Institution: Queen's University Belfast
Unit of Assessment: 6

a. OVERVIEW

Background and Structure: During the REF cycle the Institute for Agri-Food and Land Use (IAFLU; formed in 2006) has undergone strategic expansion and re-development to form the **Institute for Global Food Security (IGFS)**. Underpinned by strategic support and research success, IGFS now provides a dynamic, multidisciplinary research and education environment that encompasses core competencies in key elements of global food security. IGFS comprises four inter-linking research themes: (i) Animal Health & Parasitology; (ii) Food Safety & Integrity; (iii) Human Nutrition & Health; (iv) Plant & Soil Sciences. The themes carry out fundamental and applied research that underpins the development of research-led, innovative solutions to agri-food industry problems, aiming to deliver novel research data that are directly relevant to the global agri-food industry. All 36 IGFS staff are included in this UoA6 REF return; all work collaboratively across IGFS and many work with other University staff and / or research institutions nationally and internationally.

Relationship to the School of Biological Sciences (SBS): IGFS resides within SBS, one of four Schools in the Faculty of Medicine, Health and Life Sciences. Most SBS staff are affiliated to IGFS and returned within UoA6; remaining staff focus on ecology, economics and the environment.

Management, Planning and Implementation: Management of SBS is overseen by an 11 member School Management Board (SMB) which includes six PIs from IGFS including the Director of IGFS (DI), a Director of Research (DR) and International Liaison. The IGFS Management Group comprises the DI, DR and research Theme Leaders (TLs); it develops and moulds IGFS research strategy and reports to SMB. External input is received via an International Scientific Advisory Board comprising global research leaders from academia and industry; it reviews research activities and infrastructure in the context of strategy and global research needs, providing guidance that helps shape IGFS development and planning.

b. RESEARCH STRATEGY

Evidence for the Achievement of Strategic Aims

Significant Changes to Research Environment**:** One QUB corporate priority is to enhance internationally-recognised, globally competitive and sustainable research areas. As a consequence of its strategic growth, success and potential to impact serious global challenges, IGFS has become one of eight QUB priority research areas identified within successive (including current) Integrated Operating Plans for strategic support and investment (see Section d).

University support since 2008 has included: the provision of multiple additional academic positions (20, including three international research leaders); the allocation of multiple strategic postgraduate (PG) studentships (~£2m); new and expanded PG and undergraduate (UG) training programmes to meet local and international needs; additional investments in facilities/infrastructure; and, the provision of additional space to accommodate expansion. IGFS now forms the hub for all QUB research activities relating to global food security.

In 2008 the embryonic institute (formerly IAFLU) comprised 12 academic staff. A core strategy during the assessment period was to increase the international competitiveness and sustainability of the institute by fostering the growth of existing research strengths and adding new core research competencies, providing for a more dynamic research unit that is able to respond to key global food security research needs. A series of key achievements / milestones help highlight progress:

- Strategic, sustained growth and restructuring of an embryonic IAFLU to form the new IGFS
- Considerable increase in number of category A academic staff (from 12 to 36)
- One of three UK holders of a prestigious SWAN Athena Gold award (2013)
- Expansion in FTE postgraduate researchers - 67 current and 84 completed PhDs
- >£18m new research grant awards
- Infrastructure investment *ca.* £5m and initiation of a new £33m building programme
- Development of sector-leading ASSET Technology Centre (partnered with Waters Corp, USA)
- Establishment of a new International Scientific Advisory Board
- Selection as QUB priority research area and inclusion in *Beyond* fundraising campaign

Broad Research Ethos and Current Plans**:** The pursuit of academic excellence, the translation of research findings and ensuring sustainability through investment in people and infrastructure are

our guiding principles. More specifically, IGFS strives to be a key partner in global and national efforts to provide the world's growing population with a sustainable, safe and secure supply of high quality food. A vision of excellence in research seeding innovation within the agri-food sector underpins research activity. Our primary research goals are to establish IGFS as:

i. an internationally competitive unit that contributes globally to scientific enquiry and excels in core-elements of agri-food research (see Sections c & d for quality research funding, international connectivities, diverse impacts and expanding reach), education and training;
ii. a leader in research on food-chain integrity through the development and exploitation of novel pioneering approaches to food forensics technologies (the new ASSET Technology Centre [for **AS**sured, **S**af**E** and **T**raceable food; www.gub.ac.uk/asset]);
iii. a primary research provider for large multinationals, national food producers, SMEs and artisans with the aim of enhancing economies internationally & locally (in addition to formal linkages with leading multinational companies, local SMEs are an integral part of IGFS which is working to meet the key research needs of industry and government; see Section d).

Main Objectives over Next Five Years: IGFS is focused upon supporting an innovative research culture based around core research themes, central to global food security. It is anticipated that this approach will continue to provide an extensive, global role for the new Institute as a deliverer of research-led solutions and innovations in sustainable food production. More specifically, over the next five years we aim to continue to develop our research capacity and strengthen IGFS through additional planned, sustainable and strategic developments:

i. *Increase our Academic Excellence* - Build additional academic excellence through the appointment of high quality researchers and leaders in key areas. In particular, we have plans to grow elements of nutrition research, our Plant & Soil Sciences research theme and to develop a new theme in fisheries and aquaculture with the expectation that IGFS will grow to 45 academic staff over the next five years. Strategic appointments will either strengthen current research activities or, build new competencies that allow us to better respond to national / international priorities. Our ISAB will play a key role in helping shape our specific appointment proposals.
ii. *Expand and Diversify the Impact of our Research* – We have numerous active and productive collaborations / linkages with industry. Over the next cycle we will strive to increase the translation of our research through the growth of our interactions with industry and the development of longer term partnerships with leading companies. Multiple negotiations are currently underway with major commercial / pharmaceutical companies. We will also encourage and nurture efforts to translate research findings, for example, we have four recently funded proof-of-concept awards to help facilitate commercialization.
iii. *Inspire and Facilitate Early Career Researchers* – Firstly, we will strive to identify talented researchers at an early stage and help foster their research development. For example, our current contract researchers lead four Phase I Gates Grand Challenges awards and we will provide the facilities and support needed to ensure these translate to competitive Phase II proposals / awards. Secondly, we will also grow our PG taught and doctoral training programmes, helping to develop our research leaders of the future.
iv. *Continue to Develop and Enhance our Research Infrastructure* – We will consolidate all of our research activities into one building, specifically designed to accommodate significant growth and adapted to enhance state-of-the-art research needs. The latter will include the up-scaling of bioinformatics infrastructure and elemental analysis capabilities for trace / macro-nutrients and elements of agri-toxicity concern. Planning of the new building has started, funds have been committed and we are actively seeking additional funds from industrial / commercial partners.

Research Groupings and Selected Achievements: Within the REF cycle the institute has grown considerably, broadened its research portfolio and developed much-expanded programmes of both fundamental (supported mainly by RCUK [x15] and EU [x30] funding streams) and applied research (supported mainly by EU and UK government departments, The Gates Foundation [x5] and diverse Pharmaceutical, Diagnostic, Biotechnology and Food industries). These developments have involved a dramatic evolution in research structure / infrastructure and a concurrent growth in core research competencies and staffing. Specifically, the Institute has fostered considerable growth in Food Safety & Integrity [from 4 to 11 PIs] and in Human Nutrition & Health [from 4 to 8 PIs]; has added new niche competencies through the strategic addition of two new research themes in Animal Health & Parasitology [11 PIs] and Plant & Soil Sciences [6 PIs]).

IGFS now has 36 PIs, with 20 new appointments during the assessment period.

International collaborations have proliferated, as evidenced by extensive international co-authorships on outputs, and a broad portfolio of active research programmes involving collaborators across the EU, Africa, Asia, North and South America. Many of the research programmes are fundamentally multi- and inter-disciplinary involving currently active collaborations with researchers in biodiversity, chemistry, computer science, ecology, economics, engineering, management, medicine, pharmacy, physics and SPACE (Planning, Architecture and Civil Engineering). Each theme has sustainable research programmes built around key strengths and supported by a variety of short-term and longer-term funding.

(i) The Animal Health & Parasitology theme has 11 PIs (Maule [TL], Allan, Brennan, Dalton, Law, Marks, Mousley, O'Connell, Prodöhl, Robinson, Trudgett) with research activities that encompass the identification and control of parasites and viral infections, the improvement of animal welfare and aquatic resource management. Fundamental and applied fish population genetics studies (funded by EU, NERC), focusing primarily on the impacts of human exploitation on wild stocks and the interactions between wild and cultured stocks, are designed to leave a legacy in sustainable aquatic resource management. Much of the animal health research is applied, building on the success of the sector-leading circovirus vaccines with growth in disease horizon scanning and the development of novel diagnostics for transboundary diseases (main funders DARD, EU, RCUK). The livestock welfare improvement work has attracted major funding from local government and encompasses much proactive technology transfer and developing impact, e.g. it has developed novel approaches to the management of pig litter sizes; so far, the latter has been adopted on one third of NI pig farms with estimated savings already in excess of £200K (DARD).

Much of the parasitology research is fundamental and involves work on the discovery and functional assessment of parasite molecules / immunomodulators and their exploitation as new drug or vaccine targets (main funders FP7, RCUK). BBSRC-funded research with Indian collaborators and a recent major ERC award are facilitating the expansion of liver fluke vaccine research with new vaccine trials ongoing. Staff were the first to develop novel reverse genetics approaches for liver fluke and tapeworms, helping drive the development of post-genomic tools for parasites (main funders BBSRC, Gates). These biotechnology platforms attracted BBSRC-LINK funding (2013-16) for collaboration with Merial on flukicide discovery.

In addition to producing over 250 publications in the REF period, most involving international collaboration, staff have contributed significantly to public engagement and provided expertise on circovirus vaccines to the FDA (USA), on the epidemiology of broiler welfare to the European Food Safety Authority and reports used to inform changes to EU laws in broiler health and welfare.

(ii) The Food Safety & Integrity theme encompasses 11 PIs (Elliott [TL], Campbell, Cao, Connolly, Fanning, Grant, Koidis, Mooney, Nelson, Situ, Subrahmanyam) with a diversity of applied and basic research activities encompassing: analytical / bioanalytical chemistry; bio-sensor development and technology; disease diagnosis; endocrine disruptors; genetic mechanisms of antimicrobial resistance; molecular binders; molecular epidemiology; toxins. The contamination, accidental and deliberate, of feed–food supply chains with chemical and microbiological threats are major issues in delivering safe and authentic food to the consumer. The increasing complexity of supply chains brought about by globalisation, increased industrial competiveness coupled to ever increasing global pollution and climate change have greatly exacerbating these difficulties for industry and regulators. Across Ireland (North and South) a feed contamination incident in 2008/09 caused by dioxins resulted in >£400m economic losses and severe reputational damage to industry. The management and prevention of such contamination incidents arising locally and across European and Asian supply chains has become a major focus of research. Working closely with industry, IT tools to assess and manage the multiple risks of accidental and fraudulent contamination were developed and implemented. Cutting edge biosensor technologies using innovative protein binding elements such as antibodies, phage and aptamers were developed and applied to perform rapid monitoring for both high risk microbiological and chemical targets. Understanding the risk of human exposure to contaminants has also been a core objective and novel proteomic / metabolomic tools were utilised to identify biomarkers of exposure of farm animals to illegal drugs and naturally occurring toxins. Spectroscopic fingerprinting technologies have been developed and applied to detect non-conformities in feed and food materials. The use of high end mass spectrometry within the ASSET Technology Centre has enabled the development

of a suite of methods which can detect multiple chemical contaminants in feeds and foods which conform to EC Directive 2002/657 and can be used in both industrial and regulatory environments – work that has attracted extensive international recognition.

(iii) The Human Nutrition & Health theme has eight PIs (Green [TL], Cuskelly, Dean, Galkin, Gong, Panov, Meharg, Timson) with multi-disciplinary research spanning a range of fundamental, applied and policy-relevant research activities using biochemical, genetic, psychological bioinformatics and dietary-intervention techniques. The development and application of biomarkers assessing the impact of food contaminants on human health combined with diet / lifestyle / public health interventions is a key focus (both in developing and developed nations). Assessing and preventing children's exposure to mycotoxins in developing nations is part of a 15-year programme grant funded by the NIEHS USA, MycoRed, and Gates Foundation consortia. This work also benefits EFSA's working group on *Fusarium* mycotoxin risk assessment. WCRF funding has enabled accurate measurement of heterocyclic amine formation in foods, and this has made it possible to quantify population intake (and assess risk) for the first time.

There is additional focus on cellular mechanisms underlying human disease, particularly metabolic conditions, inflammatory bowel disease, neurodegenerative disease and cancer. This is fundamental and far-reaching and includes: the first application of high resolution metabolomics to profile human brain tissue to discover unidentified nutrient / metabolite deficiencies in human Alzheimer's disease (3 x ARUK grants); the study of dysregulation in rRNA synthesis (MRC) and respiratory chain function (MRC x 2); cytoskeletal scaffolds in cell signalling (BBSRC); ion beam/antiproton effects on cells with implications for novel radiotherapies (EPSCR).

Highly policy-relevant research determines how food labelling affects dietary choice, consumer habits and food-related health issues. This contributed to the design of UK government research evaluating impact of 'front of pack' nutrition signpost labelling schemes on purchasing behaviour www.food.gov.uk/multimedia/pdfs/pmpreport.pdf). The theme also contributed to the FAO (United Nations) report on *"Mandatory nutrition labelling tool: Assessment of consumer understanding and use of nutrition labels"* which will be published late 2013.

(iv) The Plant & Soil Sciences theme encompasses six PIs (Meharg [TL], Dalzell, Liu, McGrath, Smertenko, Williams) with a diversity of applied and basic complementary research expertise encompassing: fundamental plant molecular biology; plant adaptations to environmental stress; food-chain transfer of pollutants and phosphorus fertilization of soil and its use efficiency in plants.

Although this theme is recently formed, with five staff appointed since 2011 and three of these in 2013, the research highlights provide clear evidence of our focus on academic excellence. Research highlights have included: seminal studies on chromatin-level regulation of plant gene expression and flowering time (*Science* 327:94; *Nature* 62:799), adaptation to abiotic stresses by dissecting chromatin-level gene expression regulation (*Science* 335:1621), molecular mechanisms of programmed cell death (*Plant J* 33:813; *Current Biol* 14:R339; *Proc Natl Acad Sci* 102:14463), and identification of the first biological substrate of the metacaspases (*Nat Cell Biol* 11:1347). Along with work on *de novo* transcriptomics looking at wild species phosphorus and arsenic ecophysiological adaptations (*New Phytologist*, advanced online), and developing work on rhizosphere released microRNAs for gene silencing in root pathogens, momentum is growing strongly. Staff have applied cutting edge approaches to the study of soil chemistry and molecular biology *in situ* through the use of Diffusive Gradient in Thin-film and Diffusive Equilibrium in Thin-film approaches with inductively coupled plasma mass spectrometry, and advanced microbial molecular ecology, respectively, leading to enhanced understanding of key problem areas such as phosphate cycling in soils. Societal relevance of the themes work is illustrated by work on plant pathogen defence, phosphorus fertiliser recovery, eutrophication and plant phosphorus use efficiency issues and the lack of regulation of arsenic in foods.

c. PEOPLE

(i) Staffing Strategy and Staff Development

Academic Staff: During the REF cycle there has been a dramatic change in academic staff profile in line with research strategy. A key task has been to establish critical mass in our four core research themes and to strengthen research quality and leadership. At RAE2008 IAFLU had 13 staff; this has grown to 36 (33.4 FTEs), including 20 new appointments during the assessment period (16 Lecturers; one Reader; three Professors). Currently, the 36 staff includes seven

Professors, 11 Senior Lecturers/Readers, 17 Lecturers and one international research fellow (eight are early career researchers). A central tenet of the Institute's strategic direction has been to enhance excellence through strong research leadership (e.g. new professorial appointments) to complement existing expertise and build core activities targeted for development, e.g. Meharg was appointed to lead the new Plant & Soil Science theme. The IGFS research strategy will seed a projected growth to ~45 PIs which is expected to further enhance longer-term stability, adaptability and an academic grade profile that allows for effective succession planning.

New Staff Appointments: New academic staff are on probation for three years, complete a PG Certificate in Higher Education and Teaching and receive formal training in PG student supervision and grant writing. New staff are assigned to an *ad hoc* committee that comprises at least three senior academics and which monitors their progress through regular reports and annual presentations. Feedback highlights strengths and areas for improvement, with agreed action plans as appropriate. Also, each new appointee is assigned a senior mentor who provides help and advice at regular formalized meetings. Mentors ensure new appointees experience a friendly and supportive environment that helps guide them towards confirmation in post. All new lecturer-level staff benefit from the provision of essential research / office facilities, start-up funding (appropriate to grade), a three-year restriction on teaching load and an allocation of fully-funded PhD studentships. Collaboration with established staff is encouraged. New staff can avail of support targeted at the development of international linkages through a competitive 'Internationalization Funding Scheme' that supports international research visits and seeds new projects.

Staff Development: Staff engagement in IGFS activities is facilitated through involvement in SBS and IGFS committees responsible for fundraising, health and safety, infrastructure, management, research strategy, PG training/progression and student-consultative committees. All staff attend regular School Board (SB) meetings that facilitate the discussion and delivery of research strategy. Most (21) IGFS staff are on/have been on probation during the REF cycle. Of the remainder, six have been promoted to Senior Lecturer and one has been promoted to Professor.

Non-probationary staff have six-monthly appraisal meetings designed to assess performance with respect to key performance indicators and to set new, agreed targets for the coming year. Targets are designed to ensure excellence in research (outputs and granting), educational activities, administration and public engagement/community service. Personal development is central to the appraisal process with an emphasis on the generation of agreed development plans that are closely mapped against academic grade profiles to encourage progression towards promotion. Staff engagement in leadership courses is actively encouraged. A university-wide staff training and development programme offers a variety of generic skills training opportunities. Staff training in equality and diversity is mandatory and all policies are compliant with current legislation.

Concordat Implementation and Career Development of Researchers: The principles of the 2008 Concordat to Support the Career Development of Researchers (http://www.qub.ac.uk/research-centres/crs/Concordat/) are fully supported in our unit. We provide institutional support for PhD students and early stage researchers to develop their careers. Careers support for PhDs includes the university's PG modules and the support of regular events for social interaction and scientific development, e.g. funds allow PGs to organise their own symposium series, attracting diverse research presentations from external research leaders and on research activities such as grant writing. Postdoctoral researchers undertake full annual appraisal with built-in personal development planning that ensures they are integrated into a supportive research culture.

The Society for Contract Researchers & Postdoctoral Scientists (SCR&PS; http://www.qub.ac.uk/research-centres/InstituteforGlobalFoodSecurity/Research/ResearchSocieties/) was established to represent, assist and engage contract research staff in IGFS to identify solutions for improving personal development, career progression and social interaction. SCR&PS feeds into decision making through representative attendance at Research Theme and SB meetings, ensuring that contract research staff can influence decisions that affect them. For career development, IGFS encourages contract researchers to undertake training in grant writing and to make applications, e.g. since 2012 contract research staff have won one Leverhulme Trust Early Career Fellowship, one DEFRA-funded PhD studentship and four Gates Phase I awards.

New Research Staff attend an annual reception organised by SCR&PS and the SBS Postdoctoral Forum, which provides for interactions between contract research staff from across SBS for both general discussion and inter-theme networking. This also provides members with the

opportunity to network with all academic staff. The Forum has a web portal which provides information on a wide range of postdoctoral needs. Amongst the Grant and Fellowship information is a section highlighting grants directly aimed at encouraging women to stay / come back into science.

Equalities and Diversity: Under our SWAN mission, we support equality and diversity. IGFS is a major component of SBS, the first School in QUB to gain a Silver SWAN award from Athena, contributing to QUB's unique institutional Silver award (2012) as a national leader in gender equality in employment. In 2013 SBS won a prestigious Gold SWAN Award in recognition of its outstanding progress in promoting gender equality and addressing the unequal representation of women in science (http://www.athenaswan.org.uk/content/gold). QUB is one of only three UK Universities to hold a Gold SWAN Award.

We monitor gender statistics at all levels, from work experience placements to professorial advancement and implement practical measures such as research-only periods for academics returning from maternity leave. We co-opt a female member of unpromoted staff to SMB to address the lack of women at higher levels. Our 2008 action plan addressed several gender parity bottlenecks in the academic pipeline and implemented key actions to improve gender balance; 31% of IGFS staff are female. QUB's code of practice on the fair and transparent selection of staff for inclusion in REF2014 submissions ensures that IGFS can return staff with reduced outputs due to individual circumstances such as maternity leave; our return includes all IGFS academic staff.

(ii) Research Students Sustainable Doctoral Research Training: IGFS management recognises successful doctoral training programmes as critical to research development. Funding for PhD training comes from a wide variety of sources including local government, EU, The Irish Agriculture and Food Development Authority, diverse industries and charities. Internal funding streams support: inter-disciplinary PhD projects involving supervisors from distinct research units; international studentships, and; studentships with 50% external co-funding, typically involving industrial or stakeholder support. Masters level degrees targeted at international as well as home students are offered in Advanced Food Safety, Food Safety & Biotechnology and in Molecular Biology & Biotechnology. International PG student numbers are being boosted through exchange programmes and co-funded projects with institutions in Brazil, India, Malaya and Thailand.

Concomitant with the growth of IGFS has been a rapidly expanding doctoral degree programme in which 84 PG students completed their doctoral training during the REF period; 33 new doctoral students commence their training within IGFS between August and November 2013, providing evidence of very strong growth. All students are provided with computer access and individual desks / writing areas close to their laboratories. In their first semester, PG students undertake Health and Safety Training and generic Skills Training and assessment. In addition, all students enrol in a University Postgraduate Researcher Development Programme which comprises a comprehensive range of training courses, 1-2-1 support and skills development opportunities. All students undertake a minimum of 30 days training and development activity over the course of their research degree, ensuring that all students benefit from the multiple training options available.

Integrated Research Student Culture: The Postgraduate Research Committee oversees the development of PG research programmes and monitors all formal PG progression elements. All students have a minimum of two supervisors and, if one is on probation, the other must be a senior academic. A rigorous monitoring and reporting regime requires each student to complete an Initial Review at three months, Differentiation at 6-9 months and annual reports at the end of each academic year. Individual Initial Review, Differentiation and Progress Review Panels provide specific, independent advice and help identify problems in student performance. Where problems are identified, intermediary targets are agreed with student and supervisors to facilitate progression. The Postgraduate Staff-Consultative Committee meets each semester and provides a forum to identify problems and seek agreeable resolutions in an open and friendly environment.

In addition to routine, informal supervisor-student interactions, PG students complete six formalized meetings each year and they give a presentation at the annual IGFS Postgraduate Research Symposium attended by all PG students and staff. The students organise the symposium and, in addition to the support provided by IGFS, can apply for additional QUB funding to support student-led initiatives that facilitate the invitation of external speakers and the provision of hospitality during symposium week, e.g. in 2012/13, the PGs attained over £1k support for the symposium. Whilst PGs attend the regular seminars given by visiting research leaders and IGFS

academics, the mix of student presentations and social events within the symposium week have been most successful in enhancing the sense of identity and PG integration into IGFS.

d. INCOME, INFRASTRUCTURE & FACILITIES

Income Strategy**:** In spite of 20 new appointments since 2008, with most in their first academic position, IGFS research income during the REF cycle totalled £18.3m. A significant proportion of the grant awards obtained was from prestigious sources, e.g. 47% from EU (e.g. FP7, ERC) and RCUK (mostly BBSRC and MRC) with another 47% from major industry and stakeholders.

The granting strategy encompasses core elements of fundamental research ensconced in discovery and of applied research designed to meet industry / stakeholder needs. Grant awards during the REF cycle provide clear evidence of significant activity in both. For example, concomitant with IGFS growth and broadening research portfolio has been the development of much-expanded programmes of both fundamental (supported mainly by RCUK [x15] and EU [x30] funding streams) and applied research (supported mainly by EU and UK government departments, The Bill & Melinda Gates Foundation [x5] and diverse industries).

To enhance translation, a number of significant research partnerships have been established with major industries, providing for additional growth and sustainability. Industrial funding is split between the local food industry, major multi-national companies and multiple joint UK/EU government/industrial funding awards, e.g. 13 KTP/RCUK-LINK/InvestNI co-funded industrial partnership awards since 2008. These developments have enhanced the dramatic evolution in research structure / infrastructure that underpin the growth in core research competencies.

Investment Plans / Sustainability: Longer term support for IGFS has been secured: starting in 2013, a five year, £140m, international fundraising campaign (designated *Beyond*) by the QUB Foundation in support of transformational projects including the IGFS; new research and teaching facilities within a new £33m building for completion in 2016; development of a dedicated site adjacent to the new build for industry partners to 'hot-desk'. The clear commitment to ensuring that IGFS has scientific, technological and physical links to the academia-industry interface is seen as critical to its strategic development and longer term impact, reach and sustainability. Looking forward, a series of high-level engagements with major industries / leading companies are underway with a view to additional infrastructure investments in the new building.

Infrastructure, Facilities and Significant Equipment: The growth in staff numbers has been accompanied by QUB investment in facilities, refurbishment and expansion (>£5m). Billions of people now depend on science and technology to ensure that what they eat is safe – IGFS aims to boost the contribution and impact of its core research activities through a state-of-the-art technology base and a strong and dynamic interface with industry and other end-users.

Physical resources encompass bespoke analytical, bioanalytical, molecular biological, genomics, proteomic, cell / tissue culture and bioimaging laboratory space. Currently, the IGFS staff benefit from the Bioimaging Core Technology Unit with flow cytometry, microscopy, live cell and *in vivo* imaging system facilities, high resolution slide scanning and microinjection equipment and a dedicated server for data storage and remote access.

One major infrastructure development within the assessment period has been establishment of the ASSET Technology Centre (£2m in 2009 and a further £6m in 2013) which boasts unique, custom-built technologies that draw on inter-disciplinary skill-sets that support the development of innovative strategies and techniques in animal and human health, food safety monitoring and traceability, providing a niche food-forensic strength for IGFS. At the official opening of IGFS in 2013 it was designated as an official research partner for Waters Corporation. It also houses in-kind donations of spectrometry (ultra-pressure liquid chromatography, triple quadropole, Q-TOF-, LC-TOF- and GC- mass spectrometry), spectroscopy and biosensor equipment from Waters, Thermo-Fisher, GE Healthcare, Nomadics Corp., Fortebio, Axela, Ridgeview and Precision Photonics. ASSET is a sector leader in the development and exploitation of biosensor technologies for food safety and integrity, it has been recognised as an international training centre by The British Council which funds visitors from developing countries and it became an official UN collaborating centre in 2012. A Fluoromax-4 Spectrofluoremeter with stopped-flow capacity for kinetic analyses is available, as is an adjacent NMR facility within the School of Chemistry.

Capacity in genomics includes an ABI 3730XL 96 Capillary DNA analyser with 16-plate stacker (96 and 384 well plates) for high-throughput Sanger sequencing and microsatellite genotyping.

Associated facilities include: robotic workstations for automated DNA extraction, liquid handling and PCR; banks of thermocyclers, real time PCR machines and UV digital recording systems.

Other facilities include a pilot-plant for waste-water treatment, 50, 120 and 200 L fermenters and down-stream processing for microbial biotransformations. Researchers also have access to state-of-the-art animal house/holding facilities (£5m). Parasite behaviour assessment to validate parasite drug and vaccine targets for industrial partners encompass purpose-built bioassay systems, motor function and muscle assay rigs and a range of computational behavioural analysis platforms that provide a unique facility dedicated to parasite functional genomics.

Animal welfare researchers have a base at the Agri-Food & Biosciences (AFBI) institute at Hillsborough, providing for collaborative access to high-quality pig and dairy units. The pig unit has 150 sows which breeds and finishes all pigs with 180 pigs available at 3-week intervals. The pig unit includes specialized facilities for behaviour and welfare research including open-field test arenas and electronic feeders. Animal accommodation contains different flooring and moveable pen divisions so environmental conditions can be controlled. The dairy unit comprises a 300 high-genetic dairy herd with access to detailed animal records (genetics, health, productivity), footbath and milking facilities for digital dermatitis research, and animal accommodation.

Research Governance**:** QUB Research and Enterprise Directorate manage research governance. It has implemented regulations, policies and procedures that must be complied with for research involving humans and / or animals. A research governance team supports and advises academics on governance issues. All research undergoes scrutiny by the office for Research Ethics Committees in Northern Ireland and the various governance organisations prior to formal approval.

e. COLLABORATION & CONTRIBUTION TO DISCIPLINE OR RESEARCH BASE

Examples of Contributions to the Discipline Within Assessment Period

Fellowships / Awards / Honours: Brennan (Visiting Prof, University of Madras, 2011); Dalton (Canada Research Chair 2009; Royal Society Wolfson Award, 2013); Elliott (Chair of Government review of integrity and assurance of UK food supply networks; Adjunct Prof in Food Safety, Chinese Agricultural University, Beijing); Maule (Bueding von Brand Memorial Lecture Award, American Soc of Parasitologists 2008; Membership of the Royal Irish Academy [RIA] 2012).

Editorial Board/Specialist Editor Activities (excludes special issue editorships): Allan (Vet Microbiol; DEFRA); Connolly (Front Predict Tox); Dalton (Int J Parasitol; J Infect Dis; Parasite Immunol; PLoS NTD; Nat Health & Med Res Council-Australia; Nat Sci Eng Res Council-Canada); Fanning (FEMS Microbiol Lett; App Env Microbiol; Foodborne Path Dis; Microbial Drug Res; Res Microbiol [Pasteur Inst]); Grant (App Environ Microbiol); Green (Sci Pharm; World J Gastroenterol); Maule (Front Endocrinol; Int J Parasitol; Int J Parasitol-Drugs Drug Res; J Helminthol; Parasitology); Meharg (Environ Exp Bot; Environ Poll; Environ Int; New Phytol); Mooney (Recent Pat Endocr Metab Immune Drug Discov); Mousley (Invert Neurosci); Prodöhl (Associate Editor, J Fish Biol; Front Evol Pop Gen); Timson (Biosci Reports; World J Biol Chem).

Selected Advisory Boards/Consultancy/Formal Peer Review Positions: Allan (Merial; Devonish Nutrition; FDA, USA); Connolly (Fusion Antibodies; XenoSense Ltd.); Dean (FAO & FSA reports, 08,09); Elliott (Neogen Corp; Chief Scientific Advisor, IAEA/FAO; Agri-Food QUEST); Fanning (Director WHO *Cronobacter* Centre; Academy of Finland; MRC; UN, FAO & FSA adviser); Grant (International Forum on Transmissable Animal Diseases & Food Safety); Marks (Vector Disease Surveillance Unit; Disease Advisor & Trustee, TACT); Maule (Infectious Disease Comm, Swedish Research Council); McGrath (Microbiology Awareness Campaign - NI Assembly & Oireachtas, RoI); Meharg (FDA; Fund for Scientific Research, Belgium; External for PhD Programme, Parma-Italy); Mooney (AgriFood QUEST Competence Centre Steering Comm), Prodöhl (ICES Working Group, Genetics in Fisheries & Mariculture; NERC Advisory Scientific Comm).

Selected Learned Society Positions: Brennan (Treasurer & President Microscopical Society of Ireland); Cuskelly (Nutrition Society [Irish Section] Committee Member); Dalton (founder, Australian Parasitology Network); Grant (Executive Committee and Trustee for Society of Applied Microbiology); Green (Secretary NI Branch of Society of Biology); Maule (RIA Life Sciences Committee and Selection Committee); McGrath (Chair, Society [Irish Section] for General Microbiology); Meharg (Fellow, Royal Society of Edinburgh [RSE], International and Selection Committees of the RSE); Mousley (Council Member and Treasurer, British Society for

Parasitology); Timson (Member of Council and Chair of Biochemical Society Irish Area Section).

Selected Conferences Hosted / Organised: 2008 - Microscopical Soc of Ireland Symposium, QUB; Advances in Modern Biotechnology and Molecular Techniques in Veterinary Parasitology, Alagappa-India; New Phytologist Symposium on Arsenic in Plants. 2009 - International Colloquium on Biotechnology and Management in Animal Health, Alagappa-India; Australian Soc for Parasitology, Sydney. 2010 – Breeding Low Arsenic Rice, Bangladesh; Arsenic 2010, Taiwan; Regulatory Peptides Meeting, Belfast; COST-RNAi Training School, QUB. 2011 - Symposium on Parasite Control, Chennai-India; Recent Advances in Food Analysis, Prague; 1st Food Integrity and Traceability Conf, QUB; Irish Soc for General Microbiology, QUB; ICOPTE 11, Florence; Trace Elements in Food 4, Aberdeen; 9th International Conf and Workshop on Lobster Biology and Management, Norway. 2012 - 4th International Feed Safety Conf, Beijing; SafeFood Chemical Residues Knowledge Network, Dublin; Arsenic 2012, Brisbane. 2013 - Technological Advances in Parasite Control, Aligarh-India; 11th International Mammalogical Congress, QUB.

Extent of Collaboration / New Strategic Linkages

International research leadership and collaboration are key principles of the IGFS research strategy. Research activities involve a huge array of national and international collaborations with a variety of schemes to support the development of research collaborations, e.g. staff can draw on support for co-funded studentships, external speakers, conference travel, research visits and internationalization. IGFS researchers have responded successfully to major initiatives in animal health / parasitology (major BBSRC-CIDLID, DEFRA, FP7, NPD - Ireland and INTERREG awards) and food safety (major FP7 awards; RCUK, NSF, INTERREG, DEFRA, FSA); the re-modelling and growth in core research themes means that IGFS staff are better placed to respond rapidly to research initiatives across global food security research.

Effective Academic Collaboration: The research within IGFS involves diverse interdisciplinary collaborations involving researchers from other Schools such as Chemistry, Computer Science, Engineering, Management, Medicine, Pharmacy, Physics and SPACE.

Much collaborative activity is international. Joint peer-reviewed publications involving IGFS personnel and international collaborators represent 64% of those returned in this REF exercise. Formalized collaborative projects have been established with researchers across Africa, Asia, Europe, North and South America. For example, researchers in the areas of Animal Health & Parasitology, Food Safety & Integrity and Plant & Soil Sciences coordinate or partner a range of major international grant awards involving multiple collaborating partners including EU-, RCUK- and DfID-funded projects with multiple current, formal international partnerships, e.g. BioCop, INTERREG-Celtic Sea Trout Project, CIDLID, DeLiver, Helivac, QSAFFE, Collab4Safety, DeTech21, Conffidence, Microaqua, Paravac, SALSEA-MERGE. Research development has also been enhanced through the establishment of formal links with The Institute of Food of and Health and Veterinary Medicine at University College Dublin (UCD).

Collaboration with Government Agencies and Industry: With respect to seeding innovation and impact development, formal linkages with multiple, global stakeholders are established through the QUESTOR and ASSET centres and collaborative research with government associated research centres in NI (FSA, DARDNI, Agri-Food Biosciences Institute) and RoI (Teagasc) facilitate the cross-fertilization of research activities and enhance research outcomes. A series of knowledge networks have been established collaboratively between IGFS and *safefood* on the island of Ireland that help integrate activity and provide for research synergy; the IGFS footprint in Ireland is further enhanced through the developing Fortress Food concept.

Industrial research collaborations during the REF cycle involved diverse Pharmaceutical [Aviagen, Bayer, DOW, GlaxoSmithKlein, Merial], Diagnostic [Neogen Corp., R-Biopharm AG, Syngenta, Virbac], Biotechnology [Waters, Xenosense] and Food [Avondale, Agrisearch, BioAtlantis, Crossgar Meats, Dromona, Dunbia, Fleming Poultry, Moypark, Nestle, Skea Eggs, Thompson's Feeds] industries. Many of these are ongoing and / or expanding.

Staff pursue the commercialization of research ideas, e.g. looking forward, four new Invest Northern Ireland Proof of Concept awards were won in 2013 by IGFS staff, seeding early stage IPR and development activities.