Institution: University of Glasgow
Unit of Assessment: 15 (General Engineering)
a. Context

Research from the **School of Engineering** has significantly enhanced the competitiveness of UK and international industry. Impacts are manifest in multiple formats including licensing of Intellectual Property, formation of spin-out companies, direct co-development work with industry partners (e.g. more than £1.2M to commercialise nanoelectronic device technologies) and through consultancy. The School has worked with more than 250 industry partners over the period on a broad range of projects. In addition, we are a key partner for Government agencies and health organisations and participate in public engagement activities.

The School (with 84 FTEs) is structured around five research divisions: Electronics & Nanoscale Engineering; Infrastructure & Environment; Systems, Power & Energy; Aerospace Sciences; and Biomedical Engineering. However, our research and its impact are thematic in nature and often cut across the Research Division structure.

Nanoscale engineering underpins our impact on a broad range of applications: photonic devices, medical diagnostics, medical devices, electronics, defence, gas sensing, fibre-to-the-home, terahertz technology, DNA sequencing and power electronic devices. **Simulation and predictive modelling** research has led to significant and lasting impact, including tools for design and manufacture in the semiconductor industry and electrical machine industry. Computational mechanics and material modelling extend this impact into the Aerospace, Civil and Nuclear industries. **Biomedical** research has delivered a range of diagnostic devices, tools and assistive technologies for surgery and rehabilitation, and new functional materials for medical applications. **Space Engineering** research has resulted in a novel ultrasonic drill for planetary exploration, deployable technology for space debris mitigation and orbital analysis for space mission design. **Environmental Engineering** is primarily focused on innovative solutions for the treatment of wastewater and energy harvesting. **Energy Engineering** is a growing activity that focuses on geothermal energy, coal gasification, microbial fuel cells, thermoelectrics, energy scavenging and solar energy. UK, Australian and Canadian Civil Aviation Authorities have benefitted from our research in **Aerospace Engineering**.

We have delivered research benefit, design and technology for leading international and UK companies. Industries that have benefited from our world-leading expertise include micro-electronics (Intel, IBM, TSMC, ARM, CSR, Wolfson), opto-electronics (Oclaro, Huawei, CSTG, IQE), security and defence (Selex, DSTL, RFMD, e2v, QinetiQ), biomedical (Alere, Johnson & Johnson, Epigem, GSK, Malvern), computational mechanics (EDF Energy, Halcrow) and ultrasonics (Magna Parva, Ethicon, Mectron).

Since 2008, we have been awarded >£3M in industry funded research contracts, our staff have spun-out 4 companies, we have won awards for knowledge exchange (best KTP in Scotland, two RAEng entrepreneurial awards, one RSE enterprise fellowship), worked with more than 30 SMEs to accelerate innovation, commercialised the world's leading software tools for the design of electric machines (SPEED (**case study**)) and verification of very-large-scale integration systems (Gold Standard Simulations (**case study**)), and secured 34 industrially funded PhD studentships.

b. Approach to impact

The School has created robust pathways that utilise our facilities and capitalise on mechanisms for knowledge transfer to build partnerships with industry. We support our staff to develop projects that will lead to impact, encouraging them to access funds for knowledge transfer. We aim to pump-prime projects that enable early engagement in order to achieve long-term relationships (e.g. KTA, IAA) and free-up staff time, where appropriate, to focus on impact from their research (e.g. RAEng secondments). Our main approaches to impact are described below, together with examples that demonstrate the success of this approach:

b.1 Facilities

The School has invested in its research facilities in key strategic areas, developing internationally

recognised expertise and capability, and providing a variety of mechanisms for staff to interact and engage with users.

- The James Watt Nanofabrication Centre (JWNC) allows our research in nanotechnology and advanced devices to be translated directly to industrial applications. Major multi-national companies such as Taiwan Semiconductor Manufacturing Company Ltd (TSMC) and Semiconductor Research Corporation (SRC) are examples of direct users of the JWNC. In addition, Kelvin Nanotechnology Ltd (KNT, University owned company) utilises the JWNC to provide nanofabrication services to over 250 customers worldwide.
- Following a £720k investment by the University, our clinic-based research facility in Glasgow's Southern General hospital was opened in 2008 (**case study**). The Centre is embedded in the Queen Elizabeth National Spinal Injury Unit (the only one in Scotland). Working with clinicians, we have delivered rehabilitation technologies to patients with a variety of disabilities.
- Our large wind-tunnels are used for industrial collaborative studies (e.g. Selex-ES, QinetiQ, BAE Systems) into problems ranging from dynamic stall to offshore turbine blade performance.
- Our unique mechanical testing equipment (e.g. 10MN compression machine) is used for on-going testing programmes since 2010, e.g. carbon fibre plates for Bombardier Aerospace.

b.2 Institutional and external mechanisms

The School has played a pivotal role in attracting, managing and exploiting institutional funding opportunities for knowledge transfer. In 2009, the University of Glasgow was one of only 12 institutions in the UK to be awarded an ESPRC-funded Knowledge Transfer Account (KTA 2009-12). This award was the result of our strengths in nanotechnologies and the research and industry portfolio in this area. The School promoted the benefits of the KTA to staff and secured £982k to support 26 industry collaborations. This led to significant income from follow-on activities totalling £1.58M to date, a return on investment of 160%. Successes for KTA include: three spin-out companies (Gold Standard Simulations, Clyde Biosciences, SAW-Dx); 4 license agreements; 7 patents filed; and development of 9 prototypes/demonstrators. As an example, a KTA project, supported by EADS Astrium and Magna Parva has delivered an ultrasonic drill test device mounted on the Astrium Mars Rover, successfully trialled in 2012 at the European Space Agency test site in Tenerife. We have also utilised the KTA to organise events such as industry sandpits and themed industry events (e.g. with Freescale and Selex ES).

The School of Engineering has also supported the University's **Innovation Network**. We have collaborated in 27 **First Step Awards**, totalling £124k. These awards provide £5k innovation grants for SMEs to work with academic staff on short-term feasibility studies, reducing the risk of first engagement and promoting longer-term relationships. In addition, the foreground IP is made freely available to the business. For example, *First Step Awards* with:

- Compound Semiconductor Technology Global: led to an award winning KTP project which created a capability for testing and development of next generation feedback lasers for passive optical networks. A second KTP project is now underway.
- Clyde Space Ltd: led to several collaborative grants (>£100k) to deliver Aeoldos – an end of life deorbit system for CubeSats – which Clyde Space are now marketing.

The School has encouraged RAEng Industrial Secondments. For example, **Kim** and **Harkness** have both worked with Clyde Space, with **Kim** designing two controllers for the UKube-1 satellite.

The University of Glasgow has partnered with a **venture capital** group, The IP Group. This has provided access to a £5M seed fund that has supported the development of a number of new companies. To date, the IP Group has invested over £862k in 3 spin-outs from the School of Engineering (Mode DX, Clyde Biosciences, SAW DX) in both start-up and follow-on funding as part of larger consortia with partner venture capitalists.

The College of Science & Engineering runs a biennial Industry Day (>500 participants since 2010), that showcases key interdisciplinary themes and provides a forum to discuss industry needs, leading to a series of new projects (*e.g.* with Freescale, Invibio and Selex). Since 2010, *Business Development Managers* have been devolved to the College of Science & Engineering to identify Industrial and Government funders and to match these with our researchers. They provide support

and guidance on schemes designed to achieve impact (both institutional, e.g. KTA, and external, e.g. TSB) and facilitate opportunities for collaborations (*e.g.* industry days, company visits and creativity workshops). They also provide support for developing and delivering impact plans.

Enterprise and commercial awareness training is part of our researcher development programme. The University's Enterprise Club provides opportunities for researchers to work with industry partners to solve commercial problems. **Craig** (Clyde Biosciences spin-out (**case study**)) and **Reboud** (SAW-DX spin-out (**case study**), received the Royal Academy of Engineering ERA Foundation Entrepreneurs Award in 2012 and 2013 respectively. Knowledge Exchange activities are now embedded in the job descriptions of all academic staff in the School, measured through the University's annual performance review process, and assessed on applications for promotion.

Scottish Enterprise Proof-of-Concept awards provide funding to commercialise leading-edge technologies and translate ideas and inventions to the marketplace. The School has secured 3 awards totalling £1.47M in the REF period, e.g. **Cooper** et al secured £395k for SAW-DX.

b.3 Industrial partnerships

The School has developed key strategic relationships leading to commercialisation and industrially funded research. Examples include:

- The translation of our Molecular Beam Epitaxy equipment to a new company, Quantum Device Solutions Ltd, has enabled Gas Sensing Solutions Ltd to continue their manufacture and development of CO_2 and other gas sensors for high sensitivity, safety-critical applications. This demonstrates our use of mechanisms such as First Step Awards, KTA and contract research to develop our knowledge base and build a relationship with Gas Sensing Solutions.
- Our relationship with TSMC supports their programme of continued miniaturisation of semiconductors through a rolling programme of research contracts since 2011 (>£500k) and secondment of their staff to our School, with access to our facilities and academics.
- EDF Energy Generation Ltd has funded a rolling programme of projects (4 contracts starting 2009, >£550k) for analysis of the graphite core of the UK's 14 AGR nuclear reactors to inform future decisions related to extension of plant operating lifetime.

Staff involvement in industrial and government advisory boards (e.g. Scottish Science Advisory Council, Home Office Advisory Committee, Ultrasonics Industry Association (UIA)) enables us to influence strategy and policy. For example, as a Director of the US-based UIA, **Lucas** built a relationship with Ethicon leading to company funding for novel ultrasonic bone cutting blades and support for an EPSRC project (EP/K020013/1) on ultrasonic needles.

The School leads a University initiative in Sensors and Sensor Systems (£3M) resulting in the Scottish Funding Council (SFC) supported Scottish Sensor Systems Centre (2012) (www.sensorsystems.org.uk), which provides seed-corn funding for academic-industry collaboration. This laid the foundation for an SFC funded (£10M) Centre for Sensors and Imaging Systems (CENSIS) in 2013, again led by Glasgow. This centre will form a major part of our School's forward impact strategy.

b.4 Public engagement

Staff are supported in public engagement activities, highlighting the importance of engineering to society, raising the profile of our research and inspiring future generations of engineers. Activities vary from science festivals to the performing arts. We contribute to the annual Glasgow Science Festival, now one of the UK's largest, where we ask school pupils to explore the material properties of chocolate, and design, build and race their own solar-powered car. In 2012, **Drysdale** gave the Isambard Kingdom Brunel Award Lecture at the British Science Festival, exploring "The Ethics of Seeing through Clothes", discussing his THz technology research. **Cossar** provided the engineering expertise to *Torque*, an RAEng supported music and dance piece, incorporating ideas from renewable energy. Our staff and students regularly contribute to comedy events, including *Science Slam* and *Bright Club*. **Gallagher** (PhD student) toured with his RAEng-sponsored show "*How big can we go? How small can we go*" (sold-out at the Cheltenham Science Festival) and was 2nd in the UK final of FameLab in 2012 (an event showcasing future science communicators). **Younger** has made numerous radio and television appearances as an energy expert.

c. Strategy and plans

Our strategy for knowledge exchange and impact is to invest in key technologies and sectors, developing partnerships with end-users and widening our reach through internationalisation. We respond to a dynamically changing environment by investing in existing, and recruiting new, talent.

c.1 Increasing end user engagement: widening access to facilities

Building upon our international reputation for reliable delivery of commercially significant projects, the JWNC became a partner in the EPSRC-supported National III-V facility in 2011. In 2013, we formed the Kelvin-Rutherford joint venture (www.kelvin-rutherford.com) with STFC and Kelvin Nanotechnology Ltd to provide a complete nanotechnology service, delivering seamless support from device concept to realisation. These represent important developments in delivering impact from our nanofabrication research and are aligned with our plans to continue to invest in JWNC. We will now work with our partners to establish a national nanofabrication facility with the School taking a leading role in achieving that vision, enabling the UK to compete at the highest levels.

c.2 Developing industrial partnerships

As noted above, CENSIS is a major initiative for developing links with industrial partners from SMEs to multi-nationals. The decision to focus on sensors and imaging was partly in recognition of the large sensor activity in Scotland (Scottish Enterprise estimate 130 companies generating £2.3bn). Furthermore, significant investment in CENSIS by 17 industrial partners (£3.6M) and support from the public sector (e.g. Scottish Environment Protection Agency) reflect the enormous potential for innovation and impact. Our School will continue to play a leading role in the multi-disciplinary Centre. We have secured a £3M capital investment from the University to create a new space (~1000 m^2) within the School of Engineering to host a major spoke of the innovation centre.

The School's **Industrial Liaison Committee** includes representatives from Thales, Freescale, IBM, Selex-ES, Howden, Mott MacDonald and Halcrow. The Committee has working groups to advise on key areas and will guide our impact and knowledge exchange plans.

We will further develop and strengthen our strategic partnerships with end-users in key areas, reflecting our recruitment strategy. For example:

- Since 2008, we have recruited significantly in Energy and Water & Environmental Engineering (8 staff). We are now developing links with the water industry in the UK to support their strategy for comprehensive water and wastewater management (from source to tap). We aim to grow RCUK and EU funding in this crucial area and are building relationships with Scottish Water (**Sloan**) and with Yorkshire and Northumbrian Water (**Younger**). The University's Impact Acceleration Account (IAA) has provided a Business Partnerships manager to support the development of these relationships.
- We have developed a strategic partnership with Halcrow (a CH2M HILL company) resulting in a £150k investment to create the Halcrow Chair of Transportation (joint with Social Sciences). We have also formed a consortium with Halcrow and University of Dundee to successfully bid to Transport Scotland for the provision of services relating to Scotland's transport infrastructure.
- Reflecting the importance of the space sector to the UK economy, David Willetts, UK Minister for Universities and Science, launched **Space Glasgow** in 2012 under the School's leadership. We are growing this activity with new staff (**Harkness**, **Ceriotti**) and will enhance collaborations with the UK Space Agency and companies, such as Clyde Space and Magna Parva.
- The School has an established expertise in Quantum Technology (**Sorel**) and will respond to the recently announced BIS, DSTL and EPSRC prioritisation in this area. The appointment of **Hadfield** and the Glasgow Physics-led International Max Planck Partnership add fresh dimensions to our existing strengths. Dedicated deposition equipment (value £0.5M) has been acquired and we will now position the JWNC to act as a UK foundry for Quantum Technologies.

Further to the success of the KTA, we will utilise the University's own institutional Knowledge Exchange Fund (£900k over 3 years) and the University's EPSRC (IAA) (£1.3M) to establish further routes for Knowledge Transfer. In particular, we will look at broadening the areas that receive impact funding, reflecting areas where we have invested.

c.3 Developing people

We will continue to support the development of our staff and their creative ideas. Several staff have attended the Royal Society of Edinburgh's leadership and development programme aimed at future research leaders (Scottish Crucible). The presence of senior staff (e.g. **Asenov**, **Cooper**, **Marsh**, **Younger**), with experience of leading commercial activities and creating pathways to impact, provides a network for support and encouragement. For example, **Younger** is a board director of Five-Quarter Energy Ltd, that recently qualified for the UK Government Guarantee scheme for up to £1.2bn to process unconventional gas. As demonstrated (**case studies**), the University provides excellent support for commercial activities and the School will continue to support its staff to achieve impact from their research, whether through commercialisation or close engagement with end-users and beneficiaries. **Asenov** is currently seconded (50%) to GSS, **Marsh** was seconded (90%) to Intense and **Kelly** was seconded (50%) to Amphotonix. **Reboud**, following support and mentoring, applied for and was awarded the 2013 RAEng ERA Foundation Entrepreneurs Award.

c.4 Internationalisation plans

As part of our internationalisation strategy, in 2011 we established a subsidiary of the University of Glasgow in Singapore, in collaboration with the Singapore Institute of Technology, focused on Engineering. This initiative delivers undergraduate engineering degrees and research and knowledge exchange. By 2013, we already have 9 permanent Research & Teaching academic staff employed in Singapore. We have subsequently established an agreement with the Singapore Economic Development Board for the delivery of PhD training in collaboration with industry. This strategy sees the School at the heart of the University's internationalisation plans and we have now extended this activity to UESTC in Chengdu, China, where the focus is Electronics. These two initiatives are a major part of our future plans to ensure impact from our research and to enhance the reputation of the School as an international centre of research excellence.

c.5 Intellectual property (IP)

Over the last three years, the University has pioneered a new way of sharing IP with industry. Building on the First Step Awards scheme (described above) where our foreground IP has been made freely available to SMEs, **Easy Access IP** provides royalty-free licences to University technologies. Agreements are expected to be concluded within 28 days, significantly lowering the barriers associated with accessing University IP and accelerating knowledge transfer. IP is provided to the company against an agreed exploitation plan. This approach will provide us with a means of promoting our technology on the world stage, shortening the development cycle and building new partnerships. In a more targeted approach, as part of our strategy to develop industrial partnerships (**section c.2**), we will increase the IP developed in conjunction with industry.

d. Relationship to case studies

Our approach to the development, investment and access to our major facilities has been a key factor in a number of impact successes described in the case studies. This is exemplified by the JWNC, which underpins the activities leading to the **Intense**, **QCL, Gemfire**, **Ion Torrent** and **Lab-on-a-chip** case studies. The **Rehabilitation Engineering** case study demonstrates our commitment to impact for health and well-being. The establishment of a major facility in the Southern General Hospital represented a "leap-of-faith" in our ability to translate research into the clinic, delivering impact to clinicians and patients. A number of case studies are borne from the School's recognition of the importance of strategic industrial relationships. For example, **SPEED**, prior to its acquisition by CD-adapco, had 69 industrial consortium members who relied on the research and training outputs from the School. The translation of our research to new safety regulations is demonstrated by the **Autogyro** case study. The School has supported engagement with partner companies to deliver impact from research and individual researchers have been supported to work with the companies: for example, the secondment of **Marsh** (90%) to **Intense** as CTO. The **Lab-on-a-chip** case study also demonstrates our support of research that delivers outcomes directly to industry and for nurturing activity from conception through to commercialisation. Professors (**Asenov**, **Miller** (retired), **Cooper**) were given the space and resources to develop world-leading research activities (**GSS**, **SPEED**, **Lab-on-a-chip)** and the freedom and encouragement and support to exploit the commercial opportunities.