Institution: Lancaster University

Unit of Assessment: UoA7 Earth Systems and Environmental Sciences

A. OVERVIEW

Following substantial investment in the research infrastructure of the Lancaster Environment Centre (LEC) during the RAE2008 period, the REF2014 period has been one of continued growth and investment in staff, and increased success in research discovery, delivery and leadership. We are now a fully integrated unit that delivers world-class research, through strength-in-depth in core disciplinary research supporting user-relevant, inter-disciplinary research. We have made strategic appointments to enhance both our disciplinary strengths and our capacity to lead interdisciplinary environmental research. We have developed our global network of collaborations with research organisations and users, both in the UK and internationally, in particular in Brazil and China.

Core disciplinary groupings continue to be the fundamental foundation of the department's research, with groups in Atmospheric Sciences, Biodiversity & Conservation, Environmental Chemistry, Earth Sciences, Plant & Crop Sciences, Society & Environment, and Soil & Water Sciences. Many staff work across more than one disciplinary group, and we encourage such breadth of research vision. Our Integrating Research Centres (IRCs) in Water, Chemicals Management and Sustainable Agriculture have been successful in providing explicit connections between our disciplinary groupings and our research partners. We are building on that success by bringing new inter-disciplinary groupings together as the focus for LEC's future approach to delivering world-leading research and effective partnerships that lead to genuine impacts.

B. RESEARCH STRATEGY

Our fundamental research strategy is to sustain strength-in-depth in our core disciplines which can then support effective inter-disciplinary research, and so address major global environmental challenges such as water, food and energy security, pollution assessment and reduction, responding to climate change and protecting biodiversity. As detailed below, the major strategic objectives defined in RAE2008 have been met during the REF period, and remain key elements in our strategy to grow LEC's research.

i. Our over-arching RAE2008 objective for "a fully integrated School [in the Environment] to be formed by 2009" was delivered on time. LEC hosts a range of research disciplines that work together to deliver research outputs which are greater than the sum of our parts.

Research is at the heart of the department's mission. Three of the four Associate Directors on the department's management group (Research, Post-Graduate Research (PhDs) and Enterprise and Business Partnerships) work with the Director to develop and deliver research strategy, and to support staff in making a full contribution to departmental research. Our investments in new staff (see Section C) and new infrastructure (see Section D), combined with our expanded network of national and international partnerships (Section E), deliver research excellence founded on disciplinary strengths as the basis for innovative research that transcends disciplinary boundaries, and that embraces effective collaborations with research users (Section E).

We have invested in the vitality and sustainability of LEC's research environment, leading to tangible improvements in key measures of our research success. For example:

- We made linked investments of staff and facilities in environmental chemistry at its interfaces with (i) Earth Sciences, to bring new strength in stable isotope chemistry (three FTE and £450k facilities), (ii) ecotoxicology (one FTE and £300k facilities), (iii) atmospheric sciences (one staff and £75k facilities) and (iv) Soil & Water science (one FTE). This investment has been instrumental in the publication of eleven papers in Nature family journals, one in Science and one in PNAS. These appointments have also delivered significant increased research collaborations, notably with British Geological Survey (BGS), Centre of Ecology and Hydrology (CEH), and Chinese Academy of Sciences (CAS) (see B.ii and Section E).
- Our co-ordinated investment of two staff in Biodiversity and Conservation and two in Society and Environment has been designed (i) to strengthen inter-disciplinary collaborations and (ii) to underpin our growing research activity in both natural and managed ecosystems in the tropics, especially our collaborations in Brazil (see below). These two research groups delivered three papers in Science and one in Nature during the REF period.

As a result of our strategic support for research, during the REF period fourteen staff (31% of staff returned) from five of our research groups have co-authored 18 papers in the Nature family of

journals and 4 in Science. Approx. 73% of LEC's returned papers (approx. 55% of all our papers) are in the top 10% of journals in their field, as defined by Thomson-Reuters Journal citation reports. According to Thomson Reuters Essential Science Indicators (January 2000-February 2010), we are ranked 32nd globally and 5th in the UK for citations in environment and ecology.

ii. Our second major RAE2008 objective "to strengthen research collaborations with key overseas partners and "to exploit opportunities by greater integration at our borders (with Engineering, Physics, Computing, and Sociology)" has been achieved. The vitality and sustainability of our research are strongly enhanced by an effective network of strategic collaborations (also see Section E). During the REF period, our "integrating research centres", in Water, Chemicals Management and Sustainable Agriculture, have been the highly successful foundation on which we have developed a network of strategic collaborations (see Section E). We use different mechanisms to support different partnerships (including external funding and targeted appointments, some co-funded by our partners) to enhance specific areas of research synergy.

Our partnership with CAS has led to 15 joint PhD students and provides access to world-leading facilities and CAS's network of laboratories and field sites. We have made one joint academic appointment with CAS and will appoint more soon. We are establishing new laboratories with CAS and joint appointments/secondments are enabled under our joint International Research and Innovation Centre for the Environment (I-RICE). Our Chinese collaborations were also supported by RCUK funding for the China Bridge project (Davies: 2009-2012: £1.33M). In Brazil, we have established a dual PhD scheme with Federal University of Lavras (Section C), supported by new staff both in Lancaster and Lavras. Within the UK, our long-term collaboration with CEH remains an important element in our strategy, now supported via a new joint academic appointment. We have also appointed joint-staff to establish and deepen our new research collaboration with BGS.

We have worked strategically with other academic departments at Lancaster to engage in research relevant to the environment. The Centre for Global Eco-innovation (CGE), a £9.8M ERDF-funded project led by LEC, involves our departments of Computing & Communications, Engineering, and Physics. The link between LEC and Engineering is also strengthened through Energy Lancaster, a cross-departmental initiative that grew from LEC's Centre of Sustainable Energy, and now led by LEC's Andrew Jarvis. This link has been underpinned in LEC by three new appointments relating to carbon capture and one on the ecological impacts of renewable energy generation. Another major success is our collaborations with Sociology including, the winning of EPSRC/EDF "DEMAND: Dynamics of Energy, Mobility and Demand" Research Centre funding (Walker: total value £7.1M), and agenda-setting theoretical analysis on the Anthropocene (Clark and others).

iii. The third major RAE2008 objective, to d*evelop the 'interfaces' between our fundamental research and external stakeholders, making full use of our Enterprise and Business Partnerships team"*, has been fulfilled very successfully. From its foundation LEC has recognized the need for world-leading research to deliver environmental solutions, and in many ways this internal RAE objective anticipated the vital role of research impact now explicitly recognized in the revised structure of REF. Much of our resultant progress in relation to this objective is described in the Impact Template. Supporting our researchers to deliver genuine impact, based on world-class research, is a central part of LEC's research strategy, facilitated by our dedicated Enterprise and Business Partnership team. During the REF period, we have continued to grow our national and international network of collaborations with stakeholders, which has been central to translating our research to the benefit of research-users.

Future research strategy: 2014-2020

The evidence presented above demonstrates our success in implementing the strategic goals defined in RAE2008. For us, the REF period highlighted the need to deliver research that addresses the 'complex spaces' in the environment, for example between energy-food-water-biodiversity. We recognize the difficulty of delivering world-class research in such grand challenges and our research strategy has been developed to address this.

1. Our appointment strategy is part of the on-going process of renewal and re-focusing. Our initial priority is continued investment in Society and Environment, focussed on building new strengths in environmental social science, and in particular the capacity to work in interdisciplinary teams within a sustainable science framework. We have appointed seven new staff since RAE2008, and have four more confirmed lecturer appointments who will start by early 2014 (see Section Ci). Building

on the strengths of established staff (e.g. Clark and Walker) the aim of these appointments is to deliver our strategic research goals by further strengthening LEC's distinctive social science grouping and, through their involvement in our new research actions (see below), to enable inter-disciplinary collaborations with, for example Earth Sciences, Biodiversity & Conservation and Plant & Crop Science. Beyond Society and Environment, our future appointments will sustain existing research strengths within the focus provided by our network of strategic partnerships and securing environmental innovation as a priority in our research (see 3 and 4 below).

2. We will extend the model of our "integrating research centres" (IRCs) to develop three new broad-based and directed "research actions" in 2013/14. We have recognised both the success of the IRCs and the limits inherent in their relatively narrow foci (Water, Chemicals Management and Sustainable Agriculture). This has led to the new actions being more broadly focussed in (i) Understanding our Changing Planet (ii) Improving Global Stewardship and (iii) Innovation for a Better Environment. While emerging from our own experience, the new actions are intentionally aligned with wider research initiatives, such as the "Future Earth" initiative of the International Council for Science (http://www.icsu.org/future-earth/). These new research actions will provide (i) explicit connections between our disciplinary groups, complementing and extending core research strengths, (ii) a focal point for investment and new appointments, (iii) a focus for our strategic partnerships in relation to our approach to major global research challenges and so (iv) stimulate research that has genuine impact as well as excellence.

3. Our network of strategic partnerships will grow and diversify nationally and internationally, focussed especially through the research actions. We will look to broaden our partnerships to include organisations involved in environmental policy, which we recognize is under-represented at present. Internationally, a major priority is to develop LEC research bases in China, South America and Africa. In China, we will build on our partnership with CAS to fully establish I-RICE as "LEC-China". We are using these three bases (i) to establish an international doctoral training centre and (ii) to further extend the LEC-CAS collaboration to include a wider range of disciplines, especially around the "Innovation for a Better Environment" action. We will work with our partners in University of Lavras, and with CEH and Rothamsted Research and their Brazilian partners, to (i) broaden our collaborative research-base in Brazil, and (ii) increase PG-R numbers from Brazil. We will also explore stronger links in sub-Saharan Africa. These will focus on the University's new campus in Ghana (especially in eco-toxicology and contaminated land management), and our growing links in agro-ecological research in East Africa.

4. Building on our Centre for Global Eco-innovation, we will lead in developing "Innovation for a Better Environment", based on world-class environmental research in both the natural and social sciences, Planned developments in China will be a key step here, including new Chinese-funded CGE studentships to start 2013-14. We will develop CGE as an eco-innovation "flagship" through new investment in staff and infrastructure. The recent HEFCE-funded Catalyst award (July 2013), delivering post-graduate research projects with CAS and Chinese research-users, will accelerate these Chinese collaborations. As with the current CGE, future developments will embed effective partnerships with our strategic partners, such as CEH, with a wide range of eco-innovative business (in the UK and overseas).

C. PEOPLE

i. The research strategy described in Section B underpins our future staff recruitment plan. The appointment of new staff with excellent research records has strengthened the vitality and sustainability of all our disciplinary groups. Appointments that provide focal points for our network of research partnerships have also been a strategic priority. Our new staff not only bring research excellence in their specific fields but also leadership in delivering the department's strategy in relation to inter-disciplinary research and research partnerships.

While new appointments meet the strategic needs of the whole department, it is convenient to describe them here by our broad disciplinary groups. Investments in physical infrastructure that have under-pinned specific appointments are noted briefly, but described in detail in Section D.

In Earth Sciences, Holland, Kampman (who is formally linked with BGS) and Zhou (formally linked with CAS) were appointed to develop a unique research focus on stable isotope and noble gas chemistry that connects Earth Sciences and Environmental Chemistry. This builds on the earlier appointment of Wynn (ECR at RAE2008) and our strong synergies with both CEH and CAS in this area, and has been underpinned by a major investment in new analytical facilities. Young was

appointed to Atmospheric Science as the next step in sustaining this research area beyond the REF period. He specifically adds strength in ozone chemistry, building on the appointment of Wild during the RAE period. In Environmental Chemistry, Sweetman was appointed to a senior lectureship formally linked with CEH, tasked with leading further development of that partnership.

The medium-long term sustainability of Soil & Water Sciences has been supported through the appointment of Haygarth to bring process understanding that complements existing modelling capacity, and to sustain the balance between world-leading research and external impact. These appointments are complemented by those of Ostle and Stevens appointed into Biodiversity and Conservation, and Dodd into Plant and Crop Sciences, to build integrated strength across the soil-water-vegetation-atmosphere continuum. These appointments also form focal points for our wider collaborations (Ostle with CEH, and Dodd with Rothamsted Research). These new appointments in the Natural Sciences have been complemented by targeted improvements to our glasshouse, controlled environment and field facilities. Also within Biodiversity and Conservation, Barlow was promoted to Senior Lecturer at the end of his RCUK Fellowship.

Society and Environment has been the focus of significant investment in posts to build new strengths in environmental social science and in particular the capacity to work in interdisciplinary teams within a sustainable science framework. Clark has provided new leadership in critical theory; Ellis, Beisel and Markusson build on Lancaster-wide expertise in science and technology studies; Bettini, Fraser and Parry (plus Childs (politics of environmental governance), Roy (sustainable cities), Neimark (bioprospecting and commercialisation), and Whittle (community-environment relations) to start by early 2014) form a new political ecology and development focus that embraces many within Biodiversity & Conservation.

LEC's recruitment during the REF period **has recognised the great value of staff with a wide range of research backgrounds and experience**, especially in interacting with international partners. Of the 21.4 FTE staff appointed during the REF period 14.4 FTE were from outside the UK. As a result, 22% of the staff returned to REF are now international (up from 13% at RAE2008), representing seven countries. International recruitment also extends to other staff categories: 10% of our core technical team, 29% of researchers and 36% of PhD students are now international. We also value the contribution of **visitors and Fellows** to both the vitality of our research community and the delivery of our strategic goals. Dr L. Nizzetto (2008-2009), Dr R. Graham (2011-2014), Dr A Capponi (2012-15), Dr A Cincinelli (2012-2015) and Dr G Zhuang (2013-2015) all held Marie Curie Fellowships within LEC. Dr A. Blechschmidt held a NERC NCAS fellowship (2010-2012). Excluding the large number of short-term visitors from academia, research and research-user organisations, over the REF period, LEC has been host to 110 formally-recognised visiting researchers (defined as those working within LEC for a period >3 weeks). These visitors were from 23 countries and of non-EU countries the largest number of visitors came from China (15) and Brazil (8) reflecting our strategic growth of research relationships with those countries.

LEC staff have been successful in winning a range of personal research fellowships. Hewitt holds a Royal Society Wolfson Research Merit award (2009-2015) and Maher held the same between 2006 and 2012. Tuffen is a Royal Society University Research Fellow (2010-2015). Wilson held a Leverhulme Senior Research Fellowship in 2012-13. Stevens held a Leverhulme Research Fellowship (2009-2012) and NERC Policy Placement Fellowship with Defra in 2010/11. Parry holds an ESRC Future Research Leaders fellowship (2013-16) and a World Social Science Fellow (1 of 20 fellows awarded by the International Social Science Council). Romdahl holds a one-year Fulbright fellowship from 1st October 2012. Barlow holds a Special Visiting Researcher scholarship from the Brazilian Research Council (CNPq) (2012-14). Jones is senior visiting international scientist with the Chinese Academy of Sciences, 2010-present. Hewitt is a Visiting Scientist at the US National Centre for Atmospheric Research.

We are committed to supporting equalities and diversity in our staffing strategy, as we are in all our activities. In September 2013 LEC gained the Athena Swan Bronze award as a department, building on the same award held by Lancaster University as an institution since 2008: These awards are steps towards the department's aim of higher levels of award in the coming years. We support colleagues returning after maternity leave, who have care commitments or who are returning to work after long-term illness through individually-designed working arrangements. Arrangements are customised to meet individual needs and include flexible working and, where appropriate, additional mentoring-support to assist staff to re-engage with their research.

We have taken a lead at Lancaster in **approaches to career development**, and contributed to the award of the University's European Commission "HR Excellence in Research". All new members of staff undertake formal training provided at Faculty and University level. Within the department, all new appointments enter in to a formal probationary agreement that strongly emphasises support as they establish themselves as independent researchers. The department assigns mentor(s) to all new members of research staff. Mentors are experienced members of staff chosen in relation to the specific ambitions and development needs of individuals.

We support staff throughout their careers in fulfilling their research aspirations in relation to departmental strategy. All staff have annual performance and development reviews that include discussion of opportunities and constraints for individuals' research, and which feed in to departmental planning of future workload allocations, including sabbaticals. Our workload allocation system includes a "core" research component (normally 20%), plus any additional research time supported by external funding, but with scope for increased allocations for staff with exceptional commitments to research. We value the role of sabbaticals in supporting individual research vitality, and the department is pro-active in encouraging staff to make effective use of sabbaticals. During the REF period, 65 staff received sabbaticals equivalent to a total of 22 staff years - based on average salaries, this is equivalent to c. £1M in support for research active staff.

Lancaster University has implemented the concordat to **Support the Career Development of Researchers**, and established a University-wide researcher group, including a member from LEC, that liaises directly with the University's senior management team. We build on these University support systems through department-specific support for this group of staff, especially though our LEC Researcher Group. We have agreed a specific departmental Researcher Concordat that defines the additional support and career development provided by LEC. For example, all researchers starting in LEC meet individually with the Associate Director for Research and Chief Technician who provide an explicit statement of our position on researcher support and career development, and discuss specific technique/method training needs to be provided by the core technical team. In consultation with the researchers' group, we provide specific training sessions in addition to the courses/support from Faculty and University. LEC researchers elect a representative to the LEC Research Committee and so directly inform our decision making.

ii. **In RAE2008 we set ourselves the ambitious target to "*at least double our research studentships and broaden and increase our funding base, building on our partnerships*".**

At the time of the REF census date, we have 155 FTE registered PhD students, compared with 72.7 FTE at the RAE census, a 2.15-fold increase, so exceeding the target stated at RAE2008. Averaged over the REF period, we have recruited approx. 40 students per annum compared with just 24 per annum for RAE, an increase of 67%, far exceeding the increase in staff numbers. This increased has occurred largely late in the REF period (so not yet reflected in submissions) as we have progressively broadened our PhD funding base. We have won two bids for doctoral training partnerships from BBSRC (2009 and 2012), one from ESRC (North West DTC: 2011-present) and one from NERC (LEC led the recently awarded ENVISION DTP that will fund twelve studentships per annum from 2014 -2018). We have won 25 CASE projects (with funding from NERC, BBSRC, EPSRC and ESRC), 12 studentships funded directly by industry, and 44 funded from outside the UK (including 6 from China and 7 through our dual PhD scheme with University of Lavras in Brazil). The growing interdisciplinary collaborations within LEC directly led to the award of four NERC-ESRC interdisciplinary studentships, focussed especially at the interface of ecology and environmental social sciences. Finally, the LEC-led Centre for Global Eco-Innovation (CGE) supports 17 LEC PhDs, all in collaboration with SMEs, and we provide the management/support for a further eight eco-innovative CGE PhDs across our faculty. This diversity of available PGR funding has helped sustain the number and quality of applicants for open competitions, which has been exceptional in many cases, for example, almost 1000 students applied for the CGE PhDs.

In the belief that well-supported students are more likely to fulfil their potential, and in part given the need to support far more students than during the RAE period, we have invested in improving training and support for our research students. We have established an extra administrative post specifically to support our PGRs and further improved communication through a dedicated virtual learning environment. We have introduced (i) more structured and well-defined mechanisms for dealing with personal and supervisory problems, (ii) individual academic

coaching to all PGRs and (iii) a PhD buddy scheme, where established PGRs provide support for new starters. We have completely revised our induction programme for new students, including our departmental PhD handbook. Our PhD staff-student committee has led initiatives such as our PG forum (an open meeting for all PGRs), and a student-led seminar programme in parallel with the normal departmental seminars. We made a strategic decision to move away from PhD offices dedicated to specific research groups to shared offices that transcend traditional disciplinary boundaries. Tangible outcomes have included a 'bottom up' initiative (the "Incredible Inter-disciplinarians") led by PGRs to provide a forum to discuss the opportunities and challenges of inter-disciplinary research, especially for PGRs and early career staff.

Effective support and training is backed-up by progress monitoring in which the student's progress is assessed by a panel of cognate academics at approx. 6 months intervals until completion. Given LEC's mix of PhD funding, appraisals specifically address the opportunities and challenges of CASE studentships, projects funded directly by industry, etc. Appraisals are based on written statements of progress from the student and the supervisor, plus draft thesis chapters or papers and a short presentation. The panel also provides the student with an opportunity to raise concerns about supervision. Appraisal panels provide written feedback focussing on progress towards on-time completion and any additional support or training that may be required. All panel reports are reviewed by the Associate Director for Postgraduate Research who may take further action if required, for example follow up meetings with the student and/or supervisor. Student engagement with these new support and appraisal systems has been high and feedback from the students is excellent. The fraction of students submitting within 4 years has increased substantially over the REF period (95% for those completing their PhDs during 2012-13).

D. INCOME, INFRASTRUCTURE AND FACILITIES

LEC's research income (REF 4b) during the REF period averaged £5.51M per annum (£27.56M for 2008-11) compared with £3.1M per annum for RAE2008, an increase in annual research income of 73%. Our funding sources are increasingly diverse and have supported not only high-quality original research but also its translation into significant impacts.

Total income/spend from RCUK was £14.88, comprising £7.67M from NERC, £4.11M from EPSRC, £2.11M from BBSRC, and £0.83M from ESRC. As well as numerous individual successes supporting a range of high-quality outputs, we have won significant RCUK funding to implement our strategic objective of strengthening our research collaborations (see Section B). The EPSRC China Bridge project "Human Impact on water availability and quality: Natural environments domestic use and food production" (Davies 2009-12: £1.3M) has been critical to growing and deepening our collaborations in China (see Section E). Similarly, our collaborations in Brazil are strongly enhanced by the LEC-led (Barlow) research consortium of 5 UK and 4 Brazilian organisations supported by the £3.6M NERC/FASEP award (ECOFOR: Biodiversity & Ecosystem Functioning in degraded & recovering Amazonian and Atlantic Forests: 2013-). RCUK funding also supported the productive collaborations between LEC staff and researchers in other Lancaster departments, including the EPSRC "Understanding walking and cycling" project (2008-11: £0.96M) and the RCUK/EDF DEMAND centre (Walker 2012-16: total value £7.1M).

Our total research income from UK government over the REF period has been £6.92M. Of this total, £5.2M was from Defra, with the remainder from a range of sources including the Department for Communities & Local Government, Environment Agency and Agriculture & Horticulture Development Board. This government funding has helped us meet our strategic objective of delivering impact from our research through effective interfaces with research users, e.g. the River Eden Catchment Consortium (£1.2M), is a LEC-led (Haygarth) consortium of 12 partners testing measures to reduce diffuse pollution from agriculture.

Our Enterprise and Business partnerships team has been instrumental in aiding our research staff to win funding for research in collaboration with commercial end-users, including three Knowledge Transfer Partnerships (total value £487k). During the REF period, LEC won £0.67M in direct research funding from industry, commerce & public corporations, supporting ~45 research projects with 70 companies ranging from Waitrose, Unilever, and United Utilities, to approximately 40 SMEs. Although not research income *per se*, funding from the European Regional Development Fund (ERDF: £18.5M) also provided support for research collaborations across 7 major projects with more than 900 commercial enterprises (also see Impact statement).

EU funding for LEC research during the REF period was £2.9M, and this has supported 17

consortial projects and the Integrated Training Network iTECC. International funding from outside the EU totalled £0.66M including significant funding from Brazil, USA, and Australia.

We do not make extensive use of **consultancies and or professional services** as major elements in our departmental funding strategy. However, professional services such as targeted training for research users have indirect benefits in building and sustaining research relationships. Resource from BBSRC (£50k) and NWDA (£85k) supported the development of professional training modules in 'Plant Science for Industry' and 'Energy and Fuels from Waste'. A total of 48 training days for in excess of 150 individual companies have been delivered over the REF period.

Looking ahead, our future research strategy is consistent with plans for increasing research funding by making effective use of a diversity of funding sources, which we believe is necessary to sustain a robust income stream in the medium-long term. Our network of collaborations is one significant element to broaden the spread of funding, including the EU Horizon2020 programme and international funding from outside the EU.

The research vitality that comes from the recruitment of high-quality new staff is a strong foundation for securing competitive research funding for world-class research. Our support for new staff (Section C) emphasises helping them to early successes with grant applications. It is a departmental priority to improve our mechanisms for supporting all our researchers in making successful applications, especially to RCUK. We have introduced a more managed approach to applications, especially for large-scale collaborative projects, offering greater support to staff preparing large scale bids. We complement University and Faculty research administration through a LEC administrative post dedicated to research support. Our Enterprise and Business Partnership team, embedded within our unique environmental innovation hub (see Impact template) will continue to provide targeted assistance in winning funding with our research users and in meeting funders' expectations of world-class, innovative research combined with genuine impacts.

We are aware of the risk of reduced funding from UK government, notably Defra. We are working to (a) secure our position as partners of choice under Defra's new Evidence and Investment Strategy and (b) broaden our funding base in areas currently supported by Defra, notably through the EU Horizon2020 programme. Horizon2020 has priorities that include "closing the research and innovation divide", "boosting industry engagement through partnerships" and ensuring that "....European researchers are able to collaborate worldwide with the best in the field". These priorities, and many of Horizon 2020's specific research topics, map closely on to our departmental research strategy and we will support our staff in making full use of this opportunity, drawing on the expertise of our EBP team, and links with commercial and international partners.

We recognize that levering non-EU funding to support our research brings its own challenges. For example, such funding may support key elements of our research without appearing directly as research income to the department. We have reviewed these challenges in planning the development of our research campus with CAS in Guangzhou (see below) and our priority remains the delivery of the best quality science, not simply directly attributable income.

The department's programme of investment in our specialist infrastructure and facilities is fundamental to the sustainability of our research. In the REF period we have invested c. £2.3M in improving our core infrastructure. We have also invested over £1M in specialist equipment and facilities, working closely with our research partners to develop shared facilities to maximise the efficient use of high-value research resources.

Following the investment of £25M in new LEC infrastructure during the RAE2008 period (delivering c. 4,500m^2 of new space), during the REF2014 period we have invested a further £2.3M in new or fully refurbished research space to ensure that our estate and facilities meet our current and future research needs, in terms of high quality space to house both facilities and research staff.

Our research strategy (see Section B) has informed directed investment in new equipment to enhance the vitality of key research areas by ensuring access to a comprehensive suite of up-to-date facilities. As described below, much of that investment has been within LEC itself, but our network of strategic research partnership is providing new opportunities. We have further developed our use of shared facilities with CEH and have signed a reciprocal agreement with our partners in CAS to share facilities, giving LEC staff direct access to a significantly increased range of state-of-the-art facilities, notably at the Guangzhou Institute of Geochemistry (GIG-CAS). GIG-CAS includes two State Key Laboratories (Organic Geochemistry and Isotope Geochronology &

Geochemistry) which are amongst the best resourced in the world, with instrumentation with a total value of ~200M Chinese Yuan (~£20M) in 2012. Clear and effective collaboration and planning with CEH and BGS, including shared laboratory and equipment resources are ensured by formal links between senior LEC staff (Binley, Heathwaite, Jones) and the senior management structures of CEH and BGS.

We have optimised the relationship between staffing and our physical infrastructure/facilities, with the complete re-structuring of our team of 20 core-funded research technicians, to create a single integrated team, managed by the departmental superintendent (who sits on the Management Group) to match departmental priorities. This revised technical structure is central to the sustainability and vitality of LEC's research, providing the essential continuity of expertise and a framework to support the activities of researchers, PGRs and fixed-term technicians.

To develop a research focus on stable isotope chemistry that connects Earth Sciences and Environmental Chemistry, and building on the appointment of Holland and Zhou (Section C), we invested £350k in a state-of-the-art multi-collector noble gas mass spectrometer. Our stable isotope facility is a shared facility with CEH, and is run jointly by a dedicated LEC research technician and CEH staff, so investment here further strengthens the LEC-CEH collaboration.

Innovative research at the interface between environmental chemistry and ecotoxicology has been supported by a £300k investment in a Fourier-transform infra-red (FT-IR) microscope, two attenuated total reflection FTIR microscopes, a Raman InVia microscope and an atomic force microscope. We support this facility through a dedicated departmental research technician (1 FTE). We are seeing unexpected returns on this investment, for example its growing use by our plant biologists and by external research partners. Facilities for environmental chemistry have also been enhanced by the completion of a new suite of laboratories (108m^2 in total) dedicated to high-resolution mass spectrometry for environmental chemistry, and which also houses new analytical instruments, including two LC-MS instruments provided by one of our key commercial partners, Unilever plc. The two instruments (with total purchase costs of approx. £350k) will increase the sensitivity in our capacity for trace analysis of environmental samples by 2 orders of magnitude.

Our life-science research and its interaction with elements of hydrology and soil science have benefitted from investment in the sustainability of the new growth facilities established during the RAE period. We have invested c. £310k in successive up-grades and an additional £96k in new field facilities for plant research. This range of new growth facilities is complemented by new instruments such as a LiCOR LI-6400XT infra-red gas exchange instrument (£40k). These facilities are supported by a dedicated technician. We have also refurbished our animal ecology spaces to provide purpose-built space for invertebrate biology included rooms that are Defra-licenced for using non-native insects, facilitating Wilson's research on armyworms (*Spodoptera* spp) with collaborators in sub-Saharan Africa. For work with vertebrates, we have developed a new 630m^2 Defra-licensed physiological services unit, shared with the School of Health and Medicine, supported by a dedicated technician. The appointment of Ostle brings closer links and sharing of laboratories with CEH for soil-plant ecology and C cycling, and new investment of £200k in gas flux measurement/analysis equipment.

We have also recognized that "front-line" research facilities need to be matched by first-rate support facilities, and invested £190k in refurbishing our departmental electronics workshop, and stores/distribution centre. We have provided new or refurbished office space for PGRs and researchers. All our PGRs now occupy communal offices housing individual work stations which are fully equipped, including a dedicated PC, provided new at the start of all projects.

Looking ahead, we recognize the need to continue to up-date our core research infrastructure, consistent with our forward strategy. Our strategic objective is to move towards the main body of our estate being dedicated wholly to high-quality refurbished research space, and in 2013-14 £4M is being invested to re-locate LEC's teaching laboratories as the first step in meeting this objective. We will continue with our rolling-programme of refurbishment, with the goal of completing the process for all of LEC's estate in the next five years. Investment in specialised research equipment and facilities will continue to be a balance between our own internal investment and that made in collaboration with our strategic research partners.

As well as these important incremental investments in facilities, a major strategic investment will be in establishing a joint research campus with the Chinese Academy of Sciences, building on the International Research and Innovation Centre for the Environment (I-RICE: see Section E). As of

31 October 2013, we have (i) agreed this joint development in principle, (ii) agreed the location in Guangzhou province (Nansha), and (iii) agreed joint funding by Lancaster University and the Chinese government. I-RICE will co-locate CAS and Lancaster staff to deliver international research projects, with a particular focus on the 'global challenges' of improved environmental (air, water, soil) quality; better understanding and improvements in environment and health; improved environmental pollution control, environmental engineering/technology, eco-innovation; environment and policy; and improved natural resource management. It is intended as a platform where other strategic partners will also be welcome to establish a base, to create a truly international, state-of-the art, well-resourced, collaborative, research environment.

E. COLLABORATION OR CONTRIBUTION TO THE DISCIPLINE OR RESEARCH BASE

National or international research collaborations, with academic, industry and other bodies are central to our research strategy. We have emphasised the role of such collaborations throughout all sections of this environment statement. To summarise, during the REF period we have significantly strengthened our global network of research collaborations. Our links with China have developed strongly. We have appointed an International Partnerships Manager (Dr Hong Li) with specific responsibility for facilitating LEC's role at the heart of UK-China collaborations in environmental research. The especially successful links with Chinese Academy of Science (CAS) resulted in the establishment of the International Research and Innovation Centre for the Environment (I-RICE). To date, I-RICE has already resulted in one joint appointment with CAS (Zhou Zhang: with more agreed) and a formal agreement to share facilities. It will grow into a joint LEC-CAS research campus in Guangzhou (Section D). In Brazil we have an effective relationship with the Federal University of Lavras, Brazil, primarily through the joint PhD programme (see Section C), and our Brazilian collaborations are being significantly extended through initiatives, such as Barlow's £3.6M NERC/FASEP award (2013-). Lancaster's new campus in Ghana will provide a focus for collaborations in sub-Saharan Africa, including the six West African universities with which we have developed and signed formal memoranda of understanding.

Within the UK, LEC leads (i) the ERDF-funded Centre for Global Eco-innovation (CGE), a joint-venture with the University of Liverpool which in turn supports a network of collaborations with more than 200 SMEs, including 50 environment-focussed PhD projects and (ii) the ENVISION consortium (Nottingham, Bangor, CEH, BGS and Rothamsted) securing 12 PhD studentships per year over five years (see Section C). Another new development is the collaboration with the British Geological Survey (BGS), formalised in a joint appointment tasked with fully developing research synergies between LEC and BGS, especially in the area of sub-surface processes/earth resources (Kampman). These roles will provide access for a large number of staff to a wide range of BGS instrumentation, in effect broadening our instrumentation base relevant to shared ambitions in research areas, including stable isotopes, noble gases, organic geochemistry and isotope geochemistry. More recently we have signed a MoU with Rothamsted Research as the starting point to build on our common interests in plant science, soil science and agroecology. LEC's long-standing collaboration with the Environment Agency (EA) continues, with Prof. Roger Timmis, EA's national Air Science Manager (and National LEC-EA liaison officer), based in the Department throughout the REF period. LEC-EA links focus especially on contaminant transport; diffuse pollution; novel sampling techniques and air pollution data interpretation methodologies, and led to eleven joint LEC-EA papers during the REF period. We have a new (June 2013) Regional Strategic Alliance with the EA and the new EA Partnerships Manager post (Maddocks) created to support this activity will be based in LEC. Our collaboration with CEH remains central to our network of collaborations. This now includes productive research partnerships in aquatic ecology, water sciences, Earth sciences, environmental chemistry, ecotoxicology, plant sciences, atmospheric science, soil ecology and carbon sequestration. CEH's own data highlights £7.0M in joint research income since 2008, 11 co-supervised PhDs and 75 joint publications with Lancaster since 2010. The growing vitality of our research collaboration with CEH is reflected in the joint appointment of Sweetman to champion its further development.

LEC has taken the lead in maximising the synergy between different aspects of our collaborations to further widen research benefits, for example our strong academic links in China support the needs of UK and Chinese business (e.g. through the HEFCE Catalyst project).

Research collaborations with research users, including industry users, are one of the basic foundations of our research activities and strategy. The percentage of staff with active

research collaborations with end-users has increased from 50% of our Category A staff at RAE2008 to over 85% (also see Impact Statement). Our network of collaborations with research users is supported by our EBP team which provides an expert focal point for dialogue with industrial/commercial end-users. Our departmental Strategic Business Advisory Board, established in 2009, provides "high-level" input from external stakeholder organisations and over the REF period has included senior staff from CEH, Waitrose, United Utilities, Unilever, Technology Strategy Board and UKTI. The steering group's input into shaping our research strategy complements inputs from LEC staff with high-level involvement in the research strategy, notably Heathwaite who is Chief Scientific Advisor (Rural and Environment) to the Scottish Government.

Interdisciplinary research is a central tenet of LEC's research strategy and of the department's approach to delivering innovative research in relation of global environmental challenges (Section B). For us, interdisciplinary research includes effective collaboration between different elements of the natural sciences as well as between natural and social sciences. **Support for inter-disciplinary research** is embedded in our staffing strategy (Section C), the establishment of cross-cutting research actions that stimulate and support inter-disciplinary research (Section B), the strategic decision during refurbishment to establish "discipline-neutral" office spaces for researchers and PGRs (Section D), and LEC's role in providing "inter-disciplinary bridges" in many of our collaborations (Section E). The success of the department's support for interdisciplinary approaches over the REF period is evident in the progressive increase in research that bridges disciplinary boundaries, for example c. 17% of the research outputs submitted to REF, and c. 30% of PhDs projects starting in 2012-13.

Our support for inter-disciplinary research has contributed to the vitality of research evident in the lead taken by younger staff in leading exciting initiatives. For example the collaboration between Vermeylen and Wilson combines research in environmental law and plant-insect ecology to deliver integrated insights into food security in sub-Saharan Africa. Similarly, the interaction between Barlow, Parry, Vermeylen and Ellis is developing a "joined-up" approach to the complex interface between conservation, and the socio-economic development of local communities in South America, and we have targeted new appointments to enhance this area for the future.

Our staff are active leaders in the academic community and beyond throughout the REF period. The following overview summarises both the extent of such contributions and highlights some of the most notable examples.

- 42 staff have been members of national or international advisory boards including; Office of Technology Assessment at the German Bundestag (Beisel); Science and Industry Board for East Malling Research (Davies); CEH Advisory Group (Jones); International Advisory Group of the Chinese Academy of Sciences (Jones); Irish Environmental Protection Agency (Quinton); JRF 'Climate Change and Social Justice Programme' Advisory Board (Walker).
- More than 40 LEC staff have undertaken leadership roles in a variety of external organisations including research Councils (Heathwaite is member of NERC council; led NERC's Sustainable Use of Natural Resources Theme, and is Panel Chair for Resource Security under NERC Science Strategy), Binley, Wilson and Quinton are NERC panel members; government or government departments (Heathwaite is Chief Scientific Adviser, Rural and Environment, Scottish Government and an invited Member of Defra's Science Advisory Council), international bodies (Paul is co-chair of the Environmental Effects Assessment panel of the Montreal protocol; Quinton was part of the UK delegation to the UN FAO Global Soil Partnership), and learned societies (Davies was a member of the Royal Society Policy Group which produced 'Reaping the Benefits: science for the sustainable intensification of global agriculture'). Maher is a REF panel member for UoA17.
- More than 50 staff have been involved in peer review of research funding proposals, including Austria, China, Ireland, Finland, the Netherlands, Norway, Sweden, Romania and the USA.
- Of the many invited contributions by LEC staff at international conferences 39 were keynote lectures. 25 staff are members of the editorial boards of international journals.
- Davies was awarded a CBE for services to Science in 2011. Beven won the 2013 President's Prize from the British Hydrological Society. Binley was elected Fellow of the American Geophysical Union, Haygarth was elected President of the British Society for Soil Science, Heathwaite elected Vice President of the International Association of Hydrological Sciences.