomous maritime systems; and
- Improving telephone and internet retail financial services.

We support three specific types of companies: (1) primary spin-outs initiated and led by our academic staff members; (2) secondary spin-outs of our research which are initiated and led by our former post-doctoral researchers; and (3) start-ups initiated by our PhD graduands. ERPE can identify multiple companies formed directly from the on-going research activities of academic staff, many of which we continue to interact with. These include: digital hydraulics company Artemis (acquired by Mitsubishi); PowerPhotonic, an industrial micro-optics company; Rofin-Sinar UK, an industrial laser company; Spiral Gateway/RICAtek, a reconfigurable circuit design software company; Shapespace, a 3D modelling software company; and SeeByte, an undersea software company. Our joint industry projects with major oil companies have led to changes in processes, assisted the maximization of oil-recovery from mature fields and generated several start-up companies (e.g. Hydrafact, Epistemy).

ERPE has been very successful in supporting start-up of companies by PhD students; for example, Critical Blue, Ice Robotics and Indigo Vision; ReacTec is included as an Impact Case Study. We also include an example of how our railway engineering facilities and research have enabled licensing technology, leading to our patented polymer technology, XiTRACK, which is now widely used by the railway industry, with Network Rail approving the technology for use across the country and industrial partners Atkins and Balfour-Beatty using it internationally (e.g. in Italy and Hong Kong).

Groups of our academic staff members continue to be active in the definition of standards internationally, as evidenced by the impact cases on building and design codes such as the Eurocodes for shell and storage structures, for monitoring and controlling fire spread in buildings, and in the use of fibre reinforced polymers to improve and extend the life of infrastructure.