Institution: Lancaster University

Unit of Assessment: UoA 15 (General Engineering, Main Panel B, Sub-panel 15)

a. OVERVIEW

UoA15 at Lancaster University (LU) is led by and centred on its Engineering Department. As part of a strategic and transformative investment by LU, Engineering at Lancaster has undergone a major expansion since 2008 with 25 new staff appointments across the Department and UoA, and a new, £12M building (completion Nov 2014). Over the REF period, this has delivered a major increase in research outputs and income. This submission is comprised of 28 headcount, 25 FTE staff (21.6 Engineering, 3.4 Physics), up from 14 FTE returned under General Engineering in RAE2008.

Research is focussed around 4 groups, each led by a member of the professoriate. These are underpinned both by ground level collaborations (evidenced by joint grants and publications) and strategically established, inter-department research centres (described in §b1). Inherently cross-disciplinary, the groups are dynamic with many staff researching across more than one, so allowing the groups to evolve in response to the external research environment. The groups and research centres are:

A. Micro-Nano Systems Part of the Lancaster Quantum Technology Centre. **Lead:** Richardson.
Research focus: microsystems, test engineering, semiconductor materials & devices, ICT, sensors

B. Energy Part of the cross-faculty research centre, Energy Lancaster. **Lead:** Boxall.
Research focus: nuclear, renewables, combustion, transport and policy

C. Structures & Manufacturing Linked to the Centre for Global Eco-Innovation and including the Lancaster Product Development Unit, LPDU. **Lead:** Ye.
Research focus: composites, laser processing, additive manufacturing, functional materials.

D. E-MIT: Engineering of Microwaves, THz & Light Part of the Cockcroft Institute **Lead:** Paoloni.
Research focus: high power microwave engineering, accelerator systems, terahertz systems

These are underpinned by a multi-disciplinary blend of skills in mechanical, electronic, electrical, nuclear and chemical engineering, making UoA15 the natural sub-panel for this submission.

b. RESEARCH STRATEGY

b1. RESEARCH STRATEGY POST-2014:

Vision: Since its creation in 1969, Engineering at LU has had a vision of researching world-scale problems in partnership with research end-users, so ensuring relevance and allowing for the leveraging of end-user expertise (>60% of our research income during this REF period includes end-users as collaborators). The main strategic goals of LU's *Strategy for 2020* (recently published after extensive internal and external consultation) are for the university to be in the top 100 globally, top 10 UK. The UoA's objectives for achieving these goals in the context of its vision are as follows:

Objective 1 – To continue to improve our research performance
KPI: to raise the proportion of our outputs rated globally excellent by external benchmarks to >80%. Building on our post-2008 success, we will further improve research performance by continuing to increase research intensity. Following the recent increase in the size of Engineering, all researchers, but especially ECRs, will be supported in increasing the proportion of research active staff from 76% to 90% (see §c1 for implementation). The opportunities brought by the new staff, building and facilities will be exploited, especially with regards to new inter-group synergies – particularly in chemical engineering, nuclear, nanosystems, fuel cells, advanced manufacturing and security, all of which may leverage support and facilities from major LU research investments and initiatives as follows:

- The Cockcroft Institute for Accelerator Science & Technology, an international centre of excellence for R&D of future particle accelerators. A joint undertaking between STFC, LU, Manchester and Liverpool, the Institute is housed in a £10M building on the Sci-Tech Daresbury Campus;
- Energy Lancaster, a cross-faculty centre opened by DECC's Minister of State, 2011, with nuclear, renewables & fuel cells as major themes. Offers LU-funded 5 year fellowships and KT support;
- The Lancaster Quantum Technology Centre (QTC), a £4M investment with equipment for nano-fabrication & characterisation of novel semiconductor devices of interest to the Micro-Nano Group
- The Centre for Global Eco-Innovation, a £9.8M ERDF project with the Lancaster Environment Centre and University of Liverpool, supporting 50 PhDs to assist 50 SMEs in new green product / technology development, as well 285 SMEs additional to those supported by the PhD students

Objective 2 – To continue growing and diversifying research income sources to ensure sustainability especially *via* establishing processes to improve grant capture, see §d3 for details. **KPIs**: to increase research spend from £1.96M p.a (see Table 2 below) to £3.1M p.a. by 2020; and to increase industry related component of research spend from £0.9M p.a to £1.7M p.a. by 2020.

Objective 3 – To continue growing the size & quality of our postgraduate research provision KPI: to grow our PhD student population by 33% by 2020 (see Table 2 below), see §c2 for details.

Objective 4 – To continue developing an environment for internationally leading research As well as exploiting measures to encourage multi-/inter-disciplinary work within Engineering and across LU (see **objective 1**), this objective will be implemented through **greater internationalisation** (*via* more bids with international partners, especially those in the US, Europe, India & China), **nat-ional leadership** (*via* more multi-HEI bids to managed calls) and through our **Distinguished Visitor Programme** to bring more senior staff from global top 100 universities to LU for study visits

Objective 5 – To maximise the impact of our research and to exploit the benefits that accrue from that impact: see REF3a §c for implementation. In particular, we will seek to maximise our policy-related impacts by featuring in international policy space on a wider proportion of our activities.

b2. DELIVERY OF THE RAE2008 RESEARCH STRATEGY: PHASES 1 and 2:

Our post-2014 strategy builds logically on that for 2008-13 (See RAE2008). This had 3 aims: to increase (i) the **strength**, (ii) **interdisciplinary activity** and (iii) **delivery** to end-users through greater use of research partnerships. Delivery occurred in TWO PHASES during this REF period.

PHASE 1, 2008-Sept 2011: Revitalisation and Increased Research Intensity 9 of the 15 staff returned in 2008 left Engineering (see §c). Replacements were appointed to support key strengths, revitalise Engineering and increase its research intensity. Resultant KPI growth is shown in TABLE 1.

PHASE 2, Oct 2011-2013: Expansion and Increased Research Power Recognising the upward trajectory and vitality shown in TABLE 1, LU invested in a radical and transformative expansion of Engineering in 2011 – increasing staff from 14 to 32 headcount and constructing a new £12M building. In contrast to the research intensive PHASE 1, PHASE 2 aimed to increase research capacity and power with the following staffing aims additional to the 2008 strategy above:

(i) **To build internationality** by investing in new, internationally active, staff in all research groups.
(ii) **To provide research leadership**, both internally and externally, by expanding the professoriate.
(iii) **To ensure future sustainability and vitality** by prioritising the recruitment of ECRs.
(iv) **To exploit synergies** by building on expertise in fluid/thermodynamics, electrochemical engineering, microfluidics, functional materials, to develop a new capability in chemical engineering.

TABLE 1: KPIs for REF2014 PHASE 1 compared with RAE2008	**RAE2008 (2000-2007)**	**REF2014 Phase 1 (Jan 2008-Sept 2011)**	**Change**
Category A Staff at end of period shown	14	14.8	+6%
Research Papers / FTE / yr, as reported on WoK	1.5	2.4	+55%
Research spend / FTE / yr (all sources)[1,2]	£73K	£118K	+62%
Research spend / FTE / yr (industry (co-)funded)[2]	£50K	£65.6K	+31%
FTE PhD & MPhil research students / FTE staff (registered at end of period shown)	1.7	2.4	+41%

TABLE 2: KPIs for whole REF2014 period compared with RAE2008	**RAE2008 (2000-2007)**	**REF2014 (2008 – 2013)**	**Change**
Category A Staff at census	14	24.99	+78%
Research papers over REF period, as on WoK	150	390	+160%
Total research spend (REF period, all sources)[1,2]	£6,733K	£9,741K (Jul08–Jul 13)	+45%
Total research spend (industry (co-)funded)[2]	£4,569K	£4,721K (Jul08-Jul 13)	+3%
FTE PhD & MPhil students registered at census	24	45.5	+90%

Notes: 1 Does not include £541K from RCUK income in kind, see TABLE 3, §d3, for detail. **2** Does not include £1.84M ERDF support for industry collaborative projects, §d3 and REF3a §b for detail.

14 new staff were appointed post-2011. As per PHASE 2 aims, >50% were ECR while the professoriate nearly doubled in size to 9. Eight staff are now active in the new area of chemical engineering. Also, building on long-standing links between Engineering and Physics in the areas of accelerators (E-MIT Group) and industrial mathematics (Micro-Nano Systems Group), 4 Physics staff joined Engineering to consolidate the activities of the Cockcroft Institute and semiconductor device researchers working at the Engineering/Physics interface - the latter coincident with creation of LU's £4M Quantum Technology Centre. KPIs showing the resultant increase in research power (quality and volume) are given in TABLE 2. Examples of key successes, especially related to partnerships and PHASE 2 aims of building internationalisation and research leadership, follow:

For the Energy Group (Staff: Boxall (lead), Joyce, Jiang, Taylor, Montazeri, Andrieux, Dawson, Kemp, including the Lancaster University Renewable Energy Group, Aggidis, Ma, Campobasso)

- Being a lead partner in phases II and III of the EPSRC **Supergen Marine** Energy consortium with Edinburgh, Heriot-Watt, Strathclyde and Queen's University Belfast. Phase II covered 2007-2011 (£5.4M), phase III will span 2011-2016 (£2.9M).
- Establishing **The Lloyd's Register Foundation (LRF) Centre in Nuclear Engineering**, growing from 1 chair in 2008 to 1 chair, 1 lecturer, 3 RAs, 12 PhDs and a total grant income of £2.75M.
- Building on this success, leading a new, £2M **LRF International Research Centre in Nuclear Safety**, our second LRF centre, joint with Tennessee, Harbin (China) and the Open University.
- Being a partner in the **EPSRC Nuclear EngD Centre** (£3.6M) and its follow-up, the **Next Generation Nuclear CDT** (£16.4M, 2014-21) with Manchester, Sheffield, Leeds and Liverpool.
- Being a founding member of SACSESS (**Safety of Actinide Separation Processes**), a €5.6M FP7 project on weapons proliferation resistant, nuclear reprocessing, 27 partners in 11 countries, incl 10 govt agencies and industrial partners Areva, EDF, UK National Nuclear Lab (NNL).
- Authorship of **Policy Reports** incl. "Nuclear Lessons Learned" (for DECC/RAEng), "Electrifying the Future", "Electric Vehicles: Charged with Potential", "Heat: Degrees of Comfort" (all RAEng) and "Global Food: Waste Not, Want Not" (IMechE).

For the E-MIT Group (Staff: Paoloni (lead), Burt, Hu, Lingwood, Carter, Tucker, Letizia)

- Continued leadership of the STFC funded **Cockcroft Institute** (£20M, 2004-2017).
- Playing a leading role in the €4.9M **HiLumi LHC** FP7 project preparing for the 2021 Large Hadron Collider luminosity upgrade, a collaboration between the Cockcroft Institute, CERN, CEA, CNRS, DESY, SLAC and 11 other accelerator laboratories across the EU and US.
- Being a partner in the £5M **UK/CERN R&D programme** to develop critical components for a 3TeV linear collider, a collaboration with STFC, Dundee, Manchester, Oxford, Royal Holloway.
- Membership of the new, €31M **European Coordination for Accelerator R&D (EUCARD)** FP7 project involving 37 accelerator laboratories across 11 EU countries.

For the Micro-Nano Systems Group (Staff: Richardson (lead), Adamopoulos, Carrington, Marshall, Zhuang, Boxall, Andrieux)

- Being a lead partner in a new €2.4M FP7 **Nano-Electro-Mechanical Integration And Computation (NEMIAC) project** on nanoelectromechanical systems for microprocessors with the École Polytechnique Fédérale De Lausanne, the University of Bristol, the Royal Institute of Technology Sweden (KTH) and industrial partners IBM, STMicroelectronics, Hyperstone, Leti.
- Being invited to join the **Extended Large Scale Integration Technology** (ELITE) FP7 project (€3.6M) on 3D integration in microchips. Partners: Hyperstone, Qimonda, KTH, Numonyx.
- Being a lead partner in the **EPSRC Innovative Electronics Manufacturing Research Centre** that has shaped UK research in electronics manufacturing, funding industry-led collaborative projects. Initial project (£5.5M 2004-09) was joint with Brunel, Loughborough, Greenwich, Bath, Sheffield, and Strathclyde. Project renewal (£9.1M, 2010-15) involves L'boro, Greenwich, Heriot-Watt, Bath, and Nottingham and BAE Systems, Waymark Technology, Dynex Semiconductors, AeroEngine Controls, Cirflex, Sarantel, MMA Technology, IQE, e2v, Kyocera, CSR, Cerulean.
- Final delivery of the LU led FP6 Network of Excellence in Design for Micro/Nano Manufacture (2004-2008), associated KPI's incl. 6.2M€ of spend across 24 partners (120 staff & 25 PhDs), 442 outputs (incl. 61 journal papers), 21 mobility actions and 6.8M€ of external income attracted

For the Structures & Manufacturing Group (Ye (lead), Rennie, Turvey, Pinkerton, Aiouache, Ma)

- Leading the £10M ERDF-funded **Manufacturing, Innovation and Design Partnership** with the

Universities of Salford, Bolton, Cumbria and Central Lancashire (2006-09).
- Leading the recently awarded £1.7M ERDF-supported **Sustainable Design for Rapid/Additive Manufacturing: Engineering Design Academy** with CRDM, Quandra Solutions Ltd (2013-15).
- Contributing to reports by the BRASS Centre (funded by ESRC, 2012), TSB (2012) and RAEng (2013) on the opportunities for the UK in the area of **Additive Manufacturing**.
- Being a lead partner in the above mentioned (§b1) £9.8M **Centre for Global Eco-Innovation**.
- Co-leading the £1.1M EPSRC/BAE Systems-funded **En-ComE project** on novel composites for powering PERGAVEs (Persistent Green Air Vehicles) by energy harvesting, a partnership with Exeter, Cranfield, UCLan and DSTL, AugustaWestland, TRW Conekt and Zartech Ltd.
- Being a lead partner in the £2.1M NWDA-funded **NW Composites Centre** with Manchester, Liverpool and Bolton (2006-09).

b3 FORMULATION OF STRATEGY is the task of the Dept Research Committee (DRC), who review and up-date it in light of external drivers, LU's *Strategy for 2020* (which DRC also feeds into) and end-user perspectives provided by Engineering's Industrial Advisory Board (which DRC also reports to). DRC monitors progress *via* externally benchmarked KPIs, and addresses matters such as impact support, resources, studentships, promoting of cross-research group synergies and all aspects of the research environment, including the monthly seminar programme. Meeting monthly, DRC is comprised of the professoriate, PG Tutor, an ECR and the Head of LPDU for KT/KE matters.

c. PEOPLE

Implementing §b1's Research Strategy **Objective 1** (see §c1a, §c1b) and **Objective 3** (see §c2).

c1a. STAFFING STRATEGY AND STAFF DEVELOPMENT: Of the 15 staff returned in 2008, 6 have left the UoA, 2 by retirement, the others to senior posts at other HEIs (Lund, Newcastle, Bristol) or to the private sector (Nanotechnology Industries Association). 3 more have become emeritus and/or returned part-time to provide continuity during Engineering's expansion.

The 2008-11 staffing strategy for the replacement of these staff was designed to retain key competences across Engineering. Subject specialisms aside, the **PHASE 1** strategy had 4 key features:
- The main criterion for all appointments would be research excellence, both in quality and impact.
- New staff should have industrial experience either as a result of working with, or in, industry.
- Appointments would be in pairs e.g. a chair and ECR. This (i) attracted higher quality applicants for senior posts; (ii) provided mentors for recruited ECRs; (iii) built critical mass in target areas.
- The aspiration that new ECRs should be a blend of ECRs from within and external to LU.

9 appointments were made during **PHASE 1** including the LRF Chair, 4 international staff, 1 from industry and 3 ECR. Judged a success, this strategy was rolled forward for the **PHASE 2** expansion with the additional aims of growing capabilities retained during PHASE 1, prioritising ECR recruitment (for future vitality and sustainability) and expanding the professoriate (for leadership).

14 appointments were made during **PHASE 2** incl. 6 international staff, 1 from industry, 2 professors and 9 ECR. We also attracted 2 ad hominem RAEng Research Fellows, (Marshall, Carrington). As per the **PHASE 2** staffing strategy, all groups were bolstered by at least 5 new staff. Strategy is now focussed on increasing research intensity by increasing the proportion of research active staff from 76% to 90% (see §b1, **Objective 1**). The staffing strategy will be reviewed in 2015 once the new staff have had opportunity to establish themselves.

Individual research performance is supported through staff appraisal conducted by the Head of Engineering. Incentives are provided through probationary agreements, promotion processes and workload models, all of which address KPIs such as publication, grant capture, PGR progression, translational work and, for senior staff, discipline leadership. A significant support mechanism here is the provision of sabbatical leave. Staff promoted in the REF period include: Joyce, Richardson, Boxall (on the professorial scale); Burt, Ma (lecturer to senior lecturer); Taylor (on the senior lecturer scale).

Engineering has an established system of supporting and mentoring new staff. A probation agreement is drawn up in consultation with the appointee, usually requiring that a significant grant is won within the 3 years of probation, and that world-class publications are made in refereed journals and / or at international conferences, usually 2 p.a. The appointee is supported in this by the DRC reviewing proposals / papers before submission. It is a mark of LU's ambition that it supports new researchers in writing applications from the very start of their careers. These objectives are in addition to teaching duties, which are low relative to many comparator departments, and are further restricted

in the first 3 years of a new appointment to 40%, 60%, 80% of a full load in years 1, 2 and 3. Performance is reviewed every 6 months during probation. Support measures include equipment funds, conference T&S, study leave etc. There are numerous internal competitions for PhD studentships.

c1b. EARLY CAREER RESEARCHERS (ECRs): LU recently achieved the EU's HR Excellence in Research award underpinned by its commitment to the Concordat to Support the Career Development of Researchers. We fully support Concordat aims, particularly:

- *Retaining researchers with the highest potential*: 6 of the 14 ECRs appointed post 2008 are ex-LU
- *Researchers are supported and equipped for the global research environment*: ECRs benefit from a wide range of centrally delivered development courses and are mentored as above.
- *Researchers personal and career development is supported*: ECRs use the Research Development Framework to develop their own careers, development being monitored by a Performance and Development Review (PDR) conducted by their mentor (drawn from senior staff).

The UoA provides pump-priming funds for research, T&S and conference attendance. ECRs are given priority when applying for faculty research and travel grants, DTA studentships and RCUK small equipment grants. Fee waivers are available to attract PhD students to projects led by ECRs. Staff are required to pass the Certificate in Academic Practice during probation.

Underscoring our commitment to the Concordat, and reflecting the staff base's increased vitality, the number of ECRs returned has increased from 4 at RAE2008 to 10 at the 2013 census date. The Faculty also supports the recruitment and retention principles of the Concordat *via* provision of 3 ECR Fellowships through Energy Lancaster (see §b2). Each 5-year fellowship leads to a permanent post in the Fellow's chosen department. An Energy Fellow is being hosted by Engineering.

Reflecting the quality of training, our PDRAs are highly employable. Of our 37 RAs since 2008, 34 are in full-time employment, 8 as tenure track academics: Andrieux, Burt, McCabe, Lingwood (all LU), Brooks (UCLan), Kahanda Koralage (Southampton), Lei (Bradford), Ambattu (BITS Pilani, India)

c1c. EQUALITY ISSUES: LU is an equal opportunities (EO) employer and holds an Athena SWAN bronze award for good practice in recruiting, retaining & promoting women in SET. New staff, HoDs and Research Directors undergo diversity and EO training by HR. There is clear support from the HoD for flexible/PT working for staff returning from maternity/paternity leave. Engineering's commitment to EO is shown by diversity in protected characteristics such as gender, ethnicity, age having risen since 2008. In particular, 18% of our research community is now female. Since 2008, mean age has decreased from 47.1 to 43.7 whilst age bandwidth has widened from 30-64 in to 29-70.

c2. RESEARCH STUDENTS: PhD numbers have grown linearly post 2008, near-doubling from 24 to 45.5 (see §b). PGR in 2013 now comprises >10% of our total student number, an early realising of a key target of LU's 2009 institutional strategy for 2015. Factors driving this have been:

- Membership of the EPSRC Nuclear Engineering Doctorate Centre, allowing us to offer fully funded, industry co-sponsored EngD places and providing access to Centre training courses;
- The winning, year-on-year, of competed, peer-reviewed Nuclear Decommissioning Authority PhD studentships. LU hosts the single largest number of NDA-sponsored students in the UK;
- The winning, in collaboration with industrial partners, of openly competed, peer reviewed, fully funded PhD studentships from the ERDF-funded Centre for Global Eco-Innovation (see §b1)

PGR recruitment is buoyant, with posts in 2012 attracting >150 applicants. These approaches will continue in our pursuit of **objective 3** of our 2020 strategy (see §b1), boosted by our membership of the new **EPSRC Next Generation Nuclear CDT** (awarded Nov 2013, 80 PhDs over 5 yrs, see §b2).

The number of MSc-by-research students has also grown, up from 1.5 FTE in 2008 to 5 in 2013 (>25 in total since 2008). Mostly part-time and funded by industry, ERDF or charity, these students work almost exclusively on projects designed in collaboration with, and for, a research end-user.

PGR training, supervision and monitoring is overseen by the Engineering's PG Tutor, supported by a dedicated PG administrator. In this, we fully subscribe to the QAA Code of Practice for PGR Programmes, the RCUK Joint Skills Statement and SET for Success. Students have at least 2 supervisors led by a Director of Studies. Regular progress monitoring takes place and evidence of supervision and attendance are documented. Progress is monitored *via* submission of 6 monthly reports. These are reviewed by two DRC members external to the supervisory team. Reviews at months 10 and 22 also involve presentations at a one-day PGR review conference and *viva voce* by a panel of staff, the purpose of which is to make recommendations for annual progression and transfer of

registration from MPhil to PhD. PGR training & pastoral support is provided *via* the following routes:
Transferable Skills: The Faculty Graduate School Research Development Programme which provides training on topics including induction (mandatory), skills development, project management, thesis preparation, presentation skills (also fostered through the Engineering PGR review day and pro-actively encouraged conference attendance) and career planning;
Subject specific skills: >20 PGT modules in Engineering specialisms, underpinned by an IET commended research methods module covering e.g. technical writing, statistics, critical thinking, IP, literature search and retrieval. There is dedicated funding for attending specialist external courses;
Pastoral support: provided by the PG tutor, Faculty Graduate School and LU's Graduate College, of which all PGRS are members and which also acts as a social centre for the PGR community.

d. INCOME, INFRASTRUCTURE AND FACILITIES
Implementing §b1's Research Strategy **Objective 4** (see §d1, §d2, §d3) and **Objective 2** (see §d3)

d1 EVIDENCE OF INVESTMENT IN INFRASTRUCTURE and FACILITIES
As described in §a, Engineering will move into a new £12M building in Nov 2014. This will contain:
- a class-1000 clean room (in support of optoelectronics and photonic materials research);
- a substantially expanded wet laboratory facility (in support of microfluidics, fuel cell, sensors and functional materials research in the newly established chemical engineering area);
- dedicated closed and open source labs in support of nuclear science and engineering research.

This is on top of extensive refurbishment of current labs (£1M for a new additive manufacturing facility and wet laboratory for uranics) and £300K for new equipment (£150K from LU for electron microscopy and Raman spectroscopy for materials analysis and an adjustable floor for our wave tank; £150K from ERDF/HEIF for a selective laser melting machine for additive manufacturing).

d2. INFORMATION ON SPECIALIST INFRASTRUCTURE AND FACILITIES
These have also been substantially enhanced and, in addition to the above, include:
- A selective laser sintering machine, donated by CRDM (additive manufacturing research);
- AFM, SEM, white light interferometry, differential scanning calorimetry (materials analysis);
- A 1/50th scale wave tank, tidal flume and low-head hydropower facility (marine energy research);
- A wind tunnel and jet engine (for renewable energy and combustion research);
- A £250K laser drill and £40K chemisorption analyser (from AFC Energy, for materials research);
- Dedicated RF and microwave laboratories (in support of high power microwave research).

These are supplemented by access to a wide range of facilities *via* our collaborative links as follows.

Intra-institutionally, our membership of LU's Quantum Technology Centre allows access to £4M worth of materials fabrication and characterisation facilities including clean rooms, molecular beam epitaxy, e-beam lithography and plasma deposition CVD, SEM-EDX, XRD and a range of scanning probe microscopies. In the Lancaster Environment Centre we have access to ICP-MS, IR, TEM and one of the few fully-licensed radiochemical labs left in UK universities (with $\alpha/\beta/\gamma$ spectroscopy).

Extra-institutionally we use our extensive network of collaborations to access world-class specialist facilities where it is wise, necessary and/or economical to share access, including:
- Synchrotron radiation sources *via* our membership of the Cockcroft Institute, its associated collaborations and the N8 university research partnership;
- Neutron and α sources at Liverpool University, the UK National Physical Laboratory (NPL) and the Seibersdorf Nuclear Safeguards Labs, IAEA, Austria (for radiometric instrument testing);
- A new 5312 core SGI supercomputer cluster, located at the University of Leeds and accessed *via* the N8 university research partnership, and one of the largest HPC clusters in the region;
- Highly (radio) active laboratory facilities at the NNL's Sellafield Facility, *via* the NNL's 3rd party access agreement to which LU is a signatory;
- Radioactive hot cells at the EU Joint Research Centre's Institute for Transuranic Elements;
- Complementing our own facilities, wave tank, pump and turbine testing facilities at Manchester and Edinburgh Universities and Gilbert Gilkes & Gordon Ltd. (for marine energy research).

Through membership of the EPSRC Turbulence Consortium, we have RCUK central facilities access to HECToR, the UK's Supercomputing Service as well as the FERMI supercomputer in Italy.

d3. RESEARCH FUNDING PORTFOLIO INCLUDING FUTURE PLANS:
Mean p.a. spend since 2008 is £2.05M (incl. £541K in-kind support but excl. £1.84M ERDF-funded

support for industry collaborative projects, see TABLE 3), 70% funded through UK/EU peer review. This is up 101% from £1.02M p.a. in 2008. TABLE 3 shows that funding has diversified since 2008, increasing its sustainability. Within the doubling of income related above, notable increases occurred in income from: RCUK (up 102% against increased competition), RCUK central facilities, charity, Government and industry (more than tripled), the latter targeted as part of our impact strategy.

TABLE 3 : Research Spend by Funding source	**RAE2008**		**REF2014**		**% change in spend p.a. from RAE2008 to REF2014**
	Spend p.a.	**% of total**	**Spend p.a.**	**% of total**	
RCUK grants	£576.5K	56.3%	£1,165K	56.6%	+102%
RCUK facilities in-kind support	0	0%	£104.2K	5.1%	N/A
Charities	£1.2K	0.1%	£282.7K	13.7%	240 times greater
UK Gov't, inc local Gov't, RDAs	£70.1K	6.8%	£111.1K	5.4%	+58%
Industry – direct funding only	£59.7K	5.8%	£218.2K	10.6%	+266%
EU	£315.9K	30.9%	£176.5K	8.6%	-44%

The 2012-13 expansion affords opportunity to increase this even further. A key feature of our strategy for 2020 is a renewed focus on research intensification, analogous to that which occurred in 2008-2011 but on a much larger scale. This will require mentoring of ECRs in the writing of grant applications (see §c) and supporting new senior staff in maintaining their historical success rates.

Informed by the above, we will target the following for achieving **objective 2** of our strategy (see §b1)

- **EU bids**, especially consortium bids. Responding to the transient dip in this historically strong income stream shown TABLE 3, we have already had success in establishing 4 new projects post-2011 (EUCARD, NEMIAC, HiLumi LHC, SACSESS, see §e) and will seek to build on this.
- **RCUK** Increased by 102% during the REF period. Informed by the EPSRC capability-shaping exercise, there will be renewed emphasis on research capacity grants, fellowships and Centres for Doctoral Training, the latter already having been successful in the form of the new Next Generation Nuclear CDT, recently announced in November 2013 (see §c2).
- **Charitable support,** now 13.7% of our research income. Following awards from The Sir John Fisher (4 fully funded MSc studentships p.a.) and Lloyd's Register Foundations (LRF Chair in Nuclear Decommissioning), we have recently been awarded £2M by LRF for a new Centre in Nuclear Safety (see §b2). Charity support will be grown in collaboration with our Alumni Office.
- **Industry co-funding** now accounts for 48% of our income. Details of key partners are given in §b & e. Links have been developed *via* iCASE/iCASE-style PhDs (>30), KTPs, £1.84M of ERDF support for industry collaborative projects and LU/RDA-funded innovation vouchers (>20 SME collaborations). Building on this and supporting our impact strategy, we will target KTPs for 2020.

d4. CONSULTANCIES & PROFESSIONAL SERVICES: Managed through the LPDU, see REF3a.

e. COLLABORATION OR CONTRIBUTION TO THE DISCIPLINE OR RESEARCH BASE

e1. COLLABORATIONS AND NETWORKS: Reflecting the success of our 2008-14 strategy to deliver excellence *via* partnerships (§b2) our international and national collaborations have increased in number and strength. We now collaborate with >150 groups in >30 countries over 5 continents, all evidenced by joint funding or publications. Particularly, as measured by financial value or number of projects, >60% of our research is conducted in collaboration with end-users. These partnerships are highly prized, not only for the research delivered but also for the domain knowledge accessed that has proven invaluable in developing our research strategy and anticipating future developments.

Examples of **key international and national collaborations / networks** are given in §b1. **Internationally prestigious collaborators** additional to those given in §b1 include the Stanford Linear Accelerator Centre (novel high power accelerator cavity structures), JLab (superconducting RF accelerator cavities), the IAEA & NPL (radiometrics and nuclear non-proliferation), e2v & Rapiscan (portal scanner technology), Idaho & Savannah River US National Labs (nuclear decommissioning) EDF (nuclear safety critical software), the Culham Centre for Fusion Energy (modelling of nuclear materials breeding), E-ON (marine energy & clean combustion), Siemens & BP (clean & safe hydrocarbon-based energy), Ultra Electronics, STMicroelectronics (test engineering), AFC Energy, Ceres Power & Johnson Matthey (facilities for fuel cell research) and the Universities of Canterbury &

Auckland (New Zealand), Akdeniz & Kocaeli (Turkey), Brest & Bucharest (advanced manufacturing).

Collaborating UK HEIs additional to those in §b1 include Imperial, Cambridge (producing a Nature comment piece on the proliferation resistance of thorium), Oxford, UCL, all N8 partnership members (incl. the leveraging of infrastructure funding), and many other research intensive HEIs across all of our research groups. We also collaborate with a wide range of international HEIs (see §b2), SMEs (see REF3a §b(i), (iii), (iv)) and UK Govt Ministries (DfT, DECC, BIS) and Professional Engineering Institutions (RAEng, IET) in the form of reports influencing policy (see §b and REF3a §b(ii)).

e2. LEADERSHIP IN THE ACADEMIC COMMUNITY has been a core feature of our research strategy since 2008 and is central to that for 2020 (see §b). Since 2008, **12** staff have sat as members of **advisory boards** and **RCUK, learned society & professional body committees** incl. service as members of RCUK, Georgian National Science Foundation and R&D Management Association peer review colleges, FP7 evaluators and IET accreditors. Kemp sat on the RAEng Engineering Policy Committee, the IET Energy Policy Panel (2008-2013) and the UK Govt Chief Scientific Advisors Panel on Government's use of science and engineering (2010). Joyce was chair of the Nuclear Institute Academic Industrial Liaison Sub-committee (2007-12) and is on the Steering Committee of the National Nuclear Users Facility (2013 on). Ye is on the ASCE Stability Committee.

Staff have been invited members of numerous **international delegations, representing the UK**: to the World Micromachine Summit (Richardson, Dubai 2010); on FCO delegations to Nuclear Collaboration Workshops (Boxall, Switzerland 2010, USA 2011, Japan 2012); on the IMechE / Chinese Mechanical Engineering Society panel for China/UK engineering strategy and technology roadmap (Aggidis 2012); as UK representative to the IAEA ^{3}He replacement workshop (Joyce, Vienna 2011).

Staff and students regularly **organise and present at conferences**. Since 2008, we have given **>100 keynote lectures** at major conferences worldwide including plenaries at: European Conference on Process Analytics & Control Technology (Glasgow 2011); Catalysis in Multiphase Reactors CAMURE-8 (Finland, 2011); 19th International Conference on Chemical Reactors (Vienna 2010); RF Superconductivity (Berlin 2009); 9th World Congress on Computational Mechanics (Sydney 2010); IR Millimeter Wave THz Conference (Rome 2010, Glasgow 2011); International Vacuum Electronic Conference (IVEC) 2013 (Paris); 1st International Conference on Energy Systems Engineering (Rawalpindi 2010); Innovations in Microsystems Congress (Munich 2010); International Conference on Civil Engineering & Building Materials (Kunming, China 2011); and the Westminster Policy Forum on the Sustainability of Nuclear Power (2010). We have **organised >60 conferences**, serving as **programme chairs on 12**, incl. the prestigious IEEE conferences: IVEC 2009 (Paoloni); International Mixed Signal Test Workshop, Electronics System-Integration Technology Conference (both Richardson 2008), UK/EU/China Millimeter Waves and THz Technology Workshop (Paoloni 2013). Joyce sits on the 2018 IEEE Nuclear Science Symposium organising committee, Rennie has run the annual Rapid Design, Prototyping & Manufacturing Conference Series since 2002 and Boxall sat on the local organising committee of the Big Bang Young Scientists & Engineers Fair (2010).

Staff are on the **editorial boards** of **>20** major international journals, incl. **Editor-in-Chief** of Progress in Nuclear Energy (Joyce, 2012-date) and **Editors** of IEEE Trans. Electron Devices (Carter 2011-date); Composites Part B: Engineering (Turvey 1999 – 2009); J.Theoretical and Appl. Mechanics, Europhysics Letters (Tucker 2005-date). Staff have **guest edited** 6 special issues of journals incl. Paoloni for IEEE Trans. Electron Devices, 2013. All staff routinely review papers for a wide range of high impact journals and have externally examined **>50** doctoral theses since 2008.

Staff have received numerous **awards, prizes & fellowships** in recognition of their contributions to the community. Staff hold **fellowships** of the RAEng (Kemp), IMechE (4 fellows), IET (3 fellows), IoP, Energy Institute, Institute of Marine Engineering, Science & Technology and Nuclear Institute. Staff hold **visiting professorships** at NUDT, Changsha, China, (Joyce, Ma); Harbin & Hefei, China (Ye) École des Mines de Nantes, École Nationale Polytechnique d'Alger (Aiouache). **Awards & prizes** are held by staff at all levels of seniority: The IEEE IVEC Award for Excellence was presented to Carter in Rome, 2009 for: "visionary leadership in academia and technical research in the field"; in 2008 Aiouache received an "Oscar of innovation" R&D 100 Award for work on resolution of reactions in catalytic monoliths; **At ECR level**, Montazeri was a Humboldt Fellow (2011-13) whilst Marshall (2010) and Carrington (2012) won RAEng Fellowships in the area of semiconductor engineering, the latter also being awarded the 2011 CR Burch / British Vacuum Council Junior Medal.