Institution: Swansea University
Unit of Assessment: 15 - General Engineering
a. Overview

The College of Engineering's strategy for more than ten years has been to build a strong interdisciplinary research culture. The success of the strategy is reflected in the decision to make a single submission of 74.83 FTE staff to the REF 2014 General Engineering Sub-Panel, as its structure and strategy can now only be effectively presented as a single cohesive entity. (Four separate submissions were made to RAE 2008.) The unit conducts **distinctive research spanning three application themes** (Aerospace and Manufacturing, Energy and the Environment and Health) across three Research Centres, each housing a number of research groups. Academic staff are allocated to a single Research Centre based upon their core expertise, but the nature of the College's interdisciplinary approach results in many multifaceted, dense and productive collaborations between the groups and Centres.

- The Civil and Computational Engineering Centre (C^2EC, *33 staff, 31 postdoctoral researchers, 49 research students*) hosts the Aero-structures, Computational Mechanics, and Coastal Hydrology groups.
- The Systems and Process Engineering Centre (SPEC, *34 staff, 22 postdoctoral researchers, 82 research students*) comprises the Multidisciplinary Nanotechnology Centre, the Welsh Centre for Printing and Coating, Electronic Systems Design Centre, Centre for Water Advanced Technologies and Environmental Research, and the Centre for Complex Fluids Processing.
- The Materials Research Centre (MRC, *21 staff, 38 postdoctoral researchers, 80 research students*) houses the Corrosion and Functional Coatings group, the Advanced Material Process and Modelling group, and the Institute of Structural Materials.

The College nurtures a supportive research environment that has enabled an average of **more than 60%** of academic staff time to be devoted to research across the REF period, including one day a week (20%) devoted to supervising doctoral students (source: Time Allocation Survey). HESA Cost Centre data shows **a tripling in the ratio of research income to academic FTE**, from £67k:1 in 2008/09 to £198k:1 in 2011/12, and there are 3.29 postgraduate research students per academic FTE. Since 2008 the College has **doubled the size** of its educational and research activities. This was achieved through sustained strategic investment in areas of strength and a process of restructuring that reflects the evolving, multidisciplinary nature of engineering research. The College is undergoing growth aligned to the University's strategy to establish a **£250m Science and Innovation Campus**, which will house the expanded College and industrial collaborators. The first phase of the project began in May 2013, and it will be completed in 2015.

b. Research strategy

The College's vision is to be a *highly interdisciplinary, research-led, internationally focussed centre of excellence that enhances, supports and sustains engineering research of the highest calibre*. The College aims to be at the forefront of the development of transformational technologies, with research that is internationally excellent or world leading.

In 2001/02, the then Departments of Civil, Mechanical, Electrical, Materials and Chemical Engineering were reconfigured into a single School of Engineering, which encouraged the emergence of integrated, multidisciplinary research. The School made a significant submission to the RAE 2008 General Engineering Sub-Panel (18 FTEs) as well as separate submissions to the Sub-Panels for Civil (18 FTEs), Materials (15 FTEs), and Mechanical-Aerospace (12.5 FTEs). Over 90% of academic staff were submitted (63.5 FTEs). As a result, 73% of our combined submission was rated 4* and 3*, corresponding to 46 nominal staff FTEs. The outcome gave the University the confidence to continue pursuing its strategy of investing in proven strengths, such as engineering, and further developing a multidisciplinary research environment.

Since 2008, the unit has continued to develop its research vision, encouraging cross-cutting themes and further integration of its research structure, and following significant growth was restructured as a College in 2010/11. This has resulted in a clear direction for the College's interdisciplinary research in terms of themes, scope and application. Consequently, the College is making **a single submission of 74.83 FTEs academic staff (82.4% of eligible staff)** to the General Engineering Panel for REF 2014 that reflects upon the success of this fundamental restructuring exercise. The College has also undergone significant growth, meeting the University's ambition to double the size of Engineering at Swansea over the period.

Research in each of the Centres is clustered around the development of underpinning technologies that can be applied to the three themes of *Aerospace and Manufacturing*, *Energy and the Environment*, and *Health*. Each theme is led by a Theme Leader but individual academics can contribute to more than one theme. At least two of the themes (Energy and the Environment, and Health) extend beyond the College into collaborative work with other units, particularly the Colleges of Medicine and Science. These themes are **closely aligned to EPSRC, Welsh Government, UK Government, and EU priority** areas, including energy (conventional, novel hydrocarbon, solar, marine and bioenergy), engineering for life and health, advanced/functional materials, healthcare technologies, water engineering, and modelling the impact of climate change on our environment. The core themes reflect the areas where research at Swansea has made a significant impact over previous decades, such as the aerospace and manufacturing industries, as well as to growing strengths in fields such as medical engineering and energy-related technologies.

Performance since 2008

The strategic decision to align research activity to the three application themes is in line with the planned objectives set out in RAE 2008. For instance, in its submission to the Materials Engineering Sub-Panel, the unit described its intent to further its work on advanced coatings and smart structures for energy, to continue delivery of the successful EngD programme, and to ensure effective delivery of the Rolls-Royce University Technology Centre (UTC). Over the course of the current assessment period work in the **Materials Research Centre** has grown to encompass a research funding portfolio in excess of £46m, with research strengths in cold dwell behaviour and advanced lifing addressing materials requirements for the next generation of turbine-driven devices. The MRC's Institute of Structural Materials (ISM) is a core member of the Rolls-Royce University Strategic Partnership in Advanced Materials and is supported by an EngD programme comprising more than 30 students. An associated spin-out company (Swansea Materials Research and Testing Ltd – SMaRT) is addressing shorter-term, advanced materials investigations and has an annual £1m turnover.

The Corrosion and Functional Coatings Group is improving the durability of metal products and the understanding of corrosion mechanisms and kinetics using advanced scanning electrochemistry. This activity is linked to research centres such as the Corrosion and Protection Centre in Manchester University, the French Corrosion Institute, and the Max Planck Institute for Iron and Steel. The group hosts the £20m SPECIFIC (Sustainable Product Engineering Centre for Innovative Functional Industrial Coatings) Innovation and Knowledge Centre, a **unique research facility** with an international, multidisciplinary team led by staff from the Centre and Tata Steel. The Centre hosts the EPSRC-funded COATED Doctoral Training Centre for functional coatings and the STRIP (Steel Training Research and Innovation Partnership) project, which together have over 40 postgraduate students working with collaborating industries. SPECIFIC leads a university partnership including Imperial College, Oxford and Bath Universities, supported by industrial contributions from Tata, NSG, BASF and a range of smaller innovative materials businesses.

Similarly, the Advanced Materials Process and Modelling Group supports wide-ranging collaborations across the College with clusters of activity in metallurgy, polymer and composite science, materials characterisation techniques, and in multi-scale modelling to understand materials properties at different length scales. The group is working on advanced composites for the aerospace sector (Airbus) and on novel alloys with the European Space Agency.

In its submission to the Civil Engineering Sub-Panel in 2008, the unit set out its objectives to expand its research in multiscale modelling and uncertainty, and to develop new techniques, simulation design tools and lifecycle modelling methods. Since 2008, the **Civil & Computational Engineering Centre** (C^2EC) has strengthened its research in numerous areas, including: Computational Fluid Dynamics; Structural Analysis and Structural Optimisation; Geomechanics; Multi-physics; Geometry Modelling and Grid Generation; Graphical User Environments and Solution Visualisation; High Performance Computing; Computational Electromagnetics; Bio-medical modelling; Water, Hydrology and Environmental Engineering. The Centre has access to one of the most advanced university computing facilities in Europe, and an **extensive track record of industrial collaboration** that has contributed significantly to a number of projects, such as the aerodynamic design of the THRUST Supersonic Car, which currently holds the world land-speed record, and the Airbus A380. C^2EC has developed a new model that has provided the **aerodynamic design for the BLOODHOUND SSC**, and is a preferred academic partner for BAE Systems in the areas of computational electromagnetics and computational engineering.

The Centre leads the £14.3m Advanced Sustainable Manufacturing Technologies (ASTUTE) project, which works with industry in **all aspects of manufacturing** including design and materials. Research Groups embedded in this Centre include the Computational Mechanics group, which has a long standing international reputation in finite elements and numerical methods in general; the Aero-structures group, strengthened during the period through the appointment of Friswell and supported by a major ERC grant on morphing structures and several ECRs; and the newly established coastal Hydrology group led by Reeve and Cluckie. These investments were also made in support of the objectives expressed in the Mechanical and Aerospace Engineering submission to RAE 2008 to broaden areas of expertise into non-linear, coupled multi-physics and multi-scale systems to meet technology challenges identified by industry and society.

In our 2008 submission to the General Engineering Sub-Panel, objectives for the current period included strengthening nanotechnology research applied to health, energy and the environment. Research activity in the **Systems and Processes Engineering Centre's (SPEC)** constituent, application-led research groups encompasses Nanomedicine and Nanotechnology, Complex Fluids and Rheometry, Chemical Process Engineering, Electronic Systems Design, Theoretical Modelling and Wireless Technologies and Networks. The Multidisciplinary Nanotechnology Centre has received over £30m of investment since 2002. It has pioneered interface programmes with Medical and Clinical researchers, leading to the creation of the £22m **Centre for NanoHealth** (CNH) in 2011 with the College of Medicine, and an international network of collaborative bio-medical projects with leading institutions including Harvard, MIT and Rice Universities (USA), Imperial College London, UCL, University of Grenoble and Trinity College Dublin.

The Centre for Complex Fluids Processing, which has an international reputation for excellence in research involving Rheology, Rheometry, non-Newtonian Fluid Mechanics, Atomic Force Microscopy and Membrane Separation Processes, has been the recipient of sustained EPSRC strategic support (including two Platform Grants and a £3.1m Portfolio Partnership in Complex Fluids). Newly established research programmes in quantum-level simulation and Modelling of Semiconductor Devices have been brought together in the Electronics Systems Design Centre (with two EPSRC Advanced Fellows and approximately £2m of EPSRC funding) with established expertise in Semiconductor Device Characterisation, Power Electronics, MicroElectroMechanical Systems (MEMs) and Renewable Energy.

The Welsh Centre for Printing and Coating, one of the world's leading centres in its field for translational work, fast tracks frontier research into manufacturing techniques based on large area printing and coating. The Centre is a partner in the recently launched EPSRC *Centre for Innovative Manufacturing in Plastic Electronics*, and has attracted major investment from UK Government (£6.9m DTI/TSB), EU (€10m FP7) and EPSRC, including a Platform grant over the last 10 years.

The Centre for Water Advanced Technologies and Environmental Research (CWATER) was established following the appointment of Prof. Hilal to strengthen the research on membrane technology identified as 4* by the General Engineering Panel in 2008. Close collaboration between

this group and the Complex Fluids and Nanotechnology groups has brought internationally leading research on atomic level analysis of fluid process technologies to the challenges of water purification and waste remediation.

The research strategy since 2008 has therefore been based on **an ambitious plan of growth** implemented through continuous investment in research facilities and staff. The strategy aims to: (a) maximize impact by focussing on research at the intersections of the research centres and themes; (b) develop staff and particularly Early Career Researchers to enable them to excel in their research areas; (c) secure research income from a diverse range of private, public and third sector sponsors to contribute to the enrichment of the research infrastructure and environment, and (d) nurture a vibrant postgraduate research community. Delivery of the strategy, and the objectives set out in RAE 2008, has been achieved through a fully integrated, interdisciplinary approach structured around three Research Centres. The success of the strategy is demonstrated by:

1) The **seamless integration of interdisciplinary research activity** into three core Research Centres with activity aligned to three research themes. The nine intersection points between the themes and the Centres represent the areas where investment has been targeted. For instance, where C^2EC intersects with the Energy and Environment theme, a new coastal/hydrological engineering team led by Prof. Reeve has been established, and where it intersects the Aerospace theme the Aero-structures group was strengthened through the appointment of Prof. Friswell. Similarly, where SPEC intersects with the Energy and Environment theme, the CWATER research group, led by Prof. Hilal was established to develop novel technologies for water purification. Establishing the Health theme has led to considerable investment in computational bio-mechanics and the establishment of the Centre for NanoHealth.

2) The award of funding (including £12m from the UK Research Partnership Investment Fund) for an **Energy Safety Research Institute** (ESRI), **a £38m investment** to be led by Prof. Barron, and the award of **£27m from the Welsh Government Sêr Cymru programme** to support two research groups (linked to SPECIFIC and ESRI), a UK National Centre for the Impacts of Extreme Weather (with the Met Office), and a National Research Network in Advanced Engineering and Materials (all Swansea-led; see below).

3) HESA Cost Centre data (2011/12), which shows a **tripling in the ratio of research income** to academic FTE, from £67k:1 in 2008/09 to **£198k:1** in 2011. (The Russell Group upper quartile is £143k.) HESA data also shows a **ratio of PGR to staff FTEs of 3.29:1** (the Russell Group upper quartile ratio of 2.83:1) and a **62% growth in postgraduate research student numbers** from 143 FTEs in 2007/08 to 230 FTEs in 2012/13.

4) The growth in indexed research publications from 60 per year in 2007 to **200 per year in 2012** (source: Web of Science). Citations to papers authored by Swansea engineers have also grown from 3,129 in 2007 to 5,069 in 2012.

Sustainability and future plans

The College's sustained growth over the period, in terms of research income, staff and students, is planned to continue for at least the next five years. This is in line with the University's strategic objective to increase the quality and scale of its research, with a particular focus on science, technology, engineering, mathematics and medicine, and with the close engagement with industry that has marked the University's development since its foundation in 1920. The College business plan anticipates **a 27% increase in total student numbers by 2015/16 (from 2012/13 figures), including a 25% increase in postgraduate students**. Targeted growth in the College in the areas of Functional Materials, Nanotechnology, Computational Modelling, Energy and Environment and Advanced Manufacturing is planned in alignment with EPSRC, Welsh and UK Government, and EU research priorities.

The College's continued growth will be made possible through an ambitious campus development programme designed to capitalise on the unit's interdisciplinary interactions with major,

international, knowledge-based companies. This will result in the relocation of the entire College to purpose-built, state-of-the-art facilities on Swansea University's **new 64-acre, £250m Science and Innovation Campus**, which will open in 2015. This will include over £100m of investment directly dedicated to Engineering buildings and facilities. In order to secure the required funding for the new campus, the College's growth plans were audited by the European Investment Bank (EIB), Welsh Government, and Welsh European Funding Office; their endorsement of the strategy and projections is clear recognition of the sustainability of - and potential for - the College's research activity. EIB has described this development as a **European exemplar** for how a research intensive university can work effectively with industry and promote national growth.

Phase one of the Science and Innovation Campus involves the establishment of the Innovation Hub, an **extensive, open-innovation environment to maximise the growth of collaborative research with industry** in high-tech clusters where the College has established strengths. The unit will continue to focus research in the three Research Centres and themes of application, and will enhance its strategic partnerships with key multinationals such as Rolls-Royce, Hewlett-Packard, Tata Steel, Airbus, BP and BAE Systems. Phase one will also deliver testing and research buildings supporting the ISM/SMaRT and SPECIFIC projects, accommodation for 2,500 students, an information and resources centre, and retail facilities. The Energy Safety Research Institute (ESRI) building will be co-located with the College on the Science and Innovation Campus, concentrating elements of the University's energy research with a focus on safety, including rock fracture modelling, "fracking" and corrosion. The main collaborator will be BP (North America). The Institute is the only UK founder member of the Houston based Global Energy safety Institute (GESI). It will also house the **£10m Swansea University–Met Office National Centre for the Impacts of Extreme Weather**, which was funded by the Welsh Government's Sêr Cymru programme in 2013. The National Centre will encompass the College's coastal engineering and modelling expertise, as well as researchers in the University's College of Science. As a joint initiative with the Met Office, this facility will leverage additional staff and research income from a variety of sources, including the EU, RCUK, and Government.

The future growth of the College and the quality and breadth of its research will also be supported through Swansea's leadership of the **Sêr Cymru National Research Network (NRN)** in Advanced Engineering and Materials, which promotes, supports and enhances fundamental, transformative research, facilitating high-level skills development in the sector, attracting industries and research investment to Wales. The NRN is led by a Director, based at Swansea, who works in collaboration with the Heads of Engineering at partner institutions (Cardiff and Bangor Universities) to develop and deliver a joint research vision across three key themes: 1) Materials for energy, 2) Advanced sensors and devices and 3) Novel modelling technologies. The NRN's Graduate School will fund **at least 50 PhD studentships and 12 Postdoctoral Fellowships**, which will support the development of a critical mass of talented researchers. The Sêr Cymru programme has also funded the establishment of two major research groups, including the **largest single cash investment in solar PV in the UK**. The £6m Sêr Solar project is a strategic link with the Imperial College Energy Futures Laboratory through the appointments of Prof. James Durrant (0.5 FTE) and associated research team from 1st November 2013. The project aims to allow the SPECIFIC IKC the opportunity to become the global centre for scaling of the atmospheric deposition (printing and coating) of solar photovoltaic and solar active coatings. £3m has also been awarded for a Sêr Cymru chair to attract Prof. Andrew Barron from Rice University to Swansea to head the Energy Safety Research Institute, and to establish a research group with a view to leading collaborative research into novel hydrocarbon fuel sources in conjunction with BP. Prof. Barron is currently 0.2 FTE, becoming 100% in 2014.

The College is actively seeking further funding to expand its facilities and capabilities on the new campus by making use of regional, UK and European funding. In addition to seeking EU Horizon 2020 funding to support major research initiatives, the College will target EU Convergence Funding to support **substantial capital and infrastructure developments**. A College-led bid for an industry-facing Innovation and Training Centre is already in preparation. The primary objectives for the College's development over the next five years are therefore to deliver a truly **integrated, interdisciplinary research environment** in new, purpose-built facilities at the Science and

innovation Campus that attracts talented staff and research students, fosters even stronger collaborative links with industry, and further increases the quality and quantity of novel and rigorous applied research that has international reach and significance.

c. People, including:

I. Staffing strategy and staff development

The College's Staffing strategy since 2008 has been based on a continued and ambitious programme of expansion and investment to enhance its research position. This has been funded through doubling the recruitment of high-quality student FTEs as well as nearly **trebling total annual research income** from **£5.5m** in 2007/08 to **£16m** in 2012/13. The College has sought to recruit internationally leading academic staff and promising Early Career Researchers (ECRs).

The unit submitted 64 academic staff to RAE 2008 (63.5 FTEs). Of these, nine members of staff have since retired or left the University and six have either moved to non-research contracts or are not being returned again to REF 2014. During the period, the College has recruited **32 new staff**, including eight professors, six mid-career academics and 18 ECRs. In addition, six staff members have been promoted to chairs, and 11 ECRs submitted to RAE 2008 have been promoted to Associate Professors. During the REF census period, nine members of staff have held EPSRC, RCUK or Royal Society Advanced Fellowships. In line with the research strategy, appointments have been made to each of the three Research Centres in areas that intersect with the three application themes. The recently awarded Sêr Cymru projects will support **controlled and sustained expansion in capacity** over the next five years in tandem with the development of the Innovation Campus. In the current period, the College has attracted several world leaders in their field such as Profs. Friswell, Hilal, Barron, Summers, Huerta, Reeve, Cluckie and Meissner.

The College comprises staff from very diverse international backgrounds. Out of the 79 staff being submitted, **34 have had a component of their academic education at undergraduate or postgraduate level in a country other than the UK**. In total the staff submitted have academic qualifications from over 20 different countries. During the current REF period, the College has recruited staff from the US, Spain, Norway, Italy, South America, as well as many staff with international backgrounds that were already carrying out research in leading UK universities. The College also benefits from an active programme of external research visits by senior academics from overseas universities. Over the period, **135 foreign academic visitors** spent three months or more in the College as part of a sabbatical leave from their own institutions.

The University's **Performance Enabling** process provides clarity on the support and training available to staff to enable them to perform to their optimum level. The process incorporates individual staff KPIs related directly to measures of research success (e.g., income, publications, and PG supervision) into an on-line Professional Development Review form. In 2012 the University won a Times Higher Leadership and Management Award and a UHR Excellence award for this initiative. The University is committed to the implementation of the **Concordat to Support the Career Development of Researchers**, being one of the second tranche of HEIs to be awarded the *HR Excellence in Research Award* from the European Commission (successfully retained in 2013). The cross-institutional training unit, the Academic and Professional Enhancement Centre, Swansea (APECS), coordinates a comprehensive skills development programme. Aligned to the *Vitae Research Development Framework*, it represents a significant investment tailored to supporting researchers in the post-Roberts environment. The College places importance on training senior academic staff in leadership and management. The Head of College, Deputy Heads, Heads of Research Centres and leaders of large research groups have attended the **Leadership and Management Masterclass** course, which includes a three-day residential workshop, one-to-one tutoring on individual leadership styles, and 360^{o} assessment that involves a detailed independent survey of team members from their group and others with whom they work.

University policies provide **a supportive environment that encourages research**. At a College level, a "Staff Working Load" model is used to allocate teaching and administration duties through

the College in a manner that recognises the research contribution of staff. This ensures that senior staff with a large portfolio of research activity are not overburdened by other commitments whilst still making a contribution to teaching and leadership activities (consistent with the College's aim to provide research-led teaching). On average staff reported via the Time Allocation Survey that they were able to devote over 60% of their time over the period to research and research support. The College supports early career academic staff through a number of initiatives. For instance, ECRs are provided with **start-up research funding** and are encouraged to work within established research groups in the College. The College has also **prioritised the use of Doctoral Training Grants** to support early career staff. As part of the probation procedures, ECRs are allocated a mentor and a probation supervisor, both of whom will assist them in developing and implementing a successful research strategy. In addition, the College actively seeks to minimise teaching loads on new academic staff to allow them to establish their independent research activities.

Equality of opportunity: the University makes every effort to promote equality of opportunity through its Strategic Equality Plan. The College's multinational community of 40 international staff and close to over 600 overseas students fosters a supportive research and learning environment that promotes equality. The University's commitment to gender equality is further evidenced by its retention of the **Athena SWAN Bronze Award** in 2013, which recognises excellence in the areas of Science, Engineering, Technology and Medicine for Women in the Higher Education Sector. The College also has the support of the Women in Universities Mentoring Scheme (WUMS), a Welsh University initiative to enhance women's academic career progress.

Research quality and integrity: The primary responsibility for research is devolved to the Research Centres, managed and coordinated by the College Research Committee. To maintain standards in research, staff members are encouraged to participate in the College's research seminar series and to provide constructive feedback to colleagues who present papers.

II. Research students

The number of research students in the College of Engineering has increased from 143 FTEs in 2007/08 (112 Home students and 31 Overseas students) to 230 FTEs in 2012/13 (180 Home, 50 Overseas). The latest HESA figures (2011/12) show a **ratio of PGR to staff FTEs of 3.29:1**, comparing favourably with the Russell Group upper quartile ratio of 2.83:1. This has been achieved through a sustained campaign to invest in and attract research students to Swansea. The College has made numerous **successful bids for research training funding** to EPSRC, the European Social Fund and the Erasmus Mundus PhD Programme, and has invested a significant sum of its own funds. For instance, the College has allocated £400k per year to support 20 "Zienkiewicz Scholarships" aimed at attracting the highest calibre international applicants with full fees and stipend support. In addition, the College has secured funding through competitive bids from EPSRC for Doctoral Training Centres in Aerospace Materials (RR-EPSRC Partnership), Manufacturing (MATTER) and Functional Coating Technologies (COATED). For part of the 2007/08 to 2012/13 period, the College also benefitted from funding from the £7.5m Collaborative Training Account from EPSRC to fund MRes and EngD programmes. Further funding for Home and Overseas research students has been secured from Marie Curie Research Training Networks.

The College runs the Swansea branch of the all Wales **Knowledge Economy Skills Studentships** (KESS) initiative, which funds scholarships in priority areas of the knowledge economy aligned closely with the College research themes. The ESF-funded Steel Training and Research Innovation Partnership (STRIP) provides MRes and EngD funding in collaboration with Welsh metals and manufacturing companies. The £7m Sêr Cymru National Research Network in Advanced Materials will support approximately 50 PhDs at Swansea, Cardiff and Bangor Universities in the areas of Materials for Energy, Advanced Manufacturing and Modelling.

Training and support: the supportive and friendly study environment combines scientific rigour with applied relevance. Support and supervision is undertaken within a robust framework, ensuring effective induction and enculturation into the University and the College, with a comprehensive programme of **training tailored to individual needs** and robust progression monitoring

procedures. All students are allocated two supervisors and a "confirmation of candidature" procedure ensures there is a clear and agreed research and personal development plan for each student. This encompasses the technical, professional, and health and safety training required during the early stages of the degree programme.

The College offers a broad range of **technical and professional development modules**, which research students are encouraged to take. For students on PhD programmes, attendance at these courses is individually agreed between the project supervisors and the students during confirmation of candidature. For MRes and EngD students, attendance to a broadly fixed set of modules forms part of the programme structure. Research students are expected to attend the regular seminar sessions organised in each Research Centre, where they are exposed to the research work of leading academics. In the 2008–11 period, the University made strategic use of Roberts Funding to develop a robust research student training strategy. This included the appointment of a full-time Research Students Skills Officer and the implementation of a **research student training programme**. In October 2011, the University adopted the recommendation of Research Councils UK to introduce an "uplift" of £200 to fees for all research students and to ring-fence the income generated to fund an expanded integrated programme of skills development. A strength of the College is its **fostering of collegiality** in cohorts/student groups. This is facilitated through weekly research seminars, annual poster competitions, vibrant local engineering societies, industrial links, and student support officers, ensuring a cohesive student community, high PhD completion rates, and the retention of students to perform further research following graduation.

All postgraduate research students are allocated office work space and individual IT facilities, as well as access to the appropriate laboratories or High Performance Computing resources. Despite the forthcoming move to the new Science and Innovation Campus, over the REF period the College has continued to invest in its current facilities in order to ensure that they are at the highest standards required for internationally leading research. This includes not just the laboratories and equipment but the provision of common breakout areas and collaborative workspaces that facilitate the interdisciplinary research advocated by the College strategy. All postgraduate research students have access to the facilities described in section D below.

Progress monitoring: research students' progress is formally monitored at least annually through reports prepared by supervisors, which are discussed in the Postgraduate Progress Committee of the College and considered by the Academic Board for Research. This process is particularly important at the end of the first year of PhD and EngD studies, which is considered probationary. At this stage, students are expected to write a summary report and to deliver a presentation before a progress report is completed. The College has agreed detailed probation and progression criteria that are contained in student handbooks.

d. Income, infrastructure and facilities

Income: Research has been funded by national and international organisations, including RCUK and the European Union. The University has a **Strategic Relationship with EPSRC**, having received EPSRC research awards totalling £37.4m between 2007 and 2013. A significant proportion of this funding is attached to the College of Engineering, which has a current EPSRC funding portfolio of **£17m**. This includes large grants such as the SPECIFIC IKC (£9.5m EPSRC/TSB, £4m Welsh Government and £6m industry), the Rolls-Royce–EPSRC Partnership in Aerospace Materials, and the Chairmanship of the Flood Management Research Consortium. The College has received one senior award from the European Research Council (£2m). In addition to Research Council income, the College has attracted funding for major projects under the **European Regional Development Fund**, including the Centre for NanoHealth (£22m), with the College of Medicine; the Advanced Sustainable Manufacturing Technologies project (ASTUTE, £27m), with other Welsh universities; the Low Carbon Research Institute – Marine Renewable Energy Project (£7m); and the Steel Research and Innovation Partnership (STRIP, £6m).

As described in Section B, the College was awarded £17m in 2013 from the Welsh Government **Sêr Cymru programme**, and will also receive a significant proportion of the £10m funding to

establish the Swansea University–Met Office National Centre for the Impacts of Extreme Weather. In 2007/08, the College was awarded £9.8m in funding contracts, whereas in 2012/13, the College received **£14.9m** funding contracts (see table below).

Funding source	2007/08 (£k)	2012/13 (£k)	% change
Research Councils	2,307	3,475	51
EU	3,705	7,262	96
Industry	1,539	1,778	16
Other	2,048	2,287	12

Consultancy activity is strategically important for growing external income and external relationships that complement the College research agenda. Over the period the unit was awarded **consultancy contracts valued at nearly £5m** with companies including Rolls Royce and Airbus. Grant capture is supported by **an effective institutional framework**. Researchers work with the Department of Research and Innovation (DRI), which supports applications for and management of external funding, and provides guidance to researchers, project groups and administrators. DRI's External Funding Officers have College-specific responsibilities and advise on all aspects of research funding. DRI provides training and development of research staff through themed seminars and workshops to help increase the quality and quantity of research proposals.

Future plans to grow income include enhanced collaboration with research intensive institutions in Wales and the UK through the Sêr Cymru National Research Networks and Chair appointments (see above); intensifying the collaboration with key industries through co-location into the new Science and innovation campus facilities; continued growth of academic staff by recruiting further research leaders in areas of increased research funding; and strategic development of international collaborations to facilitate access to funds such as Horizon 2020 from the EU.

Infrastructure and facilities:

The Civil and Computational Engineering Centre has access to the University's High Performance Computing facilities. Swansea hosts of one of the two High Performance Computing Wales Hubs, is a major strategic partner of IBM, and supports one of the largest IBM facilities in any UK University. These include Blue-C, comprising a massive storage sub-system and IBM P7 processors; Blue-ICE, specifically configured for climate modelling; and IBM BlueGene-P, a massively parallel computing system. Intel-based Fujitsu equipment is available through the HPC Wales network in the Welsh higher-education sector. The Centre also uses a 450 cpu cluster (which represents an investment of ca £500k), high-end graphics workstations, and high-speed network links. Extensive software packages include commercial applications as well as systems developed in-house. The College has two flight simulators built by the Merlin Flight Simulation Group. One can be used for Unmanned Aerial Vehicle development, and can be connected to the other, so that both simulators can fly in the same virtual airspace.

Within the **Systems and Process Engineering Centre,** the *Multidisciplinary Nanotechnology Centre* has extensive capabilities for nanoscale characterisation and imaging, including STM, AFM, UHV nanoprobes, SEM and XPS techniques. *The Centre for NanoHealth* (£22m) is a unique facility within the UK, bringing together engineers, physicists and medical clinicians in a single environment that also hosts clinicians and patients from local NHS hospitals. It is strategically located within a clinical and biomedical research environment on the boundary of Swansea's Singleton hospital and University sites, giving access to patients and creating a pioneering, integrated facility in which novel devices and sensors can be designed, manufactured, functionalised, tested and evaluated.

The *Welsh Coating and Printing Centre* has comprehensive laboratories dedicated to integrated manufacture by printing in clean air conditions, with 500mm web width roll-to-roll and sheet-fed printing complementing SPECIFIC's production facilities. A materials characterisation laboratory offers facilities for manufacturing liquid and paste inks, including ink for the printing of electronics. This includes bench top testing of application processes. Analytical laboratories include white

interferometry for surface characterisation, microscope based image processing, four probe electronics testing and GCMS. There is also a colour management laboratory that includes colour measurement. All laboratories have a temperature-controlled environment.

The *Centre for Complex Fluids Processing* (CCFP) has laboratories dedicated to rheology, housing high frequency shear wave devices, extensional flow rheometers and high speed microphotographic equipment for the study of complex fluids in micro-scale deformation settings. This equipment was developed under EPSRC Portfolio, Platform and Responsive mode grants. The CCFP has dedicated laboratories for the development of Membrane Separation Processes supporting activities in its linked KTC in Advanced Membrane Technologies. The CCFP and WCPC are partners in a recently launched £5.5M EPSRC Centre for Innovative Manufacturing in Large Area Electronics. The *Centre for Water Advanced Technologies and Environmental Research* (CWATER) has facilities for process characterisation and industrial trials, nanofiltration, reverse osmosis, ultrafiltration, microfiltration, pervaporation, ozonation and advanced Oxidation.

Materials Research Centre facilities received investment of over £5m in the last three years, linked primarily to two EPSRC-funded projects: SPECIFIC and the Institute of Structural Materials (ISM). SPECIFIC is housed in two bespoke, off-site buildings with **new laboratories and a pilot manufacturing facility**. The laboratories have state-of-the-art equipment including: advanced electrochemistry, Thermogravimetric Analysis and Gas Chromatography Mass Spectrometer, and an Hitachi S4800 Field Emission Scanning Electron Microscope with 1nm resolution imaging with X-Ray elemental analysis and a cryogenic stage imaging and analysis of hydrated samples. Swansea-designed and built scanning electrochemical facilities are complemented by a Scanning Kelvin Probe Atomic Force Microscope. Recent expansion of research into scaling of photovoltaics has required considerable investment in class AAA large area solar simulators, impedance spectroscopy, time resolved electron lifetime measurement equipment and incident photocurrent equipment for determining cell characteristics as a function of wavelength and experimental techniques, developed with Imperial College to measure electron lifetimes in devices. The scale up facilities (£3m) comprise a pilot $1m^2$ sheet production line including novel, near infrared curing ovens designed in partnership with industry and based on innovative technology developments from collaborations with Imperial College London, Bath and Oxford Universities. A **further £2.3m investment** has been announced to complement the £6m Sêr Solar investment, including new XRD and surface characterisation suite (XPS and SIMS) and roll-to-roll coil coating line.

The Institute of Structural Materials (ISM) includes substantial equipment from the former Interdisciplinary Research Centre at Swansea (creep, fatigue, microscopy and metallurgical equipment) together with new equipment donated by Rolls-Royce to the University as part of the creation of the Strategic Partnership Project. This positions the ISM as one of the world's leading environments in which to study the properties of turbine blade materials. Metallurgical research has been enhanced with the refurbishment of the two Gleeble thermomechanical simulators and the purchase of new XRay tomography equipment, complemented by investments in new FEG SEM equipment at Swansea and a joint investment in TEM facilities in Cardiff University. With the development of the Science and Innovation Campus, these facilities will be improved with a larger number of SEM instruments and further investments in X-Ray imaging technologies. The College also has general purpose, large-scale workshop facilities, including extensive CNC equipment, an open-access laboratory for Early Career Researchers (equipped from a competitive bid to EPSRC), and generic wet science laboratories and equipment. Researchers benefit from access to facilities of the **EPSRC National Mass Spectrometry Service Centre** in the College of Medicine.

e. Collaboration and contribution to the discipline or research base

The College makes a major contribution to the discipline as a hub for interdisciplinary, collaborative endeavour, **promoting a culture that recognizes the value of connecting with others to achieve research aims.** Examples include leadership of large, multi-partner projects such as SPECIFIC, and joint partnership in the Rolls-Royce/EPSRC 10-year strategic partnership in Structural Materials. Measures of the College's success are provided by the range and complexity of the unit's connections. Representative examples are detailed below.

International collaborations: the College seeks to continuously measure its research against leading international institutions. This is achieved through extensive formalised collaborations with institutions such as MIT, Rice University, IHPC-Singapore, TU Munich, Texas A&M, Tsinghua University, Universitat Politecnica Catalunya, Ecole Centrale de Nante, and many others as well through countless informal research links among academics. The international profile of the College's research is illustrated by the number of **countries in co-authored papers rising from 69 to 81** over the REF period. The College is a partner in a number of strategic international research relationships. For instance, since 2006, Swansea has offered an **Erasmus Mundus** MSc in Computational Mechanics in collaboration with Stuttgart University, École Central de Nante and Universitat Politecnica de Catalunya (UPC) and recently Tsinghua University. The initial six-year funding was extended for a further six years in 2012. Similarly, in 2012 Swansea and UPC led a European consortium of eight universities to establish an Erasmus Mundus PhD Programme in Computational Mechanics. This was **one of only nine successful bids out of 133 proposals** received by the European Commission. Other significant international research partnerships include a joint PhD programme with Methodist Hospital in Texas in the area of Nanohealth and a joint PhD Programme with University of Avignon. In total the college has nine collaborative PhD programmes with international universities. The EPSRC-funded **Building Global Engagements in Research** (BGER) project has placed Swansea at the centre of a global hub, with partners including the Université Joseph Fourier in Grenoble (France), Soochow University (China's oldest private university), and leading American institutions including The Methodist Hospital Research Institute, University of Pennsylvania School of Medicine, Rice University, and the Texas A&M University. The United States Department of Commerce, National Institute of Standards and Technology, is also a partner of this hub.

Industrial collaborations: Swansea's engineering research has traditionally been driven by industrial collaboration. Now a multidisciplinary College bridging science, engineering and innovation, the unit enjoys **productive relationships with key engineering and manufacturing partners** such as Rolls-Royce, Tata Steel, BAE Systems, Airbus, NSG, BP and BASF. These organisations are fully integrated into the Centres' research portfolios, reflecting industrial demand for high quality science and engineering research, and graduate and postgraduate employees. The College established an External Advisory Board in 2007 in order to ensure that our research users can inform the strategic direction of our activities. Board members include Rolls-Royce, Tata Steel, BAE Systems, GSK and Atkins, as well as representatives from the Healthcare sector (NHS trust) and SMEs. The Board has met twice a year and informed the strategy of investment in staff and facilities described in previous sections. Many of our key research initiatives, such as SPECIFIC, the RR partnership in Structural Materials or the Energy Safety Research Institute are examples of extensive, strategic and long-standing user engagement with leading companies. Similarly, projects such as ASTUTE (see section b) or research groups such as the Welsh Centre for Printing and Coating provide evidence of a successful engagement with local research users through regional development funding. The impact case studies presented by the College provide clear evidence of the success of our user engagement strategy.

Interdisciplinary collaborations: The College benefits from the University's commitment to nurturing an environment that encourages research that crosses the boundaries of traditional disciplines. Examples include: the Centre for NanoHealth, a large, strategically important, interdisciplinary project jointly supported by Engineering and Medicine that has led to the award of other collaborative projects (e.g. BGER). The **Bridging the Gaps programme**, designed to facilitate interdisciplinary research initiatives. The programme has funded 14 projects within the College, stimulating 53 collaborations, including 22 national and international collaborations (with HEIs in the UK, Japan, India, Mexico, Sweden, Portugal and the USA, as well as with organisations such as the Mary Rose Trust, Wellcome Images, and the ABM University Health Board). **Welsh Crucible** is a prestigious programme of personal, professional and leadership development for 30 of Wales's best early career researchers. It encourages participants to find new ways of thinking and working, ensure their research has impact, develop skills in public engagement and explore how to interact more effectively with the media and policy makers. In 2011 and 2012, six researchers from the College of Engineering participated.

Exemplars of leadership: Academic staff in the College provide leadership in the international academic community as described in the table below.

Exemplars of leadership in the academic community	Count
Fellowship of main learned societies (FRS, FREng, FLSW, USNAE & CAS)	15
Conferences organised or chaired	84
Workshop, mini-symposium, special sessions organised	45
Plenary lectures	66
Invited or keynote lectures	90
Editorship of journals (chief or joint)	12
Member of journal Advisory Editorial Board	62
National or International Advisory Board Committees (including RCUK)	52
Research Prizes and similar honours	18

Individual examples of senior leadership in the REF census period include:

- **Prof. Owen**, FRS, FReng, FLSW, FICE. Foreign Member of both the US National Academy of Engineering and the Chinese Academy of Sciences. Awarded the Grand Prize of the Japan Society for Computational Engineering (2010). Awarded Doctor Honoris Causa by the Universitat Politecnica Catalunya (UPC, 2012). Chaired five conferences and delivered 13 plenary lectures. Chief Editor of two journals, Executive Council Member of the International Association of Computational Mechanics, and Council Member of the Royal Society.
- **Prof. Hassan**, FReng, FLSW, FICE. Awarded the Pollack Mihaly Faculty Medal (2012). Organised two conferences and three workshops, and delivered four plenary and three keynote lectures. Visiting Professor at IHPC-Singapore, and Member of the EPSRC Peer Review College and the Royal Academy of Engineering Membership Committee.
- **Prof. Morgan**, FReng, FLSW, FICE. Awarded the Ludwig Prandl Medal (2008). Organised three workshops/symposia and delivered one plenary and seven keynote lectures. Visiting Professor at UPC. Sits on five committees, including the Royal Academy of Engineering's Membership Committee.
- **Prof. Nithiarasu**, FIMechE. Distinguished Foreign Scientist Award (India 2011/12), and EPSRC Advanced Fellow (2006-11). Chaired nine conferences, and delivered three plenary and eight keynote lectures. Chief or Associate Editor of three journals. Sits on five Advisory Boards and the EPSRC Peer Review College.
- **Prof. Friswell**. Delivered four keynote lectures and sat on 38 Advisory Boards. Associate Editor of two journals, and sits on the Advisory Boards of seven other journals. Member of the EPSRC Peer Review College, the Royal Society Newton's International Fellowship Committee, and Honorary Professor at Nanjing University of Aeronautics and Astronautics.
- **Prof. Williams**. President of the British Society of Rheology; Member of the EPSRC Strategic Advisory Network. Visiting Professor at the Nestle Research Centre (Switzerland). Organised three conferences, three mini-symposia, and delivered two plenary and two keynote lectures.
- **Prof. Claypole**, MBE for services to Graphic Arts Research (2010), European Flexographic Technical Association Award for outstanding contribution to flexographic printing (2009), and the Technical Association of the Graphic Arts Michael H. Bruno Award for outstanding contributions to the international graphic arts industry (2008).
- **Prof. Hilal**, FIChemE. Chaired four international conferences. Editor-in-Chief of Desalination. Advisor for the Royal Society of New Zealand on Desalination (2009-10); Scientific Advisor of Alfaisal University, Riyadh, Saudi Arabia (2008-9); and Chair of Advisory Board for the Centre of Excellence in Desalination Technology (CEDT), King Abdul Aziz University, Saudi Arabia (2010-11). Visiting Professor at Universiti Teknologi Malaysia. Advisor to Dŵr Cymru (Welsh Water).
- **Prof. Cluckie**, FREng. Chairman of the EPSRC Flood Risk Management Research Consortium (FRMRC). President of the International Commission on Remote Sensing (ICRS) and a Council Member of the International Association of Hydrological Sciences (IAHS).