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

Engineering research at the University of Glasgow is undertaken within a unified **School of Engineering** with a research-focused structure, comprising **FIVE Research Divisions**:

Research Divisions	Number of returned staff
A. Electronics & Nanoscale Engineering (ENE)	28 (27.2 FTE)
B. Infrastructure & Environment (I&E)	17 (16 FTE)
C. Systems, Power & Energy (SPE)	18 (16.4 FTE)
D. Aerospace Sciences (AS)	8 (7.6 FTE)
E. Biomedical Engineering (BME)	17 (16.8 FTE)
	88 (84 FTE)

The School has an integrated research structure of sufficient scale to enable major engineering challenges to be tackled effectively. It has world class and unique facilities, internationally established research leaders, a strong PGR population and a culture of innovation and enterprise. Each of our staff has a primary affiliation with one of the School's Research Divisions. A lead academic within each Research Division manages the performance and development of the associated staff and, together, these Divisional heads form the core of the School's Research Committee.

The School of Engineering is the largest of seven schools within the University's College of Science & Engineering, comprising around one third of the College. It was formed in August 2010, through a merger of the Departments of the former Faculty of Engineering (Aerospace, Civil, Electronics & Electrical and Mechanical) to deliver multidisciplinary research across all the major Engineering disciplines and through interfaces with the physical, medical and life sciences. In RAE 2008, we made three separate submissions to UoA 24 (Electrical & Electronic Eng.), UoA 27 (Civil Eng.) and UoA 28 (Mechanical, Aeronautical and Manufacturing Eng.), with a total of 85.5 FTEs. Since then, retirals, departures and investment have enabled us to focus and enhance our research profile in areas of strategic importance.

The **vitality** of the School is evidenced through increased research awards (£15.5M in 2012/13 compared to £8M in 2008/09), knowledge exchange (e.g. 4 spin-outs), collaborative grants (e.g. 4 Programme grants, 2 Basic Technology grants) and high quality outputs. **Sustainability** is demonstrated through recruitment of academic leaders, together with a large cohort of early career researchers (ECRs), as well as growth in our PGR population and investment in facilities.

b. Research Strategy

Our primary aim is to address major engineering challenges through the integration and application of fundamental research to tackle a broad range of commercially, industrially, socially and environmentally relevant problems. This is consistent with our plans set out in RAE 2008 (across the three UoAs) to build upon our strong research base whilst aligning our activities to tackle thematic challenges in communications, energy, environment, health, infrastructure and nanotechnology. For example, biomedical engineering and energy were two research priorities identified in all three of our RAE 2008 submissions for growth and unification across engineering; this has been realised in the formation of two of our Research Divisions (BME and SPE). **Evaluating our current position** with respect to that in 2008, the success of this strategy during the REF period can be demonstrated as follows:

- The creation of a research-focussed structure that promotes our strengths, removes barriers between traditional engineering disciplines and fosters interdisciplinary and thematic research;
- The strengthening of our research base, including investments by the University (£11.8M) and through research grants and contracts, including RCUK & EU (£27.2M) and Industry (£3.1M);
- The increase of total research awards from £8M in 2008/09 to £15.5M in 2012/13;

- Targeted investment (recruitment, facilities, PGRs) to grow **priority areas** that cross all of our Research Divisions. These **priority areas** are:

  Aerospace; Biomedical; Computational Mechanics; Energy; Photonics; Sensors; Space Systems; and Water & Environment.
- Recruitment of staff to create critical mass in our **priority areas**. 40% of returned staff have been recruited during the assessment period, including 6 Professors and 24 ECRs (**Section c**);
- The increase of our PGR population by 65% since 2007, through increased numbers of scholarships (international & industrial partnerships, endowments), targeted recruitment and promotion of our research.

As part of the Scottish Funding Council (SFC) strategic investment in higher education, the Glasgow Research Partnership in Engineering (GRPE) was formed in 2007 to link our research with industry and NHS, through collaboration with other universities in Glasgow. Since 2008, we have evolved this partnership and now take a leading role in three cross-disciplinary initiatives: the **Sensor & Imaging Systems Innovation Centre**, CENSIS (www.sensorsystems.org.uk/censis); **Energy Technology Partnership** (www.etp-scotland.ac.uk); and the **Scottish Centre for Innovation in Spinal Cord Injury** (www.scisci.org.uk).

b.1 Research Divisions

The major achievements and future directions of our Research Divisions are described below and demonstrate how we have met our RAE 2008 objectives. These Research Divisions provide a structure that defines the main foci of our research activities, although a number of thematic research areas (e.g. energy, space systems engineering, sensors) cut across that structure.

*A. Electronics & Nanoscale Engineering Research Division (led by **Cumming**)*

The Division's world-leading research and knowledge exchange activities combine internationally renowned modelling, advanced material processing and systems integration to create new electronic and photonic devices and systems. The James Watt Nanofabrication Centre (JWNC), our large multidisciplinary micro- and nanofabrication cleanroom (**Section d**), underpins much of the Division's research. *Examples of achievements include*:

- Leading research on the most significant challenge facing the global semiconductor industry, namely extreme statistical variability. With many grants (EU and EPSRC), including a platform grant (EP/E038344/1), our Device Modelling research has pioneered atomistic simulations for circuit design. The spin-out Gold Standard Simulations Ltd sells a simulation design toolset to industry and works with industry leaders including CSR, IBM, Intel and STMicroelectronics.
- EPSRC funding, including a Science and Innovation Award (EP/D501288/1), has delivered III-V devices and integrated circuit technology for terahertz sensing and imaging. Working with partners Teraview, STMicroelectronics and e2v, new EPSRC funding supports research on source and detector technology for security and biomedical applications.
- Pioneering research into CMOS sensors has enabled Ion Torrent next generation DNA sequencing. We are following up this success in partnerships with Selex, STMicroelectronics, Proctor & Gamble and Texas Instruments to develop new integrated sensor technology supported by three EPSRC programme grants (EP/H024107/1, EP/K034537/1, EP/K021966/1).
- Advanced III-V MOS technology (e.g. EPSRC EP/F002610/1 and the Semiconductor Research Corporation) is now being co-researched in the JWNC with global top-5 chip manufacturer Taiwan Semiconductor Manufacturing Corporation (TSMC), with product impact expected as early as 2015 (required to meet the International Technology Roadmap for Semiconductors).
- Expansion of our semiconductor device research into power electronics and leadership of an EPSRC programme grant (EP/K014471/1) with 7 academic and 12 industrial partners, dedicated to improving energy efficiency using GaN technology.
- High repetition rate and short pulse semiconductor lasers for sensors, telecoms and atomic clocks (EP/E065112/1), and work with Compound Semiconductor Technologies (TSB 101259) who make low cost lasers for fibre to the home. We have appointed **Hadfield** (prestigious Royal

Society Research Fellowship) who works on IR single photon detection and quantum information processing (e.g. EP/I036273/1, EP/J007544/1) to expand our capability.

- Working with the National Physical Laboratory, photonics research is now applied to medicine, e.g. holograms for optical atom cooling enabling magnetometry used in cardiography and encephalography (Wellcome Trust, 089245/Z/09/Z). The technology is suitable for integration into high accuracy portable devices.

B. Infrastructure & Environment Research Division *(led by* ***Pearce****)*

The Division develops fundamental theory and new computational methods that underpin advances in Civil, Structural and Environmental Engineering. This is now enhanced by new experimental facilities (environmental engineering laboratory) and supported by a marked increase in research funding. *Examples of achievement*, which cover the **priority areas** of Environmental Engineering and Computational Mechanics, include:

- Application of new DNA sequencing technologies to develop the first generic and widely applied mathematical models of the functioning of open microbial communities. This has been supported by an EPSRC Platform grant (EP/F007868/1) and fellowships for **Sloan** and **Quince** in the area of water treatment. The Division now leads an EPSRC consortium (EP/J00538X/1), developing novel, energy-efficient, biological waste conversion technologies for developing countries and leads the recent EPSRC Frontier Engineering award (EP/K038885/1, £5M).
- Development of new bioinformatics techniques to accurately determine microbial community diversity. These algorithms have allowed more precise studies in environments as diverse as soils, marine sediments, and environmental engineering systems. They have also been applied to human-associated microbes, thereby enabling Unilever to inform the next generation of personal hygiene products. The algorithms are now industry standard; a position that is being consolidated through a TSB grant with industrial partners and the University of Liverpool.
- Pioneering new techniques in solid mechanics for the modelling of damage and fracture across different length scales, tailored for high performance computing. For example, we have developed new methods for modelling unstable fracture of nuclear graphite, providing a more accurate, efficient and robust modelling framework for EDF Energy. This is an integral part of their Predicting Life Extension (PLEX) programme for nuclear power plants.
- Development of multi-physics and multi-scale modelling techniques applied to a range of problems, e.g.: durability of composites for infrastructure (EP/K026925/1) and performance of compacted clay barriers for nuclear waste disposal (EPSRC-NDA consortium EP/I036427/1).
- Pioneering new techniques for the integration of computer aided design and numerical analysis (isogeometric analysis). The appointment of **R. De Borst** in 2011 to the Regius Chair of Civil Engineering and Mechanics was a strategic move to further enhance our computational mechanics research.

C. Systems, Power & Energy Research Division *(led by* ***Lucas****)*

The Division focuses on emerging technologies and developing interdisciplinary research activities, aligning with the other Divisions in the School. Its significant growth is a realisation of the School's strategy to build capacity in our **priority areas** of Energy and Space Systems engineering, whilst maintaining our strength in ultrasonics. *Examples of achievement include*:

- Application of innovations in high-power ultrasonics to a diverse range of technologies, from new surgical devices, where we are world-leading in ultrasonic orthopaedic surgical devices (EP/G046948/1, EP/K020013/1), to drilling technologies for planetary sample retrieval (ST/F003587/1). These have all been developed in collaboration with industry (e.g. Mectron, Ethicon Endosurgery, Magna Parva, EADS Astrium).
- Creation of new technologies for Space applications. Examples include: Aeoldos CubeSat deorbit module, now being commercialised with Clyde Space; two attitude controllers incorporated in UKube-1 satellite (launching Feb 2014) for reducing initial angular velocity and sun tracking for orienting the solar panel; high-frequency, low-power drill tool trialled on the EADS Astrium Mars Rover at the European Space Agency test site in Tenerife, leading to the

recent award of €2.43M FP7 Space project for an *Ultrasonic Planetary Core Drill*.

- Establishment of a distinctive energy engineering theme, focusing on unlocking novel resources in geothermal energy, unconventional gas and combining underground coal gasification with carbon capture and storage. This has delivered strong industry partnerships through TSB (TSB1306_FS_NRG_EMET_244343), KTP (KTP 9401) and EUFP7 (EU FP7 608517) grants, enabled by the professorial appointment of **Younger** in 2012. Work by **Younger** with Five-Quarter Energy Ltd on processing of unconventional gas extracted from below the North Sea has led to their qualification for the UK Government Guarantee scheme for up to £1.2bn.
- Pioneering new thermoelectric and photovoltaic systems, realisable in the same physically small packaging and combined to generate heat and electricity. These are being developed through key industry partnerships with European Thermodynamics and Doosan-Babcock and we are leading the EPSRC SuperGen Solar Energy Challenge (EP/K022156/1).

D. Aerospace Sciences Research Division *(led by* ***Thomson****)*

The Division is a focus of our current investment strategy, which is based around the recruitment of **Kontis** to a chair in 2013, and recruitment of new ECRs. We are significantly enhancing our world-class wind tunnel testing facilities to include supersonic and trans-sonic capabilities, enabling us to align with the themes of greener, faster and safer travel, and to support the priorities of the National Aerospace Technology Strategy. *Examples of achievement include*:

- A major simulation-based study of the airworthiness of gyroplanes for the CAA, which informed the new regulations, and subsequently has influenced the configurational design layout of a number of new autogyro types.
- Development of novel control strategies for a low-cost, laser-based anti-missile system for protecting civilian aircraft against surface-to-air missiles. These have been realised through a close partnership with Selex ES and have been implemented into their next-generation aircraft protection system.
- Software tools in partnership with UK and Australian MoD that allow the analysis of operational scenarios and tactics for improved helicopter survivability in the modern battlefield.

E. Biomedical Engineering Research Division *(led by* ***Cooper****)*

The Division is a realisation of our RAE 2008 objective to bring cognate researchers together from across the Engineering disciplines into a single unit. The Division hosts a Doctoral Training Centre (www.gla.ac.uk/research/opportunities/dtc/), recently extended until 2017. Activities combine the world class fabrication facilities of the School with prototype manufacturing capabilities to realise a range of industrial, clinical and academic collaborations. *Examples of achievement include*:

- In medical diagnostics, developed new point-of-care technologies for the analysis of biomarkers as proxies for cancer (BB/E015212/1), and for infectious disease diagnosis (POC/13-LSM003). This has led to the spin-out of two companies: Mode-DX and SAW-DX. The award in 2013 to **Cooper** of both an EPSRC Established Career Fellowship (EP/K027611/1, £1.5M) and a recently awarded £1.7M ERC Advanced Grant (ERC-340117) further demonstrates our role in pioneering next generation devices.
- In pharmaceutical applications, worked closely with GlaxoSmithKline and Johnson & Johnson to develop and validate new high throughput imaging systems based on optical measurements of cells' electrical activity, providing a measure of cardio-toxicology of new candidate medicines (BB/H013369/1 and POC/BPT011), activities that led to the spin-out of Clyde Biosciences.
- Developed and evaluated systems for functional rehabilitation of spinal injury. These technologies, which focus on the interaction of patients and machines (EP/F069022/1), are also becoming increasingly relevant to other acute and chronic conditions (e.g. stroke and diseases of aging). For example, brain-computer interface technology is now being co-developed with clinicians for neuro-rehabilitation and pain therapy (MRC/G0902257). This activity takes place in a unique clinical-academic environment for patient therapy (www.scisci.org.uk).
- In cell and tissue engineering, pioneered stem cell differentiation using nanopatterned substrates (e.g. BB/G008868/1). This is being implemented in next generation orthopaedic

devices, in collaboration with the NHS (Mr Meek, Southern General Hospital) and Invibio Ltd. The professorial appointment of **Salmeron-Sanchez** in 2012 brings expertise in mechanical interactions between cells and interfaces (recognised by the award of ERC Consolidator grant).

- Pioneered the development of microfluidic systems for proteomic technologies and synthetic biology, implemented through a series of major awards, namely: the Bio-Nanotechnology Interdisciplinary Research Centre (IRC, GR/R45659/01); the BBSRC IRC in Proteomic Technologies (BB/C511572); Basic Technology Awards (EP/F040857/1 and E032745/1); EPSRC Research Landscape Award (EP/I017887/1); and EPSRC SynBio Flashlight Fund (EP/H04986X/1). The appointment of **Franke** to a chair in 2013 further strengthens this activity.

b.2 Future strategic aims and initiatives

The School's research-focused structure is the foundation upon which we will further build capacity in strategic areas. We have demonstrated our ability to respond to a dynamically changing environment, investing and recruiting into new areas and building teams that attract major research funding – details in **Sections c** and **d**. Over the next 5 years, we will:

1. Develop our large cohort of ECRs into future research leaders (**Section c**) through mentoring and ambitious target setting, coupled with the University's own robust performance and development review process.
2. Capitalise on existing SFC and University initiatives in the areas of sensors, energy and healthcare, reflecting UK priorities, to build capacity and develop new industrial and clinical interactions. As an example, the School leads a University initiative in Sensors and Sensor Systems that underpinned a SFC funded (£11M) Innovation Centre (CENSIS) in 2013 hosted by the School. This subsequently led to the appointment of three tenure-track research fellows (**Moran**, **Bernassau**, **Lahiri**) and a senior lecturer (**Dahiya**). This centre will form a major part of our School's plans to build an international activity in integrated sensor systems, working with industry and funding councils.
3. Develop centres of excellence in our **priority areas**, building on existing investment, to attract further funding and grow capacity. For example, the School has led the formation of a cross-university research cluster (*Space Glasgow* – officially launched in 2012 by Willets, Minister for Universities and Science) and we will seek to expand this area in the near future.
4. Lead new strategic initiatives at international, national and local levels, around broad technology platforms, and build upon the foundation created by appointments made in the current REF period, in Synthetic Biology (**Reboud**, **Lavery**), Quantum Technology (**Hadfield**) and Simulation & Modelling **(R. De Borst**, **Simpson**). The University's new EPSRC Frontier Engineering Award led by **Sloan** (£5M, EP/K038885/1) is an example of our internationally-leading research profile at the boundaries of biology, mathematics and engineering.
5. Maintain and strengthen our leading position in nanotechnology, including the James Watt Nanofabrication Centre (**Section d.3**), which underpins many of the initiatives described above (Sensors, Synthetic Biology, Biomedical Engineering, Energy, Quantum Technology, etc.) through continued investment in people and facilities.

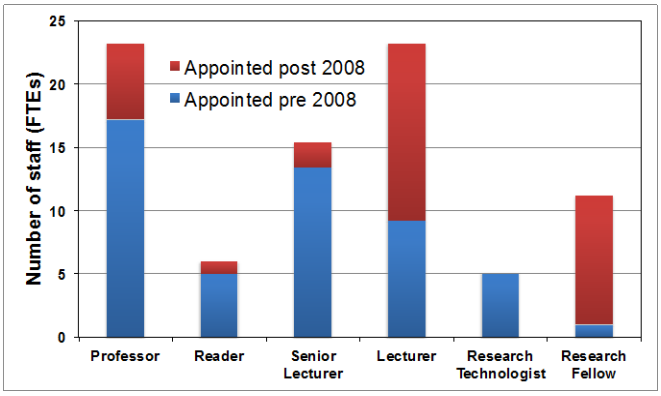
Our future plans for continuing growth in research funding are described in detail in **Section d.2**. These plans are centred on our strategies of developing strong multi-disciplinary teams to tackle major engineering challenges, fostering our industrial partnerships and building capacity in our new international locations. We have established a subsidiary of the University of Glasgow in Singapore (with permanent staff), in collaboration with the Singapore Institute of Technology (2011), focused on Engineering. We have also launched a joint School with UESTC in Chengdu, China (2013), where the emphasis is Electronic Engineering, with joint research initiatives initially focussing on Assistive Living and Future Cities.

Our strategy for knowledge exchange and impact is focused on investing in key technologies and sectors, developing strategic partnerships with end-users and beneficiaries and widening our reach through internationalisation. Full details are given in **REF3a**.

c. People, including:
I. Staffing strategy and staff development

The School's strategy for the development of staff and the realisation of their ambitions has focused on:

- Recruitment of research leaders and ECRs to create a sustainable critical mass and build our talent base in areas of strategic importance;
- Development of research staff across all grades;
- Mentoring and support of our ECRs;
- Restructuring technical and administrative support to facilitate delivery of our research strategy.



34 new members of staff have been recruited in the assessment period, representing 40% of returned staff. This includes 24 ECRs and 6 Professors. Our age profile is now well balanced between upcoming talent and seasoned research leadership.

Consistent with being a leading international research School, we have recruited academic staff from institutions across the world. Since 2008, 40% of our new staff have joined us from institutions abroad (US, Europe and Asia), e.g.: Michigan Tech, Virginia Tech, TU Eindhoven, TU Vienna, Valencia, EPFL, Nanyang Technological University, Hong Kong UST.

Research Leadership

Each Research Division has a lead academic who is responsible for line management of staff and for co-ordinating and encouraging research. Professorial research leaders have been recruited in our **priority areas** (see table below) to reinforce our strong international reputation for undertaking fundamental research in areas of global importance. To ensure that these 6 Professors have been able to rapidly establish their activities and help build capacity, we have invested £3.9M in facilities, PGRs and RAs. In addition there have been 3 internal promotions to Professor and 4 to Reader.

Name	Division	Position
R. De Borst	I&E	Regius Chair of Civil Engineering & Mechanics
Franke	BME	Professor of Biomedical Engineering
Hadfield	ENE	Chair of Photonics
Kontis	AS	Mechan Chair of Engineering (Aerospace Engineering)
Salmeron-Sanchez	BME	Chair of Biomedical Engineering
Younger	SPE	Rankine Chair of Engineering (Energy Engineering)

Early Career Researchers (ECRs)

ECRs appointed to academic positions have been recruited to support our **priority areas:** Aerospace (2), Biomedical (6), Computational Mechanics (3), Energy (2), Photonics (2), Sensors (3), Space Systems (2), and Water & Environmental (4). In addition, to the mentoring programme described below (**staff development**), ECRs have had a start-up package to help them establish their independent research activities. They have benefited from a targeted infrastructure/equipment fund of £365k (since 2011), including £172k from an EPSRC small equipment grant. They have also been offered at least one PhD studentship and a flexible budget of £8k to support travel, networking and maintaining and developing international collaborations.

Research Fellowships

To further support **priority areas** and build our talent base, we have utilised personal research fellowships, funded both externally and internally. We have established a robust and demonstrably successful mechanism for sifting the School's preferred applicants (internal and external) for open competition fellowships. For example, we currently host three RAEng research fellows (awarded in

successive years), where typically only 8-10 are awarded each year across all of the UK. We have further utilised other fellowship opportunities, including EPSRC, Royal Society, Royal Society of Edinburgh, EU and Leverhulme, as shown below:

- Royal Academy of Engineering, Research fellowship (5 years) for **Neale**, **Tassieri** and **Clark**.
- EPSRC, Career Acceleration (5 years) for **Quince**, Established Career (5 years) for **Cooper**, Postdoctoral Prize (2 years) for **Lavery**.
- EU Marie Curie, International-Outgoing (3 years) for **Gonzalez-Garcia** and Intra-European (3 years) for **Casaburi**.
- Leverhulme Trust, Senior Research (1 year) for **Gollee**
- Royal Society of Edinburgh, Enterprise (1 year) for **di Prodi**

Additional fellowships awarded in 2007 but held during the REF period include:

- EPSRC Advanced (5 years) for **Sloan** and **Moran**, Royal Society University Research fellowship (7 years) for **Hadfield** and Royal Society of Edinburgh Research fellowship (3 years) for **Yin**.

Our success in attracting fellowships is a clear indicator of the School's excellent research environment as host institution. The University has also developed its own research fellowship scheme through which we have appointed 5 additional fellows in open competition (**Bernessau**, **Lahiri**, **Moran**, **Mulvana**, **Reboud**). Four of these appointments are associated with the University's initiatives of Sensors & Sensor Systems and Synthetic Biology.

Neale, **Tassieri**, **Quince** and **Moran** have been appointed to full academic positions. **Sloan** and **Gollee** already held academic appointments. **Hadfield** was recruited to a chair position. **Clark**, **Lahiri**, **Mulvana** and **Reboud** will be migrated to full academic positions, subject to satisfying agreed performance criteria.

Research Support

We have established support structures that are flexible and responsive to evolving needs. Administrative staff have been pooled to create a dedicated research office (grant and HR support) and a thematic technical support structure (mechanical, electrical and specialist services). We have evolved the expertise of our technical staff to reflect our strategic priorities (8 new technicians and 3 modern apprentices since 2008). In a School with a diverse range of laboratories, we give safety a high priority. We have a single school-wide Safety Officer, responsible for oversight of safety procedures and culture, while Heads of Research Division are responsible for risk assessments. Research & Business development managers have been devolved from the University to the College to provide focused support for academic staff.

Staff Development

The School undertakes annual personal development planning and performance review for all staff, a key element of which is objective setting to encourage individuals to develop their roles. Through the University, we offer a comprehensive programme of researcher (academic, RA, PGR), administration and technician development, supporting individuals in their current role and preparing them for future careers (practical skills development, team working, creative thinking, project management, public engagement and enterprise and entrepreneurship). For example, the College of Science & Engineering runs an annual Crucible event for ECRs to promote inter-disciplinarity and imaginative thinking.

All ECRs undertake the University's New Lecturer programme leading to a Postgraduate Certificate of Academic Practice. This provides training and support in both teaching and research and provides a forum for new staff to think creatively about their professional approach and share experiences across the University.

In addition, the School has developed a mentoring programme to give more targeted support:

- All ECRs are assigned an experienced academic as a mentor;
- Each year, we run a research grant-writing workshop, illustrating good practice, providing practical advice, highlighting funding opportunities, introducing the key support mechanisms,

providing feedback on draft proposals and facilitating mock panels (with ECRs chairing and speaking to the proposals of their peers);

- Workload is carefully managed to permit the rapid establishment of research activities. Teaching in year 1 is restricted to 10 credits (20 hour lecture course), increasing to 20 credits in year 2. Administration in year 1 is minimal.

Concordat to Support the Career Development of Researchers

The Concordat was launched at Glasgow as part of the University's first annual Research Staff Conference in 2009. The University is a regular contributor to national events relating to Concordat Implementation and in 2010, the University was awarded the 'HR excellence in research' award from the European Commission in recognition of its commitment to supporting its researchers' career, personal and professional development and management. Reflecting the Concordat's main principles, the School has:

- Developed and implemented standardised job descriptions for Research Assistants/Associates/Fellows to support the recruitment, selection and retention of researchers with the highest potential to achieve excellence in research;
- Ensured that annual processes (performance and development review, recognition and reward and promotion) are implemented for all research staff, demonstrating their importance as an essential part of the School's human resources and a key component in our strategy to achieve world-class research;

The University has signed up to the Manifesto for Public Engagement and appointed a public engagement officer to support researchers in engaging with the public, media and policy makers.

Equality and Diversity

The School has been proactive in developing a culture of appreciation for equality and diversity. The approach is multi-faceted and has had demonstrable outcomes:

- The School Management Board and all Heads of Research Division (primary line managers) have taken training via *Equality and Diversity Essentials* - an online course that outlines the key legislation in relation to the Equality Act 2010, the protected characteristics and types of discrimination and harassment.
- The University is a Bronze Award holder from the Athena SWAN Charter and is committed to advancing women in STEMM disciplines. In addition:
  - The School has recruited 8 female academics in the assessment period (**Bernassau**, **K. De Borst**, **Busse**, **Gauchotte-Lindsay**, **Gonzalez-Garcia**, **Jin**, **Meehan**, **Mulvana**) – 1 Reader, 1 Senior Lecturer, 3 Lecturers, 3 Fellows. This represents 24% of new academic staff in the same period (c.f. 15% of engineering graduates in UK are female).
  - Women hold senior management positions in the School, with **Lucas** as Deputy Head of School and Head of Research Division (SPE), **Tanner** as Head of Biomedical Engineering Teaching Discipline and **Goldie** as Head of School Administration.
- We provide support for staff while on and returning from parental leave, including: flexible parental leave and phased return arrangements; strong co-supervision arrangements for PGRs to reduce impact on all parties; flexible working options for parents (three male staff have currently opted for reduced working hours, reviewed annually); a robust performance and development review process that supports staff with parental leave. These arrangements extend to other care scenarios where applicable.

c. II. Research students

The School has a thriving PGR community with a current cohort of 187 (July 2013) students originating from across the globe (63% from outside the UK). The diversity of backgrounds contributes to a vibrant and stimulating research environment for staff and students alike. There has been a growth of 65% of registered PGRs since 2007 that can be attributed to an increase in externally (international and industry) and internally funded studentships. The School has a PGR recruitment drive each year allowing us to recruit high quality students utilising our EPSRC DTA and School PGR scholarships. Projects are advertised widely and the review of applications

focuses on the quality of the candidate as the primary criterion for selection. We have also recruited 10 PGRs since 2009 from China under the CSC scheme.

Researcher training, as described above, extends to research assistants and research students alike. PGRs are formally enrolled in the College Graduate School, thereby benefitting from activities across Science & Engineering. A training programme for PGRs is delivered jointly by the College Graduate School and the School of Engineering which complements the training provided centrally by the Researcher Development programme. Reflecting the Vitae Researcher Development Framework, *Domain A* (knowledge and intellectual abilities) is primarily delivered by the School and the Graduate School primarily delivers *Domains B* (personal effectiveness), *C* (governance & organisation) and *D (engagement)*. All courses are optional but a minimum number of credits must be achieved in year 1 (8 credits) and year 2 (6 credits). The courses cover, for example: ethics, scientific writing and applied statistics. In addition, the School has developed a number of initiatives for training, support and progress monitoring:

- A robust annual progression monitoring process, which includes assessment by independent academics. This process allows early intervention to be made in the minority of cases where progress gives cause for concern.
- All students are assigned either a co-supervisor, or a second-supervisor for pastoral support.
- Since 2010, the School provides each PGR (not already supported on a grant) a budget (£2,500) to self-manage, support conference attendance and other training requirements. This establishes a base-line of support, designed to supplement other sources of funding sought by the student or provided by their supervisors.
- All PGRs are required to present their research as part of the Divisions' vibrant seminar series, providing an opportunity to have their research peer-assessed in a supportive environment.

Within the broader context of the University, Glasgow was one of the first universities to appoint (2007) a dedicated careers adviser for researchers, as well as providing CV workshops, employer-led mock interviews and one to one appointments. 'Making an impact with your PhD' (shortlisted for a THE award) encourages researchers to consider the broad range of career opportunities open to them. Glasgow's Postgraduate Leadership Programme (accredited by the Chartered Management Institute) offers a unique personal development opportunity for researchers. 'Insights to Industry' sees interdisciplinary teams work on a real industrial problem set by a local business, while 'Research Ventures' and 'Social Innovation for Researchers' bring students into contact with local entrepreneurs, lawyers and support organisations, informing them about research commercialisation opportunities and encouraging them to become more enterprising in their approach to their career, identify opportunities and communicate ideas.

d. Income, infrastructure and facilities

d.1 Income & Awards

The School's research income and investments reflect our strategy to maintain, grow and strengthen thematic and cross-disciplinary research. The key metrics of our income and awards are:

- Research income since 2008 is £42.2M (**excluding** SFC income for GRPE of £5.5M and £1M from our EPSRC DTA). This represents an average income of £100k/FTE/annum and 49% increase on the equivalent income for the previous RAE period;
- Research awards have seen a recent significant increase from £8M in 2008/09 to £15.5M in 2012/13.
- More than 60% of income from EPSRC. Some notable EPSRC **awards** include:
  - 2 Programme grants as PI (**Thayne**, **Cumming**) and 2 Programme grants as CI;
  - 2 Platform grants (**Asenov** (2007/12), **Sloan** (2008/13));
  - 2 Supergen projects (microbial fuel cells (**Sloan**) and solar energy (**Knox**));
  - 2 Basic Technology grants (**Cooper**);
  - Research Landscape grant (**Cooper**);
  - Frontier Engineering Award (**Sloan**), starting October 2013;

- European Research Council grants (**Salmeron-Sanchez** (2012), **Cooper** (2013))
- External fellowship awards of £4.6M since 2009 (e.g. EPSRC, RAEng, EU, Leverhulme)

d.2 Future plans for research funding

We will continue to build depth and capacity in our **priority areas**, develop longer and deeper relationships, with Research Councils, Scottish Funding Council, EU (all 3 pillars of Horizon 2020), Scottish Enterprise, TSB, industry and other universities to diversify our funding routes:

- The recent award of several large grants (see above) is evidence of the success of our strategy to develop strong multi-disciplinary teams to tackle the major engineering challenges, mirroring UK priority themes. We will continue along this successful path, diversifying into more of our **priority areas** (Aerospace, Computational Mechanics, Energy, Photonics, Space Systems).
- We will build and strengthen strategic industrial partnerships to both attract research contracts and enable us to leverage EU and Research Council funding.
  - For example, relationships with Unilever, EDF and TSMC have all led to substantial research contracts. We will look to develop more such relationships.
  - We are building links with key industrial sectors. For example, we are working with the Water industry to help refine their research strategy and build a strategic alliance.
  - Activities such as our biennial Industry Day and the devolution of business development managers to the College are all designed to increase our interaction with industry.
  - We have been awarded 9 TSB grants since 2009. We will utilise our industrial partnerships to increase this source of funding.
- We have outlined our strategy for capitalising on a broad range of initiatives (**Section b.2**) to build sustainability, growth and vitality. For example, we will build on the SFC funding for the Innovation Centre in Sensors and Imaging Systems to leverage and attract further funding.
- We will build international collaborations with industry and universities and establish new avenues of research funding. Our international locations in Singapore and Chengdu (**Section b.2**) will form a major part of this initiative; we have already established an agreement with the Singapore Economic Development Board for the delivery of PhD training with industry.

d.3 Major Facilities

James Watt Nanofabrication Facility (JWNC – www.jwnc.gla.ac.uk**)**: Houses over £20M of nanofabrication tools in a 750m^2 clean room. The Centre undertakes the development of new fabrication processes, to build devices and systems and to undertake fundamental and applied scientific research. It underpins many aspects of our research, cutting across all divisions (and Schools in the University). Through Kelvin Nanotechnology Ltd, the commercial portal to the facility (University owned), we have supplied components and devices to around 90 universities and around 250 companies worldwide. Since 2010, the JWNC has been part of the UK III-V National Facility, demonstrating its UK importance, and is a key technology provider for the joint Glasgow/STFC Kelvin-Rutherford Microfabrication Partnership which commenced in January 2013.

Since 2010, the University has invested an additional £1.4M in new equipment (including a metal evaporator, sputter deposition system and silicon etch tool). The JWNC recently secured £3M in equipment funding from EPSRC as part of the Government's Key Technologies initiative.

The Centre houses two electron beam lithography tools and is one of the few places in the world that can undertake sub-10 nm electron beam lithography across substrates with dimensions up to 200 mm. It also houses a nanoimprinter, a nanoinjection moulder, an optical lithography tool and many other high-value tools for dry-etch, metrology, metal deposition, etc. This sets the JWNC apart as the UK's premier nanotechnology facility, with world leading capability that will continue to support our research priorities. We are committed to large on-going investments in the JWNC to ensure that it remains one of the world's leading nanofabrication facilities.

Environmental Biotechnology: University investments totalling £900k have created a new facility to support the rapidly growing area of Environmental Engineering. Chemical analyses are enabled by a wide array of equipment including gas-chromatograph (GC)/mass spectrometer (MS), GC-

GC/MS, total organic carbon analyser, and ion chromatography. Optimisation of water, wastewater and waste-to-energy processes is carried out in the bioreactor facility.

Advanced Medical Diagnostics: The suite of laboratories (580 m^2) and the diversity and range of equipment provide an excellent 'under-one-roof' facility for work at the interface between engineering and the physical and life sciences. Advanced microscopy (FLIM, FCS, Raman, TIRFM, SPR and AFM), scanning laser vibrometry and photonics work is undertaken in individual dark rooms, with dedicated rooms for chemical synthesis, cell culture, prototyping and electrical characterisation. A wide range of experimental platforms based upon 'Lab-on-a-Chip' technologies is enabled by the breadth of this facility.

Rehabilitation Engineering: In 2008, we opened a new, £720k clinic-based research facility at the Southern General Hospital, embedded in the national facilities for spinal injury (the Queen Elizabeth National Spinal Injury Unit). The facility allows our staff to undertake their research within a clinical environment, working closely with patients, consultants, nurses, physiotherapists and technicians. Developing engineering technology to improve health and quality of life for people with spinal cord injury, the facility is extremely well-equipped: Lokomat robotic assisted treadmill system, Erigo robotic assisted tilt table, pQCT and ultrasound scanning equipment.

High Performance Computing (HPC): The School has invested in its HPC facilities (£1M in two clusters, totalling >2,000 cores and the associated infrastructure) to support the users in computer modelling across the Divisions. Such is its importance, we have appointed a dedicated HPC manager. Usage of the system is free (staff and PGR) to encourage access.

Materials & Structures Testing: In 2011, consistent with our RAE 2008 plans, all our mechanical testing equipment was co-located into a single laboratory. This £600k investment has created a new fit-for-purpose facility that is used by researchers across the School and for industrial contracts. The 14 machines vary from high-speed 2kN compression/tension (Zwick) to 10 MN compression (Lofenhausen) machines (one of only two in the UK).

Aerodynamic testing facility: This is located off-site in a dedicated building. The facility combines two large wind tunnels and is one of the few testing facilities of its type in the UK. Both tunnels are closed return, atmospheric tunnels with large working sections (2.13m x 1.61m and 2.65m x 2.04m) and flow speeds up to 60m/s. They are equipped with state-of-the-art instrumentation for aerodynamic testing. We are further enhancing these facilities to include supersonic (Mach 3-5) and trans-sonic capabilities. We are part of a bid (led by Prof J Morrison, Imperial) to establish a National Wind Tunnel Facility; the Glasgow component is £1.26M out of a total bid of £11.87M.

Sensors and Imaging Systems: In 2013 the University invested £3M in a major refurbishment to establish 1000m^2 of flexible space over two floors, enabling the creation of an exciting research hub for our sensors research.

Facilities for Research Students: In addition to well-equipped office space for all PGRs, the School provides a dedicated postgraduate suite for technical and social meetings and seminars and is currently developing a new inter-disciplinary research space as part of the Innovation Centre in Sensors and Imaging Systems, providing dedicated space for students to work on projects that cross Research Divisions, Schools and Colleges. The University's Gilchrist Postgraduate Club also provides a mechanism for social interaction with researchers from across the University.

e. Collaboration and contribution to the discipline or research base

e.1 Research collaborations

National and international multi-institution projects & initiatives

The School has **led** many multi-institution projects and initiatives across the broad range of our activities, demonstrating our strategy to build collaborations and provide leadership. For example:

- *Silicon compatible GaN Power Electronics* (EP/K014471/1, £6.2M). EPSRC Programme grant. Led by **Thayne**. With Sheffield, Nottingham, Manchester, Liverpool, Cambridge, Bristol and 12 industrial collaborators. As a member of the III-V National Centre Strategy Group, **Thayne** participated in a key road mapping exercise that directly led to his leadership of this partnership.

- *The Multicorder* (EP/K021966/1, £3.4M). EPSRC Programme grant. Led by **Cumming**. With Oxford and Newcastle and 9 industrial collaborators (e.g. Selex, Proctor & Gamble and Texas Instruments). **Cumming** utilised the sensors initiative to build this successful team.
- *Scalable Solar Thermoelectrics and Photovaltaics* (EP/K022156/1, £2.45M), EPSRC Supergen. Led by **Knox**. With Exeter, Cardiff, Manchester, Heriot-Watt and 5 industrial collaborators. **Knox** fostered collaborative links with these industry and academic partners over a period of years.
- *Ultrasonic Planetary Core Drill, UPCD* (£2.1M). EU FP7 Space. Led by **Harkness**. With 3 industrial collaborators (Magna Parva, Lidax Ingenieria, Space Systems Finland). **Harkness** developed this partnership with European industry as a result of a successful KTA project.
- *Listening to the Micro-World* (EP/F040857/1, £1.25M). EPSRC Basic Technology grant. Led by **Cooper**. With MRC National Institute for Medical Research, Oxford, UC Dublin and Glasgow Physics, building upon an EPSRC Bio-Nanotechnology IRC.
- *Ultrasonic Needles based on Mn-doped Ternary Piezocrystals* (EP/K020013/1, £982k). EPSRC Healthcare technology grant. Led by **Lucas**. With Edinburgh, Dundee and 3 industrial collaborators. **Lucas** fostered this partnership over a series of projects, bringing together engineers, biophysicists and clinicians.
- *A Global Solution to Protect Water by Transforming Waste* (EP/J00538X/1, £956k). EPSRC. Led by **Collins**. With Cranfield, Sheffield, Newcastle and Ulster. An EPSRC sandpit for Grand Challenges in 'Water for All' enabled **Collins** to pull together this multi-disciplinary team.

The School has also been a key partner in numerous national and international multi-institution projects (e.g. Basic Technology grants, IRCs, Research Landscape Award). We have been partners in several large EU grants with both academic and industrial partners across Europe; these include three FP7 ICT Future and Emerging Technologies grants. As part of the UK III-V National Facility (Glasgow, Sheffield, Nottingham, Cambridge), we are taking a leading role in providing UK research infrastructure. We are the key technology provider for the joint Glasgow/STFC Kelvin-Rutherford, providing access for UK industry to the JWNC (**Section d.3**).

e.2 Research leadership

Advisory bodies (key contributions)

Funding Council: **Younger** is a member of EPSRC's strategic advisory panel providing strategic advice to the EPSRC executive (2011 -). **Cooper** serves on TSB's Biomedical Catalyst major awards committee.

International Associations: **Marsh** was president of the IEEE Photonics Society in 2008/09. **R. De Borst** is member of Executive Council of the International Association of Computational Mechanics (IACM). **Pearce** is a member of the General Assembly of the European Community on Computational Methods in Applied Sciences (ECCOMAS).

Government: **Paul** is a member of the Cabinet Office High Impact Threats Expert Group, the MOD Defence Scientific Advisory Council (DSAC) and the Home Office CBRN Scientific Advisory Committee. **Cumming** is a member of the Scottish Science Advisory Council (2012-), Scotland's highest-level science advisory body. **Howell** was the UK (HMG) representative at the 2011 International Atomic Energy Agency Consultancy Meeting on Proliferation Resistance and programme reviewer for the US-DOE's Office of Nonproliferation Research & Development in 2009. **Lucas** is on the National Measurements Office Working Group on Acoustics and Ionising Radiation. **Younger** was appointed to the Scottish Government's Expert Panel on Unconventional Gas in 2013.

Industry: **Lucas** is a member of the Board of Directors of the Ultrasonics Industries Association. **Knox** is a Director of the Energy Technology Partnership. **Kontis** is a member of the Aerospace Council, UK Aerodynamics Centre.

Fellowships, awards & prizes (key examples)

Royal Academy of Engineering: Five RAEng Fellows (**Cooper**, **De La Rue**, **Marsh**, **Tanner**, **Younger**). Contributions to the Academy's activities include: Review panel for geological disposal of radioactive waste (**Younger**); Policy project on shale gas extraction with Royal Society (**Younger**); Working Group for Report on Synthetic Biology (**Cooper**).

Royal Society of Edinburgh (Scotland's national academy of science and letters): Eight fellows (**Asenov**, **Cooper**, **R. de Borst**, **De La Rue**, **Knox**, **Marsh**, **Paul**, **Sloan**).

Royal Society: Wolfson Research Merit Awards for **Cooper**, **Cumming** and **R. de Borst**. Only 17 such awards have been granted in the UK in the field of Engineering.

Fellows of Engineering and Science Professional Bodies including:
ICE (**R. De Borst, Pearce, Younger**); IChemE (**Younger**); IEEE (**Asenov, Cumming, De La Rue, Marsh**); IET (**Cooper, De La Rue, Knox, Marsh**); IoMMM (**Tanner**); IMechE (**Knox, Kontis, Lucas, Tanner**); RAeS (**Kontis**); IOP (**Cooper, Hadfield, Marsh, Paul**); Geological Society (**Younger**)

R. De Borst is a member of the Royal Netherlands Academy of Arts and Sciences and Officer in the Order of National Merit, France, awarded for scientific cooperation.
Drysdale received the National Microelectronics Institute R&D Achievement Award, 2012.
Drysdale delivered the Isambard Kingdom Brunel Award Lecture, 2012 British Science Festival.
Hadfield received the 2012 J&E Hall gold medal of the Institute of Refrigeration, an international prize for advances in refrigeration technology.
Lavery won the Scopus Young Researcher UK Award in Physical Sciences, 2013.
Lavery won the Emil Wolf Outstanding Student Paper Competition, 2013.
Reboud won the 2013 Royal Academy of Engineering ERA Foundation Entrepreneurs Award.
Tanner was awarded the President's Prize of the UK Society for Biomaterials in 2009 in recognition of her outstanding contributions during a lifetime career to the UK Biomaterials field.

Visiting/Adjunct Professorships:

Grassl, University of Pau (2011); **Ironside**, University of Western Australia (2009-); **Radice**, National University of Defence Technology, China (2009-) and Nanjing University of Aeronautics and Astronautics, China (2013-); **Sloan**, University of Newcastle (2009-); **Tanner,** Hedda Andersson Visiting Professor, Lund University (2013-).

Journal Editorships, editorial/advisory boards:

Editor-in-chief: Intl. J. for Numerical Methods in Eng (**R. De Borst**), Aerospace Journal (**Kontis**).
Editor: Intl. Journal for Numerical and Analytical Methods in Geomechanics (**R. De Borst**).
Associate Editor: Journal of Computational Electronics and Computational and Theoretical Nanoscience (**Asenov**); IEEE Transactions on Biomedical Circuits and Systems (**Cumming**); The Aeronautical Journal (**R. De Borst**); IEEE Sensors (**Dahiya**); Optics Express (**Hadfield**); Aerospace Sciences & Technology (**Kontis**); Intl. Journal of Aerospace Innovations (**Kontis**); International Journal of Modelling, Identification and Control (**Li**); Journal of Aerospace Engineering, Sciences and Applications (**Radice**); Int. Journal of Fluid Dynamics and Aerospace Engineering (**Radice**); Nature-ISME Journal (**Sloan**).
Editorial/advisory boards: 47 journals, e.g. Lab-on-a-Chip (**Cooper**), J. Roy. Soc. Interface (**Tanner**), Strain (**Lucas**), IET Systems Biology (**Kim**), Computers & Structures (**Pearce**).

Notable Lectures: Our staff have delivered plenary, keynote and invited lectures at national and international conferences, technical meetings, workshops and science festivals. Notable examples include: **Asenov** delivered keynote talks at IEDM 2008 (San Francisco) and 2013 (Washington), DAC 2013 (Austin), ICCAD 2012 (San Jose). **Cooper** delivered plenary at SPIE (the international society for optics and photonics) Photonics West 2012, San Francisco (4,500 papers). **R. De Borst** delivered plenary at 10th World Congress on Computational Mechanics, Sao Paulo 2012 (1,800 papers). **Younger** delivered the Ineson lecture in 2012 (www.iah-british.org/ineson-lecture-2012/).

Conference Leadership: Our staff have organised and chaired a number of major international conferences in the REF period, including: Simulation of Semiconductor Processes and Devices, SISPAD 2013 (**Asenov**); Computational modelling of concrete structures, Euro-C 2010 (**R. De Borst**); International workshop on multi-scale methods in computational mechanics, 2009 (**R. De Borst**); Experimental Mechanics, 2011 (**Lucas**), Ultrasonics Industries Association Symposium, 2011 (**Lucas**), 1st European Conference on Unsaturated Soils, 2008 (**Wheeler**), 11th International Conference on Ultimate Integration of Silicon, 2010 (**Roy**). In addition our staff have contributed to numerous workshops and symposia and served on many conference advisory boards.