Institution: The University of Leeds (UoL)

Unit of Assessment: UoA5 Biological Sciences

a. Overview

Building on our excellent fundamental, applied and interdisciplinary research strengths as identified in RAE2008, we introduced several strategic changes to consolidate and improve our research performance yet further. We expanded the collaborative and translational research links of four large research groups described in RAE 2008 (**Structural Molecular Biology** - 19 returnees**, Integrative Membrane Biology** - 12 returnees**, Plant Science** - 9 returnees**, Ecology and Evolution** - 16 returnees). Two further research groups (**Virology** - 7 returnees, and **Medical Engineering** - 4 returnees) have been developed through expanding long-standing activities in these areas. Intensification of our interdisciplinary research has resulted in more staff (23) of the Faculty of Biological Sciences (FBS) being returned in other UoAs (e.g. Cardiovascular, Sport and Exercise Sciences in UoA26 and Neuroscience in UoA4) than before and consequently fewer in this return than in RAE2008 UoA14. This UoA comprises only members of FBS. Since 2008, these changes have enhanced the diversity of biological disciplines within the Faculty, and increased interdisciplinary research with a greater focus on global grand challenges in biomedicine, health and sustainable agriculture. Increased alignment of basic science with translational mechanisms has facilitated outputs with a wide range of impacts particularly on health, public policy, the environment, commerce and international development. In the assessment period, we have invested >£20M in our research environment infrastructure and facilities. Staff of all research groups are now located within contiguous research space, the vast majority of which has been extensively refurbished. Research facilities have been further developed under the control of nine dedicated facility managers. This has provided a state-of-the-art research environment, underpinned by managerial expertise, which maximises efficiency of use and cross-fertilisation of techniques.

Selected highlights

Research highlights include (i) development of a model for dynein ATPases's structure and kinetic action (SB#2), (ii) elucidation of structures of ion-coupled transporters and the vacuolar ATPase complex, providing new insights into the (patho-)physiological basis of human diseases associated with membrane proteins (PH#1), (iii) novel structural models for amyloidogenic protein folding that help us to understand conformational conversion and fibrillar aggregation (SR#1), (iv) elucidation of the key role of carbohydrate-binding modules in the recycling of cell walls, the most abundant source of organic carbon in the biosphere (PKx#1), (v) use of a free-living population of Soay sheep to demonstrate the dominant role of ecological processes in generating phenotypic change (TB#3), (vi) identification of the inhibition of AMP-activated kinase (AMPK) as a requirement for hepatitis C virus (HCV) replication, which provides a potential target for anti-HCV therapies (MH#2), and (vii) the award of the *Queen's Anniversary Prize* 2012 to the *Institute of Medical and Biological Engineering (iMBE)* in recognition of innovative tissue engineering technology for the treatment of cardiovascular and musculoskeletal disease, and of the *Women of Outstanding Achievement Annual Award* to the iMBE Deputy Director, Professor Eileen Ingham**.**

b. Research strategy

In RAE2008 we described how interdisciplinary research was central to our research strategy. We have since harnessed this interdisciplinarity to apply our strengths in fundamental biological research to grand challenge areas in biomedicine and health and sustainable agriculture. Research in translational biomedicine is undertaken by staff associated with the **Structural Molecular Biology, Integrative Membrane Biology, Virology** and **Medical Engineering** groups. Sustainable agriculture challenges are addressed by the **Plant Science** and **Ecology and Evolution** groups. Each returnee has primary affiliation to one research group, but strong associations with other groups. In addition, to achieve maximum benefit from the opportunities and resources available across this large, single campus university (1270 FTE returned in RAE2008), these groups link to cross-faculty research structures. This promotes our interdisciplinary ethos and allows the Faculty to play a pivotal role in both University and external collaborations. Examples of these are given by group below together with some highlight achievements in basic and applied research. Our increasingly collaborative ethos is also shown by increases in proportions of outputs with other Leeds UoAs since 2008 (16% cf 9%), with other UK institutions

(46% cf 33%) and involving international authors (47% cf 40%). It is our intention to further strengthen such interdisciplinarity in the next REF period. We will progress research within interdisciplinary clusters assembled from our existing groups and cross-faculty centres to bring together the wide array of skills required to address biological questions of importance to society.

Structural Molecular Biology (SMB); Leader: Prof Sheena Radford (**SR**) **(Director, Astbury Centre for Structural Molecular Biology (ACSMB)); Group members:** Prof Alison Ashcroft (**AA**), Prof Alan Berry (**ABe**), Dr Joan Boyes (**JB**), Dr David Brockwell (**DB**)**,** Dr Stan Burgess (**SB**), Dr Thomas Edwards (**TE**), Dr Eric Hewitt (**EH**), Prof Peter Knight (**PK**), Dr Sergei Krivov (**SK**), Dr Kenny McDowall (**KMD**), Dr Alex O'Neill (**AO**), Dr Arwen Pearson (**AP**), Prof Michelle Peckham (**MP**), Dr Anthony Roberts (**AR**), Dr Martin Stacey (**MS**), Prof Peter Stockley (**PS**), Prof David Westhead (**DW**), Dr Anastasia Zhuravleva (**AZ**). (£707K/Whole Time Equivalent (WTE) income in REF period).
Members of SMB form a buoyant, collegiate and innovative component of the cross-faculty interdisciplinary ACSMB team, linked by common aims and objectives: to exploit the full repertoire of biochemical and biophysical methods, and to develop new techniques and approaches, that will enable the fundamental mechanisms of key molecular processes of life to be dissected and understood in full atom detail. The integration of all major structure determination technologies with single molecule experiments, high-throughput approaches and computation allows our staff to make significant contributions to understanding of biomolecular function (EH#2, SR#3, AR#1). Collaboration is common practice between group members with common research interests (virus assembly, protein folding and misfolding, muscle and motors, novel antibiotics, protein-RNA interactions, molecular immunology) or common/new research techniques (X-ray crystallography, electron microscopy, single molecule biophysics, molecular simulation, NMR, mass spectrometry (MS)). Strong links also exist with members of other groups within the UOA (particularly Virology and Integrative Membrane Biology) and members of other UoAs (chemical biology (UoA 8) and biological physics (UoA 9)) as evidenced by publication outputs. Group members are also exploiting and developing new technologies to enable insights into biological mechanisms that are not possible using traditional approaches. Recent highlights include major grant funding from the Wellcome Trust (Programme grant (SR), equipment grant of £630K for X-ray diffraction (PS)), Human Frontiers Science Programme (SB & SR), ERC Advanced Grant (SR) and BBSRC LOLA grants (SR/DB, DW) for studies of protein misfolding and disease, membrane protein folding, virus assembly, RNA packaging, and protein transport, catalysis and their function as molecular machines. Research of this group features regularly in high impact journals. Examples include discovery of the molecular mechanism of dynein motion (SB#2), outer membrane protein folding (DB#2), and conformational changes that govern protein aggregation (SR#1) and chaperone (hsp70) action (AZ#1). The group also hosts a Wellcome Trust 4 year PhD in "The Molecular Basis of Biological Mechanisms" which has recruited 30 UK and international students over the REF period and was renewed in 2013. Evidence of translational research expertise and output is also provided by involvement in two Impact Case studies (CS3, CS5).
Future emphasis will build on existing strengths including the further development and application of complementary methods (single molecule force/fluorescence, MS, NMR, X-ray, chemical biology, computational biology and cell biological approaches). These will be used to unpick the molecular mechanisms of virus assembly and genome packaging, to determine the specificity of protein-protein interactions in protein recognition, protein folding and misfolding disease, to analyse how force generation is utilised in transport, and to evaluate how protein-ligand interactions can be targeted and developed. The common over-riding goal is to define biological processes in the context of networks of dynamic ensembles of interacting species in all atom detail and to exploit this knowledge to control these processes for medical (CS3) or biotechnological (CS5) gain.

Integrative Membrane Biology (IMB); Leader: Prof Asipu Sivaprasadarao (AS); Group members: Dr Susan Deuchars (**SD**); Dr James Duce (**JD**), Prof Adrian Goldman (**AG**), Prof Peter Henderson (**PH**), Prof Nigel Hooper (**NH**), Prof Elwyn Isaac (**EIs**), Dr Lars Jeuken (**LJ**), Dr Lin-Hua Jiang (**L-HJ**), Dr Jonathan Lippiat (**JL**), Dr Stephen Muench (**SM**), Prof Anthony Turner (**AT**). (£550K/WTE income in REF period).
The overarching aim of the IMB group is to understand the structural, biophysical, cellular and physiological basis for how membrane proteins function in health and disease. Research of this

group features regularly in high impact journals. Notable examples include elucidation of the structural basis for function of transporters (PH#1, PH#2) and pumps (AG#1, SM#1), key insights into (patho-)physiological roles of β-amyloid precursor protein (JD#1, AT#1, JD#2), prion protein (AT#3, NH#2,#3), ion channels (AS#2, JL#2) and receptors (AG#3), and use of model membrane electrodes to probe catalytic mechanisms (LJ#2, LJ#4). Underpinning these key achievements is major grant funding from competitive sources, including MRC (NH, AT, AS), BBSRC (PH, JL, SD), EU (AG, PH, LJ), Wellcome Trust (AS, SD, L-HJ) and BHF (AS, SD). Four members of this group were awarded prestigious fellowships (MRC, SM; Alzheimer's Research UK, JD; ERC, LJ; Wolfson, AG). The group fosters interdisciplinary research as evident from the publications. There are strong links with groups within the University and in particular with ACSMB, as well as with other world class universities and industries (e.g. Oxford (PH#1, JL#2), Harvard (JD#1), Toronto (AG#2), Tokyo (EIs#1), Zhejiang (L-HJ#2), Illinois (AS#4) and GSK (NH#1)). An MoU has recently been signed between Leeds and Nankai (China) Universities to promote collaborative research between IMB and the world-leading structural biology group in Nankai.

Looking ahead our group will continue to solve the structures of key membrane proteins and elucidate the cellular and molecular basis of diseases associated with membrane proteins. We will develop and apply new methodologies (e.g. single molecule biophysics approaches, molecular dynamics simulations, super resolution microscopy, native MS, solid-state NMR). Over the next five years, there will be increased focus on translational research. Members of IMB have recently formed a new group with colleagues in the Faculty of Maths and Physical Sciences (MAPS) which, under the umbrella of the university-wide Pharmaceutical and Biopharmaceutical innovation hub, will drive forward research into novel therapeutics (chemical and biological), diagnostics and biosensors to address problems in the grand challenge area of biomedicine and health, e.g. Alzheimer's disease, other neurodegenerative diseases and channelopathies.

Plant Science; Leader: Prof Paul Knox (PKx); Group members: Prof Alison Baker (**AB**), Dr Yoselin Benitez-Alfonso (**YB-A**), Dr Andrew Cuming (**AC**), Prof Brendan Davies (**BD**), Prof Jürgen Denecke (**JDe**), Prof Christine Foyer (**CF**), Dr Stefan Kepinski (**SKp**), Prof Peter Urwin (**PU**). (£923K/WTE income in REF period).

Members of the Plant Science group work on both fundamental and applied aspects of molecular plant sciences, using a range of model systems through to crop plants, extending its reach to sustainable agriculture. Expertise and research strengths include cell and developmental biology (AB, BD, JDe, PKx), genome structure and regulation (AC) and regulatory plant physiology (CF, SKp). Research highlights include dissection of auxin responses (SKp#1,#3), regulation of intercellular transport (YB-A#1), molecular machineries of cell wall deconstruction (PKx#1,#4), and diverse aspects of plant gene regulation and metabolism (CF#1, AB#1). Internationality is a key facet of activity in Plant Science and staff contribute to >10 current EU consortia/programmes including leadership of the SYSFLO (Marie Curie ITN in floral development, BD) programme. Responsiveness to initiatives and capacity to interact internationally is further evidenced from the successful India Bridges Programme to promote Anglo-Indian Food Security that involves links with the Indian Institute of Science (IISC) and the Indian Agricultural Research Institute (IARI; BD, SKp, PU) and the securing of BBSRC Japan Partnering (AB) and BBSRC US Partnering (SKp) awards. Interdisciplinary links and engagement with the global challenge of food security has been extended by the recruitment of CF, a world expert on oxidative stress physiology who leads the University translational science initiative on Human Health & Food Security in Sub-Saharan Africa (Africa College). Influence extends through to stakeholders including food and agriculture industries and also government departments through membership of the BBSRC Food Forum (CF). The group's research outreach and impact activity is also promoted by the initiation and hosting of the Gatsby Plants Summer School project (£1.6M investment from the Gatsby Charitable Foundation) that brings together high-achieving UK undergraduates with research leaders to foster interest in plant science.

Near and mid-term initiatives within Plant Science will further extend our fundamental plant science into the areas of plant-related biotechnologies and sustainable agriculture/food production. In these contexts, the research group is already well positioned to lead in areas including crop defences against nematodes (CS2), stress responses and plant genetics and also to lead with its strengths in plant cell biology that will underpin both improved crop growth and crop products.

Ecology and Evolution (E&E); Leader: Prof William Kunin (WK); Group members: Prof Tim Benton (**TB**), Dr Amanda Bretman (**ABr**), Dr Steven Compton (**SC**), Dr Alison Dunn (**AD**), Dr Sophie Evison (**SE**), Dr Simon Goodman (**SG**), Dr John Grahame (**JG**), Prof Keith Hamer (**KH**), Dr Chris Hassall (**CH**), Prof Jens Krause (**JK**), Dr Glenn McConkey (**GMC**), Dr Andrew Peel (**APe**), Dr Steven Sait (**SS**), Dr Ryan Seipke (**RS**) and Dr Sarah Zylinski (**SZ**). (£455K/WTE income in REF period).

The E&E group forms a diverse but tightly interlinked group of researchers. Their work addresses the millennium challenges of global food security (e.g. SS#4) and adaptation to environmental change (e.g. KH#2), providing both fundamental and applied research on the maintenance, adaptation and management of populations and ecosystem services in a world of increasing human demands. We have documented the biodiversity consequences of agricultural management patterns (SS#1, WK#1), spatial foraging strategies in colonial seabirds (KH#1), the selective basis for imperfect mimicry (CH#1), the roles of ecological and evolutionary forces in wild mammal (TB#3) and insect (ABr#1) populations, the developmental processes governing insect segmentation (APe#1), and the role of climate change in extinctions (TB#2). Group members gained grants from a wide range of sources, including NERC (AD, TB, KH, WK, SS, JG, JK), BBSRC (TB, ABr, AD, SS), Living with Environmental Change partnership (WK), RELU (TB, SS, WK), Darwin Initiative (KH), the EU (WK, TB, KH), charities (KH), industry (AD) and overseas funders (e.g. AGIP, SG). The group has been further strengthened by key appointments (ABr, CH, APe, SZ), and has recently relocated into newly-renovated office and laboratory space with invertebrate rearing facilities. It now has excellent molecular facilities to meet the considerable need for such approaches in its research. The research group has 10 collaborative research projects in the REF period, shared studentships, formal and informal group meetings, and a long-standing E&E seminar series fostering research links.

Many members of the team (e.g. TB, KH, AD) have close ties to the conservation and policy communities at a regional, national and international level. National ongoing research links include Fera (WK), Yorkshire Dales National Park (AD) and national policy-makers (TB). Other policy-relevant research in the group addresses biodiversity impacts of tropical forest and fisheries management (both KH) and the impacts of invasive alien invertebrates and diseases (AD). Many of our research findings have garnered substantial public attention, with 100s of UK and global press stories covering WK's research on wild pollinator declines, research on Galapagos mosquitoes (CS6) and work by TB linking rapid climate change with past extinctions. The group has taken a prominent role in food security and agri-environmental research, focusing on the challenge of reconciling agricultural production with biodiversity conservation and ecosystem service provision (CS7). This work has ranged from field assessments of biodiversity and crop production under alternative management (TB, SS), through national assays of services (WK) to national leadership roles (e.g. TB is the UK Global Food Security champion). Planned development of research facilities at the University's farm in collaboration with White Rose partners underpins the strengthening of our food and ecosystem service research. The relocation of the School of Geography to adjoining space will enhance our existing links to cognate scientists there. These steps will help to further increase the international reputation of the group so assisting continued recruitment and retention of world-class researchers.

Virology; Leader: Prof Mark Harris (MH); Group members: Dr Andrew Macdonald (**AM**), Dr Jamel Mankouri (**JM**), Prof David Rowlands (**DR**), Dr Nicola Stonehouse (**NS**), Dr Andrew Tuplin (**ATu**), Prof Adrian Whitehouse (**AW**). (£721K/WTE income in REF period).

The Virology group comprises researchers with a common goal to understand the molecular basis of replication and pathogenesis of important human and animal viruses and to use this knowledge to foster the development of therapeutic strategies. Notable achievements of the group include identification of virus-host interactions implicated in pathogenesis and persistence of HCV (MH#2, JM#1), key insights into reactivation of Kaposi's sarcoma herpesvirus (AW#2) and identification of the ion channel activity of the human papillomavirus (HPV) E5 protein (AM#2). The group occupies contiguous, high quality space which has facilitated a vibrant collaborative research environment. This has been underpinned by major grant funding for HCV research from Wellcome Trust (MH - Senior Investigator), for poliovirus and foot-and mouth disease (FMDV) research from the Gates Foundation (DR, NS), BBSRC sLOLA (NS, DR in collaboration with St Andrews and other

institutions) and EU FF7 (NS, DR), and a Royal Society Fellowship for studies of virus interactions with host cell ion channels (JM). Group members regularly publish in high impact journals, e.g. PNAS (MH#2, JM#1), PLoS Pathogens (AM#1,#3, AW#2-4), Nature Medicine (DR#2) and J Virology (NS#1,#2, AM#2). There are strong links to the SMB group, some of whom (e.g. TE) have active interests in studying virus structure (TE#3,#4). Links with IMB have fostered new research into the role of ion channels in virus function (JM, MH). Group members have established interdisciplinary collaborations both within Leeds and elsewhere. The latter encompass both academic (e.g. MH with University of Dundee) and industry/government agencies (e.g. NS/DR with the Pirbright Institute, iQur, Okapi Sciences).
Looking to the next five years, the group will build on these achievements in two specific areas – first, through collaborations with the SMB group to exploit advances in bioimaging and proteomics technology in order to better understand the structure, composition and function of the macromolecular complexes involved in virus replication. A specific example is the use of super-resolution microscopy to interrogate the HCV genome replication complex (MH/MP). Second, to pursue new strategies for the prevention and therapy of viral infections. Specifically, via the design and evaluation of novel vaccine strategies exemplified by major grant funding for poliovirus and FMDV (NS, DR: Gates and BBSRC), and a rational approach to development of new small molecule antivirals utilising structure-based drug design as a platform (MH, AM, AW in collaboration with Fishwick (MAPS)). The latter is exemplified by the development of inhibitors of HCV NS2 and human papillomavirus E5, which we expect to advance to a preclinical stage within the next 5 years.

Medical Engineering (MedEng); Leader: Prof Eileen Ingham (**EI**)**; Group members:** Prof Mike McPherson (**MMP**), Prof Paul Millner (**PM**), Dr Stacy-Paul Wilshaw (**SW**). (£1.4M/WTE income in REF period).
The MedEng group aims to deliver an innovation culture with a blend of goal orientated exploratory research, translation and training, integrating academia, industry and NHS at all levels of technology readiness from knowledge creation and discovery to market introduction. Over the assessment period a larger group of researchers in FBS engaged in Medical Engineering has emerged, strategically aligned through joint participation in successful bids for major initiatives with a combined income in excess of £40 million led by the interdisciplinary research institute of Medical and Biological Engineering (iMBE Deputy Director EI): The Wellcome Trust-EPSRC Centre of Excellence in Medical Engineering "WELMEC" (Deputy Director EI; MMP, PM, SW members), the Innovation and Knowledge Centre in Medical Technologies funded by EPSRC, BBSRC and TSB, as part of a £50 million research initiative "50 active years after 50" (Executive Group member EI; member SW), the NIHR funded Leeds Musculoskeletal Biomedical Research Centre (LMBRU; leader of Biomaterials and Regenerative Interventions group EI) and the Biomedical Health Research Centre (BHRC), a £13M investment by the University of Leeds and Leeds Teaching Hospitals NHS Trust (LTHT; Executive Group member MMP). Notable achievements include research to support the development of new bearing materials with improved functional biocompatibility for longer lasting joint replacements (CS1), further understanding of the biological consequences of exposure to prosthetic wear debris (EI#4), development of novel acellular biological scaffolds for tissue repair and regeneration in the cardiovascular system (EI#3, SW#2) delivered as medical devices (CS4), biological scaffolds for musculoskeletal tissues (CS1; EI#1), novel approaches to the development of biomimetic scaffolds for tissue regeneration based upon a unique class of self-assembling peptides (MMP#1,#3, EI#2), development of parallel and electronic label free biomarker detection and sensors to support stratified interventions in musculoskeletal and cardiovascular disease (PM#1,#2). The BioScreening Technology Group (BSTG; Director MMP) established in November 2010 and funded by the BHRC developed a proprietary Adhiron™ artificial binding protein library (patent applied for) which has been screened against >70 molecular targets to develop scientific tools for research, diagnostics, imaging, drug delivery and therapeutics.
The group's goals for the next five years will be to deliver strategically-focused research to advance the technology readiness of acellular technologies as active regenerative therapies, Adhirons and diagnostic devices (with PM) towards commercialisation and clinical translation.

Development, promotion and dissemination of research: Individual research groups meet at least bi-monthly to discuss strategy and administrative issues. Research groups also hold internal

seminars and journal clubs where junior researchers can receive comment on data and develop presentation skills. We have an internal peer review policy for research grant applications that involves panel review which is conducted through these groups. Weekly seminars from invited external speakers are held through individual School seminar series, funded internally and externally e.g. by Learned Societies. To allow all researchers in FBS to attend, seminars in each School are held on different days.

University wide interactions, providing diverse fora and cross-disciplinary teams, facilitate research development and outputs. For example, staff in IMB, Virology and SMB comprise the ACSMB with chemists and physicists, those in E&E and Plant Science participate in Africa College with Food Science, Geography, Earth and Environment and others, researchers in MedEng work with staff across Mechanical Engineering as well as Medicine and Health. These cross-faculty research units hold seminars, workshops and meetings on a regular basis.

Promotion and dissemination of our research beyond traditional academic routes to the public has been achieved by the University Communications and Press Office and Campus PR, an external communications and external relations company employed specifically by FBS. These provided widespread media coverage (on average 21 releases with several hundred international 'hits' p.a.) including television and radio (e.g. BBC TV and Radio 4), specialist magazines such as New Scientist and national and international press (e.g. Observer, Daily Mail, New York Times, India Times, and The Economist). We organise and participate in regular public engagement initiatives with research talks to the public (e.g. Cafe Scientifique, Ilkley Science Festival, an open lecture series in 2013 sponsored by the Physiological Society). We promote biological sciences to school students with frequent and regular outreach visits to schools (average p.a. >800 school pupils, via 18 workshops with 48 local schools). In addition, >70 academics and researchers from FBS have delivered annually for the past 6 years the 'Discovery Zone', in which around 500 Key Stage 2 & 3 pupils try hands-on science in a tour of science exploration. For the last 9 years we have organised the annual Gatsby Summer School for 100 undergraduates to foster interest in plant sciences. Such activities have received >£1.7M of external funding from sources including the BBSRC, Wellcome Trust, Physiological Society and Alzheimer's Society.

Successful promotion of our research to industry is indicated in impact case studies (CS1, CS3, CS4, CS5). Our Enterprise and Innovation team facilitates and funds visits to industrial partners. We hosted 26 days with industrial partners (e.g. SB with GSK, Astrazeneca). Such events and industrial communication are now being co-ordinated through interdisciplinary Sector Hubs (e.g. Food Security; Pharmaceutical and Biopharmaceutical; Medical Technologies), as part of an investment of £6m of HEIF funding, which provides structures to channel larger scale support for activities with high potential for impact and innovation, and which marry external market demand with our recognised research and innovation strengths. We also promote our science to policy makers (e.g. CS2, CS6 and CS7) and have encouraged staff secondments (e.g. 80% secondment of TB to become UK Champion for Global Food Security in 2011) to enhance these interactions.

c. People, including:

i. Staffing strategy and staff development

In 2009 FBS reviewed current activity and reconfirmed its strategic direction to determine a sustainable academic and financial future. Organisational structures were arranged to facilitate the integration of research and to undertake research with impact. Research of recruited staff aligns with these groups, with 2 Professors, 8 lecturers and 8 Research Fellows joining since RAE 2008 as follows: SMB (2 L, 2 RF), IMB (1 Prof, 2 RF), Plant Science (1 Prof, 1 RF), E&E (5 L, 1 RF), Virology (1 L, 1 RF) and MedEng (1 RF). Recruitment strategy also reflects physical research infrastructure, for instance the recruitment of AZ adds buoyancy to our world class NMR facility, supporting the work of SMB. We have enhanced our research capability by recruiting externally funded research fellows (4) who we mentor through the application process and place with senior mentors in appropriate thematic areas: SM (MRC), JM (Royal Society), JD (Alzheimer's Research UK) and AR (Wellcome Trust). We retain on part-time contracts research active staff beyond retirement to enhance research leadership (4 Profs, 1 Assoc Prof as well as 1 Prof (JK) with strong research and teaching links but who moved abroad). This leads to the 67 staff returned, of whom 28 are Profs, 16 Readers/Associate Profs, 14 Lecturers and 9 Research Fellows. We return 28% staff aged <40y, 28% aged 40-49y, 28% between 50-59y and 15% >60y. Staff in groups are located in close geographic proximity whilst consolidating our refurbished research space to conjoined buildings facilitates interdisciplinarity.

Early career researchers (ECRs) represent 14 staff in the return. Our success in mentoring such staff is indicated by 86% of independent and tenure track research fellows being offered academic posts since 2008. To support their research, they receive start-up funds worth up to £100K to pump prime their research, provide support for travel and enable access to facilities. In addition, for the first three years ECRs receive significant workload remission - in the 1st year they have a teaching and administration load of approximately 33% of an academic staff member. Throughout this probationary period they receive active mentor support from a senior academic staff member, in addition to 6 monthly formal meetings with School support teams. Indeed, we enhanced such support in 2012 by introducing tailored mentorship training as well as clearly separating this role from that of probation advisor.

We will continue to recruit to our research strengths in a sustainable fashion. To ensure sustainability of staff and infrastructure, each School has an academic and financial 5 year plan agreed annually with a top level University team. All positions in these plans are aligned with current research groups. We will also continue to recruit high quality independent externally funded fellows through an annual recruitment exercise as well as targeted recruitment. To cement our interdisciplinary approach we will favour recruitment of those able to enhance collaboration across traditional disciplinary boundaries (e.g. between biology and mathematics, medicine, engineering or environment).

We are fully committed to the Concordat to Support the Career Development of Researchers and adhere to the established University Policy on the Employment of Researchers to implement this approach. There is a Researcher Training and Development Hub (joint with the Faculty of Medicine and Health) with a resourced Skills Training Team of experienced Research Training Officers and staff whose remit is the development of skills training activities for researchers, including those on fixed term contracts. In addition, in 2012 we instigated a pilot scheme where promising junior researchers aligned to our research groups are funded for up to 2 years and mentored to apply for external independent funding (not returned in this UoA).

We will continue to develop and promote existing staff whose achievements assist our research ambitions. Post-probation, all staff are mentored and development facilitated in an annual University-led “Staff Review and Development Scheme” (SRDS) undertaken with trained reviewers. SRDS helps staff achieve their full potential by providing the opportunity for 2-way review of work progress, identifying key objectives, providing constructive feedback, recognising success, providing support for improvement, and identifying and planning appropriate development, as well as allowing discussion of career aspirations. Aligning SRDS outcomes with Faculty requirements is conducted by annual academic meetings between individuals, their Head of School (HoS), Director of Research and Director of Student Education.

To facilitate staff development a wide range of opportunities are available centrally through the Staff and Departmental Development Unit (SDDU), including courses on mentoring, attracting research income, applying for funding schemes individually or as a small team, partnership with industry, leadership, commercialisation, and the University’s ‘Next Generation Researcher’ programme. In December 2010, Leeds was awarded the HR Excellence in Research Award by the European Commission in recognition of commitment to good working conditions and career development for researchers.

We are committed to delivering a supportive and professional working environment for all staff, through embedded practices supporting equality, diversity, protected characteristics, disabilities and flexible working. To set local policy and ensure implementation of local and University policy FBS has its own Equality and Diversity Committee, chaired by the Dean and attended by Pro-Deans and HoS. We strongly support the development of women’s careers in Science, Technology, Engineering, and Mathematical (STEM) disciplines as recognized by an Athena SWAN Bronze award to the University. FBS is currently developing an application for Athena Swan Bronze Award in April 2014. We have reviewed current practices e.g. through a ‘Culture Survey’ and focus groups on ‘Work-life Balance’ and ‘Barriers to Career Progression’, which has highlighted good practice and provided an action plan to embed equality. Flexible working practices are indicated by 10 of the submitted academic staff working part-time, with 34 PDRA in total with part-time contracts. Our success in staff development and reward of research accomplishment and external recognition is indicated by promotions (7 Profs and 6 Readerships/Associate Professorships) in the REF period.

ii. Research students

There are close to 190 postgraduate students (98 female, 92 male) in the UoA at various stages of their degree courses, who are members of the FBS Graduate School. At least 25% of the students participate in interdisciplinary research taking advantage of existing links and building new partnerships with researchers in the Faculties of Mathematics and Physical Sciences, Engineering, Medicine and Health, and Earth and Environment. FBS established the first Graduate School on campus and initiated regulatory procedures that are now followed across the University. Adopting the University Code of Practice on Research Student supervision, the Faculty Graduate School coordinates and administers all postgraduate training and supervision. Postgraduate students have a primary supervisor responsible for direction of the research project and typically a co-supervisor who also has academic input. The supervisory team includes an advisor (where there is no co-supervisor) and an assessor who meet formally with the student to review progress at defined time points. These include evaluation of a grant proposal or literature review in the first year, the transfer viva, typically towards the end of the first year which is examined by written report and *viva voce* and which must be successfully completed to enable transfer to full PhD registration, and a draft manuscript and thesis plan at the end of the penultimate year.

Research students in UoA5 are funded from a variety of sources. The UoA was in receipt of 3 BBSRC doctoral training grants covering the entire REF period, which funded a total of 119 students. We also host a prestigious Wellcome Trust PhD programme which funds 5 studentships per annum, which was recently renewed. University of Leeds led a White Rose University Consortium with the Universities of York and Sheffield and successfully bid for a BBSRC Doctoral Training Partnership in 'Mechanistic Biology'. The consortium was awarded 20 studentships per annum for the period 2012-2014 (joint 3rd total nationally). In addition, the UoA has hosted 6 EU funded students and 30 CASE studentships funded by BBSRC, NERC and EPSRC with a wide range of partners including Pharma, agricultural biotechnology companies and instrument manufacturers. Between 2008 and 2012, our PhD student intake per staff member has increased by 32% from 0.51 to 0.67. We increased our BBSRC Industrial CASE studentships from 1 in 2008 to 6 in 2013 and engage with the newly established cross faculty industrial 'hubs' to identify new partners and opportunities.

Our successful PhD student supervision is reflected in an overall pass rate >95%. In addition, PhD students are authors on 43% of returned outputs. Our PhD graduate first destinations are principally science related, with >85% undertaking postdoctoral research, employed in relevant industries and the NHS or in further study. In addition to laboratory research, students engage in the equivalent of ~10 days per year of professional development and training. The programme of professional development is designed and delivered through the training hub, and managed through the FBS Graduate School. This includes a broad range of workshops and events that explicitly support students as they embark on research and helps them to develop key skills for their future careers within or outside academia. Examples include project management, thesis writing, working with your supervisor and viva preparation, as well as creative thinking and problem solving, effective networking at conferences and innovative thinking. We run a highly successful annual Postgraduate Symposium, in which second year students present posters and final year students give talks that are assessed for prizes. We also give credit for self-directed training, for instance research presentations at external conferences with reflection on feedback from research colleagues.

The professional development programme is updated constantly to reflect the Research Councils' thinking and employers' perspectives. This has led to the more recent development of workshops on enterprise, public engagement with science, pathways to impact and working with industry. Good Laboratory Practice standards that are used by the research groups provide excellent training and experience for post docs and postgraduates. In addition, we actively obtain feedback from the students attending our courses via elected postgraduate representatives from each School, who sit on the Faculty Graduate Committee, as well as via anonymous questionnaires, in order to develop new workshops or improve existing ones. The Head of Skills and Careers (Ian Lyne) from BBRSC has described our programme as 'excellent'.

d. Income, infrastructure and facilities

The UoA has been awarded £62.2M of external grant income within the period, including £3.7M for equipment. To facilitate the research funded by this income, FBS has recently concentrated its research activities within the adjacent Garstang, Astbury, Manton and Miall buildings. The majority

of research space in these buildings has been part of a £20M refurbishment programme in the last 5 years. These form a 'U shape' of physically connected buildings, promoting collaboration by allowing research groups to share postgraduate and postdoctoral write up areas, laboratory space and facilities. We provide 'well found labs' through a £350K pa fund for maintenance and purchase of essential equipment, ensuring basic infrastructure and research facilities such as purified water, centrifuges and rotors, -80ºC freezers, ice flakers and autoclaves.

We invest significantly in research facilities, which have contributed to research in 62% of the submitted outputs containing work conducted at Leeds. These research facilities include (example outputs in brackets): Electron Microscopy (SB#2), NMR (SR#1), Bioimaging (PKx#1), MS (PH#1), Biomolecular Interactions (SKp#3), X-ray crystallography (PH#2), Circular Dichroism (MMP#3), Media Labs (AO#2) and the Plant Growth Suite (CF#1). These facilities are managed by nine experienced Facility Managers who provide expert advice, guidance and training.

Our facilities include an exceptional range of up-to-date equipment to underpin research in the instrument-dependent area of structural molecular biology. The ability to determine molecular structures has been enhanced by a recent (£700K) grant from the Wellcome Trust that allowed the upgrade of our NMR instruments (500, 600 and 750MHz); and the purchase of a new X-ray diffractometer, a Raxis4++ detector and cryostream, and instruments for Isothermal Titration Calorimetry (ITC) and Circular Dichroism. X-ray diffraction is further supported by a nano-dispenser and liquid handling robot, to allow sample tracking from initial screen to successful crystallisation.

For detection of non-covalent interactions as well as biophysical analysis of macromolecules state-of-the-art instrumentation for mass spectrometry is available. This includes an LCT Premier specifically modified for the analysis of non-covalently-bound macromolecules and three instruments with in-built ion mobility spectrometry and MS/MS capability. This capability is enhanced by two Analytical Ultracentrifuges. Further characterisation of macromolecules and their complexes is enabled by Differential Scanning Calorimetry, Surface Plasmon Resonance, microcalorimetry, microscale thermophoresis and stopped-flow spectrometry (fluorescence and Circular Dichroism). In addition, there are liquid handling robots for aptamer selection and colony picking. Single molecule analysis is enabled by in-house built fluorescence instruments (FCS, FRET and ALEX) as well as commercial and home-built instruments for atomic force microscopy and dynamic force microscopy.

High resolution imaging of biological samples is a critical underpinning technology that is provided by an integrated Bioimaging facility, located in a purpose-built suite and comprising both light and electron microscopy instrumentation. Light microscopy capability comprises three laser scanning confocal microscopes, and a Delta Vision Deconvolution system, allowing multicolour automated imaging of live and fixed cells over extended time periods. Fluorescence and histology imaging is enabled by two epi-fluorescence microscopes with microinjection assemblies and colour CCD cameras. The facility also provides flow cytometry and cell sorting capability, allowing multicolour analysis and cell sorting of samples. Data and image analysis software for microscopy and FACS is provided on offline workstations. Electron microscopy capacity comprises state-of-the-art instruments for cryo-EM, transmission EM and scanning EM, as well as the ability to perform 3D electron tomography, and was recently upgraded and enhanced by a Wellcome Trust equipment grant. As a result of a campaign donation and matching University funds, we have just finished building a PALM/STORM super-resolution microscope and have begun to collect data to resolve cellular structures down to a resolution of 20nm. This development led to a successful application to the recent MRC Next Generation Optical Microscopy Initiative (£1.4M) to develop a second super-resolution microscope based on structured illumination that will allow rapid live cell imaging in 3D at resolutions of ~100nm (starting in October 2013).

High-performance computing is extensively used in UoA5 for data analysis and simulation (e.g. EM, SB#2). This is provided at University level, supported by capital investments from the stake-holder Faculties of £1M biennially. This has established a 4500 core facility (45 Tflops), with an expansion of 3000 cores (60 Tflops) being added and >100TB for parallel file storage. The University also hosts and is a key stakeholder in the £2.6M regional N8 HPC facility of 5312 cores (110 Tflop/s) funded by EPSRC.

Virology research is enabled by provision of extensive containment level (CL) 2 laboratories. In addition, a large CL3 facility allows research on medically important pathogens such as HIV and HCV. This facility has been recently enhanced by the provision of a confocal microscope (Royal

Society, JM), establishing a unique resource for the study of viral cell biology.
Plant Science has extensive plant growth and tissue culture facilities. Our on-campus Plant Growth Suite consists of 9 modern containment glasshouses providing temperate, Mediterranean and tropical environments for the contained growth of wild type and transgenic plants. These glasshouses are linked to a suite of plant growth rooms and growth cabinets that provide controlled environment conditions with GM containment. In addition to this facility there is another group of six roof-top containment glasshouses providing growth conditions for both temperate and tropical plants. There are extensive facilities for the maintenance and propagation of plant tissue culture material. A distinctive feature of our research infrastructure is the 265 hectare University experimental farm consisting of arable land growing wheat, barley, oil seed rape, vining peas and potatoes in rotation, with 35.5 ha of permanent pasture and 6 ha of agroforestry. For Plant Sciences the farm provides rain out shelters, test plots and field scale sites including field scale trials with GM crops. For E&E the farm provides pollinator plots, honey bee hives, crayfish ponds, small mammal trapping, soil sensors and a weather station. We are the only UK University to have conducted GM field trials during the REF period. The farm is increasingly used in collaborations with the Universities of York and Sheffield, FERA and Askham Bryan College. It is a National Institute of Agricultural Botany test site and underpins our future research plans in the area of food security.
The farm also houses a 200 sow farrow-to-finish research pig unit which is available for use by different research groups and provides pigs for fundamental research in MedEng and IMB.
The University has two state of the art animal units for researchers' use. One unit completed in 2008 (costing £9M) is a high-health status mouse only facility specialising in cancer research and the production of transgenic mouse lines. The other unit, completed in 2012 (c£5M), is a multi-species facility for mice, rats, rabbits, fish, birds and large animals such as sheep and pigs. Large animals can also be held at the University Farm for some procedures. Each unit has highly equipped surgical suites, rooms for behavioural analyses, Category II work and flexible space to meet academics' research needs. Both provide facilities underpinning research in MedEng, IMB and Virology in this UoA as well as research in UoAs 1,4 and 26.
Our financial planning provides £350K pa at FBS level which, provides essential items of equipment (see above), can be used to match University funds to provide higher level equipment for communal use within facilities (e.g. confocal microscopes) as well as contributes to matching funds for external bids for larger pieces (e.g. NMR). The UoA has also been involved in two projects funded by Alumni gifts: 1. Sustainable Agriculture for Global Food Security, gift received for £300K which funded a Research Fellowship and part funded an administrative role (TB). The Sustainable Agriculture for Global Food Security project brings together biologists, agronomists, engineers, social scientists and transport experts to examine the social, ecological, economic and political challenges facing world agriculture and society as a whole. Leeds is the only institution in the UK and one of just three or four globally with the combined expertise to realise such far-reaching ambitions. 2. New Solutions in Biomedicine and Health, gift received for £166k – part funded a Super Resolution Light Microscope (MP), which allows around ten times better resolution than previous light microscopes.

Support for Research

Support for administration of research and innovation applications and awards is supplied via the Faculty Research and Innovation Office (FRIO; 5 FTE). Following an extensive review of research administration the University has developed and implemented new research systems providing a streamlined 'cradle to grave' environment. The grant team support the costing and pricing of applications, provide advice on funders' rules and regulations and help navigate through funder's systems. In addition to this they provide financial support for live awards highlighting available funds, identifying overspends or ineligible costs, and submit financial reports to funders. Other staff in the FRIO (3 FTE) provide administrative assistance and secretarial support to research groups and cross-faculty research groups for e.g. seminar programmes, internal peer review, open access, REF, summer research studentships.
Support to other research related activities is also provided at Faculty level. Health and Safety is overseen by a manager and 2 full time officers who provide induction training, assistance with COSHH, radiation protection, GM work etc. The Human Resources Office (6 FTE) provides assistance with staff recruitment, staff review and development, monitoring of probation etc. Purchasing of research related items (including assistance with tendering processes) is conducted

via the Purchasing Office (6 FTE, shared with another faculty) and delivery of items and maintenance of some stock items conducted through FBS Stores (4 FTE). Computing software and hardware is purchased, installed and maintained by the IT Office (11 FTE). General research laboratory requirements such as gas cylinders, autoclaving, washing up, waste disposal, water purification system maintenance etc. are supplied by a team of technical lab assistants (6.5 FTE).

Governance

High level policies for research and innovation are set at the University Research and Innovation Board, chaired by the PVC for Research and Innovation and populated by faculty Pro-Deans for Research and Innovation (PDRI) and University senior research and innovation administrators. At FBS level, research and innovation policies and strategic directions are defined by the Faculty Research and Innovation Committee (chair PDRI, members: the Dean, research group representatives, School Directors of Research (DoR) and Heads (HoS) of the 3 constituent Schools. The HoS and DoR are responsible for deciding overall research strategy, delivering a high quality research environment, space allocation, HR and staff mentoring. They line-manage staff and interact with research group leaders who champion activity in their research fields. Cross-faculty research groups are represented by relevant group leaders and the Dean and PDRI are part of the steering committees of these cross-faculty groups.

Ethical governance: the UoL ethics policy ensures that research is conducted according to the principles of academic excellence, community, integrity, inclusiveness and professionalism. Our FBS Research Ethics Committee operates under delegated authority from the University Research Ethics Committee to consider the likely benefits of research involving human subjects in relation to the potential risks. There is a separate ethical review process for research involving animals. Both ethical review committees include members who are active research staff as well as lay members. Administrative support for the ethical review process is provided at central University level by the Governance and Corporate Affairs Officer and the Senior Research Ethics Administrator.

e. Collaboration or contribution to the discipline or research base

Due to the diversity of biological research within the UoA, we have strong interactions across campus, especially with Medicine (e.g. DW#3, MH#4), Chemistry (e.g. SR#4, AB#2), Physics (e.g. LJ#1, SR#3), Engineering (e.g. EI#1, MMP#3) and Environmental Sciences (e.g KH#2, AD#2). Staff collaborate extensively with academic researchers and industry nationally and internationally. Staff have played key roles in organising large interdisciplinary national research projects, two RELU projects (TB, WK, SS, SC), and three Insect Pollinator Initiative projects (SC). TB is the national leader of the Global Food Security programme. Regionally, we host the Yorkshire Dales Environment Network (YDEN), a NERC KE initiative including 25 partners from government, NGOs, farming and industry.

Interdisciplinary links have been extended to other universities in UK via the EPSRC White Rose DTC in Tissue Engineering (60 PhDs), a CDT in Medical Engineering funded by EPSRC (10 PhDs), a CDT in Molecular Scale Engineering with Sheffield funded by EPSRC (30 PhDs) and the White Rose BBSRC DTP in Mechanistic Biology (20 PhDs). A strong focus on **translational research** is illustrated by our China Seeds collaboration with SINOCHEM, the third largest global trading company; by hospital collaborations (e.g. with LTHT and LMBRU in rheumatology and orthopaedics; with Bristol Implant Unit in vascular surgery); in Technology (DePuy); partnerships with the NHS Blood and Transplant Services; an Innovation and Knowledge Centre (IKC) in Medical Technologies engaged with 100 industry partners and several clinical partnerships.

ACSMB has recently established an Industrial Advisory Group with ~30 members from relevant industries regularly visiting the University to help develop links in areas of our strength, particularly in the bioprocessing and delivery areas. This has resulted in collaboratively funded research with AstraZeneca, Medimmune (SR) and others.

Successful **responses to international priorities** include secured funding from the Gates Foundation for a polio vaccine initiative (DR/NS). Staff played a leading role in coordination in the EU consortia SCALES (SC, KH) and SYSFLO (BD). Staff secured BBSRC Japan Partnering (AB) and BBSRC US Partnering (SKp) awards, and contributed to the foundation of the Physcomitrella Genome Consortium (AC), and led the India Bridges Programme to promote Anglo-Indian Food Security that involves links with IISC and IARI research institutes (PU, BD, SKp). Another major international impact has been through Africa College, a Leeds-hosted international research partnership working to improve food security in sub-Saharan Africa.

Further indicators of esteem/external recognition are outlined in the table overleaf:

(# - numbers during REF period): Indicator	#	Examples
National advisory board membership/ chair	102	Chairs of MRC Senior Non-clinical Fellowships Panel (SR) and Alzheimer's Research UK Scientific Advisory Board (NH); Deputy Chairs of BBSRC Integrative and Systems Biology Strategy Panel (TB) and BBSRC Tools and Resources Development Fund 2 (DW); BBSRC, NERC, MRC and EPSRC funding panel memberships.
International advisory board membership/ chair	52	Italian Ministry for Education University and Research (MIUR) panel (MMP); Committee for Research Evaluation, Italy (MMP); Belgian Research Council (FWO) grant panel (JDe); "BIRAX", Britain-Israel Academic Research Exchange Scheme (funded by UK and Israeli governments) (TB); Earth Sciences and Sustainable Energy Programme for Research in 3rd Level Institutions (PRTL), Ireland (TB); Research Council of Norway Ecology & Evolution Panel (TB); EU FP7 SILVER consortium and Gates Foundation HIV vaccine development consortium (DR); Max Planck Institute of Biochemistry (Martinsried) (SR); Japan Society for promotion of Science (PH); Advisory Board of LeanGreenFood Marie Curie programme (PKx); AERES (FRANCE) Research Assessment visiting committee (PKx); International Advisory Board of International Cell Wall meeting 12 (PKx); International Food Policy Research Institute (Washington) (TB).
Journal Editors/board membership	81	Journal of Molecular Biology (SR); Journal of Biological Chemistry (NH); Journal of General Virology (AW, MH); Plant Journal (BD); Nature Conservation (WK); Ecology Letters (TB); Journal of Neurochemistry (AT, Chief Editor).
Invited keynote speaker at international conference	162	Chair of 11th International Conference on reactive Oxygen and Nitrogen species in Plants 2013, Poland (CF); Chair of European Science Foundation Meeting on Emergent Properties of Cytoskeleton 2010 (MP); Chair of FASEB Meeting on Protein Folding in the Cell 2008, USA (SR); 3rd Annual Mass Spec Europe Conference & Exhibition 2011 (AA); 22nd Biennial Joint Meeting of the International Society for Neurochemistry and the Asian Pacific Society for Neurochemistry, S. Korea (NH); European Association of Tissue Banks 2008, Edinburgh (EI); Jacques Monod Conference: Protein Misfolding and Aggregation in Ageing and Disease 2010, France (SR); Wellcome Trust conference: Sub-Nuclear Structures and Disease 2012 (AW); Society of General Microbiology Annual Meeting 2008 (AW); Protein Society 27th Annual Symposium and Award Presentation 2013 (SR); Biophysical Society (USA) Annual Meeting 2009 (SB); Gordon Conference: Membrane Transport Proteins 2010 (PH); Gordon Conference: Protein derived cofactors 2010, USA (MMP); Gordon Conference on Angiotensin 2008 and 2010, California (AT); FASEB, Biophysical Mechanisms of Protein Misfolding 2013, USA (SR).
Organiser of an international conference	40	International Society for Neurochemistry: Membrane domains in CNS physiology and pathology 2010, Italy (AT); Federation of American Societies for Experimental Biology (FASEB) Summer Conferences: Post-transcriptional Control of Gene Expression: Mechanisms of mRNA Decay (KMD); International Conference on Neurodegeneration 2012, Mexico, (AT); The International Conference on Arabidopsis Research 2013, Australia (CF).
Prizes	13	Queens Anniversary Prize for Higher and Further Education (2012) for research in iMBE (EI); American Society for Mass Spectrometry Ron Hites Award (2009) (AA, SR); FMedSci (AT, SR); Carl Branden award (SR).
Research Fellowships	11	RCUK (AP, SK, AM, SKp); BBSRC (DW, AW); Wellcome Trust (AR); Leverhulme (AW); Royal Society (JM); MRC (SM); Alzheimer's Research UK (JD)