Institution: The University of Leeds

Unit of Assessment: 15 General Engineering

a. Overview Unit of Assessment 15 is represented by a single academic unit: the School of Process, Environmental and Materials Engineering (SPEME). SPEME is a multidisciplinary school, addressing a range of global and societal challenges across the areas of Energy, Chemical Engineering and Materials Science & Engineering.

The research activities of SPEME are clustered in three core Research Institutes:

- **Energy Research Institute** (ERI) 20 academic staff; Director: Prof. William Gale: energy science and engineering for the sustainable supply and use of energy.
- **Institute for Materials Research** (IMR) 11 academic staff; Director: Prof. Andrew Mullis: structure, properties, processing and applications of advanced materials.
- **Institute of Particle Science and Engineering** (IPSE) 17 academic staff; Director: Prof. Simon Biggs: design, measurement, modelling and manufacture of particulate materials.

During the last 5 years the School has responded to new opportunities and challenges by founding additional interdisciplinary research centres with other Schools and Faculties building on existing expertise and recruiting to new posts to meet the objectives of the Centres:

- **Centre for Integrated Energy Research** (CIER) - Director: Prof. William Gale: focussed on the synergy between energy policy and energy technology research, with input from both social scientists and engineers and highly collaborative, system-level outputs.
- **Energy Technology Innovation Initiative** (ETII) - Director: Prof. Mohamed Pourkashanian: focussed on large collaborative programmes in conventional power generation, virtual system simulation and renewable energy technologies.
- **Institute of Process Research and Development** (IPRD) - Director: Prof. John Blacker: a collaboration at the chemistry/chemical engineering interface to improve manufacturing processes for the fine chemical and pharmaceutical industries.

The School hosts the University's foremost cluster of postgraduate research in energy, the EPSRC's Doctoral Training Centre in Low Carbon Technologies, with 50 PhD students following an integrated MSc/PhD and contributing to the total cohort of 170 UK and overseas students.

In RAE2008 the Leeds submission to General Engineering, achieved a GPA of 3.0 and was ranked third in the UoA.

b. Research strategy

1. Overview SPEME aims to be within the top 5 UK engineering research schools and within the world top 40, with a reputation for achieving global impact in response to industrial and societal challenges in the areas of energy, transport, environment, materials, health, personal care and IT.

To achieve this aim requires excellence across all key measures, including the impact of our research outputs, the size of our PGR cohort and the effectiveness of our training environment. Research income per FTE academic staff is an accurate surrogate for a range of these indicators. SPEME's current strategy has been formed with an aim of increasing research income to £170k per FTE by 2016, more than 30% over the 2009 baseline.

An analysis of staff workload in 2009/10 showed that staff spent more than 50% of their time on UG and PGT education, with only 40% on research (including PGR training). Measures are in progress to rebalance workload to an average of 45% research, 45% student education and 10% administration and other activities. This target is ambitious at a time of rapidly intensifying competition in student education, however the number of taught credits in the School has been reduced by 25% as well as increasing the number of academic staff by 15% over the last 2 years. The combined effects will allow more time for research and PGR supervision, however as the majority of new staff were only recruited in 2013, it is expected that the impact on research income will not be seen until late 2014.

The increase in academic headcount has allowed the School to broaden and deepen its research portfolio compared to RAE2008 and to address **new challenges**:

- Energy: carbon capture, solar energy, algal biomass, energy technology - policy interface.
- Materials: photonic biosensors, data storage, rare-earth extraction, nanotoxicology.
- Particles: pharmaceutical manufacturing, the nuclear fuel process and petroleum engineering.

2. Research Management The 3 core Research Institutes provide focus and identity for the School's broad range of research interests. The 3 Institute Directors have a broad remit to lead the strategy development for their respective Institute, describing the requirements for investment in

staff, equipment and infrastructure. The School Management Board balances the research goals with those of student education, to monitor and refresh the School's 5-year strategy, which is reflected in staff and capital budgets.

The Management Board is supported by the Research Committee, which has both operational and strategic activities; it is the forum for driving coordinated responses to large research opportunities and for supporting the genesis of new research initiatives. It also has responsibility for all issues associated with PGR students such as the award and allocation of studentships and monitoring student progression. Research strategy is further informed by an Industrial Advisory Board made up of 12 external members selected to represent our relevant industry sectors, maintaining alignment of the School research portfolio to current and future industrial need.

The School's research strategy and investment plans are scrutinized as part of the University's annual Integrated Planning Exercise by the University's senior management team. Two annual meetings with the group review annual performance (October) and future plans (June).

The three core Research Institutes have the following profiles:

Energy Research Institute (ERI) The vision for energy-related research is to deliver the energy science and engineering needed to enable, enhance and accelerate the transition to low carbon, secure, economically viable and socially equitable energy systems at national and global levels. This is achieved through delivering advanced energy technologies for the sustainable production and use of energy and by incorporating these technologies in the whole systems context. Key sectors impacted by our research include the 'greening' of electric power generation; energy sustainability and emissions reduction for surface and air transport; sustainable industrial, commercial and domestic use of energy. The research falls into 5 areas:

- Advanced combustion science and engineering: encompassing the design of combustion systems [**Pourkashanian4**] and the design and evaluation of fuels and additives with applications in surface [**Li1**] and air transport [**Pourkashanian2**] and electric power generation. Unique aspects include studies of biomimetic combustion systems [**McIntosh1**] and energy, fuels and industrial materials from waste [**Williams P1 & 4**].
- Environmental pollution monitoring, modelling and control: Analysis and control of emissions from petrol, diesel [**Li2-4**] and aero-engines; the dispersion and environmental fate/impact of pollutants particularly from vehicles in the urban context [**Tomlin3**], fire & explosions [**Phylaktou1-4**].
- Renewable energy systems and future fuels: energy and fuels from biomass [**Jones1 & 4, Nimmo4, Dupont4**]; optimisation of biomass for power generation applications and full-scale trials [**Jones2 & 3**]; algal biofuels [**Ross2**]; hydrogen generation [**Dupont1-3, Williams P2**] and distribution [**Fairweather1**]; with growing activities in fuel-cells [**Hughes2**] and solar [**Crook2-4**].
- Carbon capture: oxy fuel carbon capture is a well-established activity [**Pourkashanian3, Nimmo3**, **Ma2**] growing areas include whole systems modelling; emissions from amine carbon capture; scale-up and modelling.
- Energy Policy: Energy demand at consumer [**Gale1**] and regional [**Gale4**] levels; global technology perspectives [**Taylor1 & 2**].

Institute for Materials Research (IMR) IMR's mission is to undertake internationally leading research in selected fields within materials science and engineering, serving the future needs of industry and society. The Institute undertakes applications-driven research related to a distinctive range of engineering materials, strongly supported by research into microstructural and nanochemical characterisation techniques. It embraces all approaches to materials science and engineering, from fundamental studies and modelling through to device fabrication, underpinned by the classical process-structure-properties paradigm. Key sectors impacted by our research include ICT, energy, health care, automotive and aerospace. The activity encompasses three themes:

- Functional and Bio-Materials including ferroelectric [**Bell1**], piezoelectric [**Comyn1 & 2, Bell2 & 3, Milne 1, 2 & 4**] and multiferroic [**Comyn4]** ceramics, thin films [**Bell4**] and crystals; photonic materials (active optical fibres and thin films) [**Jha1 & 3, Jose1-4**] carbon & carbide fibres [**Westwood1 & 2**], nanotubes, carbon composites [**Westwood3 & 4**], electrochemical and biological sensors [**Kale3 & 4**], dental materials [**Milne3, Jha2**] and nanotoxicity [**Brown2, Drummond-Brydson3**, **Kale1 & 2**].
- Metallurgy including the non-equilibrium processing of alloys [**Mullis3 & 4**], powder metallurgy and extractive metallurgy of rare earth elements [**Jha4**].

- Characterisation and modelling including electron microscopy especially of nanostructures [**Drummond-Brydson1**] and biological specimens [**Brown1, Drummond-Brydson2**], EELS [**Scott1, Drummond-Brydson4**], *ab initio* modelling of 2D structures [**Scott2-4**], microstructural modelling [**Mullis1 & 2**].

Institute of Particle Science and Engineering (IPSE) IPSE aims to create and disseminate knowledge in all aspects of the science, engineering and technology of particles and particle systems, using this knowledge to address relevant global grand challenges. It is an internationally recognised centre of excellence in the multi-scale measurement and modelling of particles and particle systems.

IPSE's research is multidisciplinary having Chemical Engineering at the core but linking to Energy, Advanced Materials, Healthcare, Biotechnology, Food Science and Chemistry. Examples include:

- nuclear waste treatment [EP/F055412/1 "DIAMOND"; EP/C549465/1 "KNOO", EP/L014041/1, "DISTINCTIVE", **Fairweather2 & 3**] colloids, emulsions and formulation [**Biggs1, Cayre3 & 4**], di-block copolymers [**Biggs2-3**], the mechanics of granular materials [**Antony1, 2 & 4, Ghadiri1-4, Hassanpour1-3, Muller2**], crystallisation processes [**Roberts1-3, Hammond1 & 2, Lai1-3**, **Muller3 & 4, Wang X1**], nanotoxicity [**Wang X3**] and applications of nano-particles and nanofluids [**Wen1-4**].

This activity is supported by two cross-cutting themes:

- Multi-scale modelling and process optimisation: including molecular modelling [**Hammond3 & 4**], discrete element modelling [**Jia1-3**], statistical mechanics modelling, computational fluids dynamics [**Fairweather4**], population balance modelling [**Wang X1**] and combinations thereof.
- Multi-scale measurements, advanced control and instrumentation: including X-Ray micro- and nano-tomography [**Roberts4, Jia4**], Raman spectroscopy and microscopy, near field microscopy, electrical tomography [**Wang M2 & 3**], on-line measurement and control of crystallisation [**Wang X2 & 4**] and multiphase flow [**Wang M1 & 4**].

3. Strategy In the audit period, staff expansion has provided the opportunity to develop and strengthen both new and existing areas of activity. In 2009, further to the plan laid out in RAE2008, a detailed activity analysis of the previous 5 years research was undertaken. This fed into a SWOT analysis of the School's research position, resulting in a revised strategy with a number of new initiatives. These have been supported by investments from both the School and the University. Where initiatives have involved recruitment of new staff, these are cross referenced in section c(i). The strategic aims, with the resulting actions/achievements in *italics* are:

S1. Accelerate impact in areas of conventional power generation, virtual system simulation, carbon capture and renewable energy technologies. *Formation of Energy Technologies Innovation Initiative (2011) to provide interfaculty opportunities for large collaborative programmes in the above areas.*

S2. Strengthen research on energy in aviation, broadening our capabilities beyond aero-fuels, combustion and emissions. *Lectureship appointments planned for 2014-15 academic year.*

S3. Create a virtuous circle between energy technology and energy policy research. *Established Centre for Integrated Energy Research with School of Mechanical Engineering and social scientists from the Sustainability Institute and Institute for Transport Studies, 2 new Chairs and 2 University Research Fellowships*.

S4. Expand impact of research into carbon capture. *Play a lead role in the new UK Carbon Capture and Storage Research Centre (Director - **Pourkashanian**) and establish Pilot Scale Advanced Capture Technology demonstrator (http://www.pact.ac.uk/; £13m EPSRC/DECC).*

S5. Develop research on energy demand reduction and distributed renewables. *Collaboration with the School of Civil Engineering (UoA 14) on energy for the built environment through ETII; 2 new chairs in Energy Technology for the Built Environment (2013).*

S6. Broadening the remit of combustion research to cover future fuels (*e.g.* algal biofuels, hydrogen economy) and extending research on renewable energy. *2 RCUK Research Fellows; £700k new funding in algal/seaweed biofuel research. Formation of White Rose Network (Leeds, York, Sheffield and Hull) for CO_2 derived solar fuels.*

S7. Expand research and impact in Functional Oxides consistent with our map onto the EPSRCs Shaping Capability exercise. *Participation in national and international collaborative programmes (total £10m); developed IP (PCT/GB2011/051356) with EPSRC CTA and RDA*

investment; spin-out company (Ionix Advanced Technologies Ltd, www.ionix.at) launched.

S8. Expand research into optical and electrochemical diagnostic biosensors. *Appointment of new Chair (2013); major 3rd party investment to exploit new IP.*

S9. Develop expertise in the toxicity of nanoparticles with School of Chemistry and Faculty of Biological Sciences. *Leading roles in 3 EU research programmes on nanotechnology (ENNSATOX, QUILATYNANO and MARINA). AXA Fellowship in Nanoparticle Risk (2013).*

S10. Sustain developments in electron microscopy. *Leadership of the EPSRC's National Facility for Aberration-Corrected Transmission Electron Microscopy (http://www.superstem.com/).*

S11. Better exploit the world leading Diamond light source for the characterization of advanced materials, functional particles, pharmaceuticals. *Secured funding from the Royal Academy of Engineering, Infineum and Diamond to initiate the University of Leeds Bragg Centenary Chair to be located at Diamond (to be appointed early 2014).*

S12. Respond to the national need for exploiting collaboration at the chemical engineering-chemistry interface. *Established the Institute for Process Research and Development with the School of Chemistry; University-funded Chair appointments (2) and University research Fellows (2); unique facilities for 40L pilot trials funded by £4.85m ERDF/RDA investment.*

S13. Strengthen joint activities with Chinese institutions on energy research. *Established a joint research institute with Chinese Academy of Sciences Institute for Process Engineering and initiated collaboration with Xiamen University Energy Research Institute*; *awarded Royal Society International Exchanges 2012 with Dalian University on biomass and waste*

S14. Stimulate research in emerging and cross disciplinary areas within the School. *Creation of Chair (2012) and lectureship (2013) in Nuclear Process Engineering; initiated "mini" CDTs in Nuclear Engineering, Process Research and Advanced Particulate Materials.*

S15. Develop Petroleum Engineering PGR profile. *Creation of a Chair (2013) and participation in the Centre for Integrated Petroleum Engineering and Geoscience (CiPEG).*

S16. Develop strategic industrial partnerships with national and multinational companies. *E.g. Leeds - P&G Simulation Centre and Sellafield Ltd Sludge Centre of Expertise established*

S17. Accelerate impact of advances in colloid processing of complex particulates for the life science and personal care sectors. *Appointment of chair and lectureship positions.*

S18. Translate expertise in atomistic and microstructural modelling and high resolution microscopy into studies of materials under extreme conditions. *Joint STFC Daresbury Hartree Centre/ Leeds tenure track appointment in applied multiscale computational modelling.*

S19. Develop expertise in the application of state-of-art electron microscopy techniques. *Award (2008) and subsequent renewal (2012/13) of EPSRC Nanoscience and Nanotechnology Equipment Facility (LENNF) specialising in characterisation of hybrid-inorganic systems*

Three of these initiatives were specific responses to how the School could address national and international priorities that cut across disciplinary boundaries. As a result, three interdisciplinary institutes were formed in collaboration with other Schools in the University:

The **Centre of Integrated Energy Research** (CIER; www.cier.leeds.ac.uk) [S2] was formed in 2010 to significantly increase research at the energy policy / technology interface, which is under-exploited both nationally and internationally. The initiative was funded (£3m) through the University's Transformation fund and involves engineers and scientists from SPEME, the School of Mechanical Engineering, the University's Sustainability Institute and Institute for Transport Studies. Two new Chairs (**Taylor and Cockerill**) and 2 University research fellows all with substantial experience at the technology/policy interface have been appointed.

The **Institute for Process Research and Development** (iPRD, www.iprd.leeds.ac.uk) [S15] was initiated jointly between SPEME and the School of Chemistry in a direct response to the EPSRC International Review which criticized the lack of collaboration between chemistry and engineering departments. It was created in 2008 with investment (£500k) from the University's Transformation Fund and was successful in attracting 2 new Chairs from industry (**Blacker & Muller**) supported by 2 University Research fellows (**Bourne/Nguyen**). The Institute is industry-facing and is able to provide multi-user, 40 litre pilot scale facilities unique to a UK university, established and supported by RDA/ERDF funding.

The **Energy Technologies Innovation Initiative** (ETII, http://etii.leeds.ac.uk/) [S1], headed by **Pourkashanian**, developed from the School's ambitions to exploit its expertise in carbon capture in larger scale collaborative programmes and develop new research on renewable energy technologies. It is currently extending its remit to smart grids and energy for the built environment

with 2 chair appointments joint with Civil Engineering.

A further outcome of the 2009 review was that areas of activity regarded as being below critical mass and with relatively low national and international priority were discontinued; examples include mining research and ferrous metallurgy.

Having strengthened and extended our research capabilities internally through new appointments, the strategy focus for the next 3 years is to develop meaningful partnerships with research sponsors and beneficiaries. We aim to consolidate our strategic partnerships:

- carbon capture, through leadership of the UK PACT facility;
- bioenergy with UK electricity generators;
- nuclear process engineering, through partnership with Sellafield & National Nuclear Labs and leadership of EPSRCs major programme on nuclear decommissioning;
- energy collaborations in China (Xiamen, Zhejiang and Xi'an Jiatong Universties)
- particle process technology as applied to food and personal care products with P&G;
- cutting edge materials analysis and modelling through partnerships with the Diamond Light Source, SuperSTEM and the Hartree Centre;
- synthonic engineering with Pfizer, Astra Zeneca and other UK pharmas.

Areas in which new partnerships will be targeted include functional materials, petroleum engineering and automotive power train.

4 Achievements

The School has published **2200 journal articles, 650 conference proceedings and 75 patent applications** since January 2008 and 5 spin-out companies have been incorporated. The work of the School is recognized both for its academic excellence and for the external impact it creates:

- Biomimetic propulsion systems based on the bombardier beetle, winning the "Times Higher Education Outstanding Contribution to Innovation and Technology Award (2010)" and licensed to Swedish Biomimetics 3000, for use in fuel injectors and fire extinguishers [**McIntosh1**].
- Research on alternative biomass fuels led to full-scale trials by UK power companies [**Jones1 & 2**] and international growth of activity in processing of algal derived biofuels [**Ross2 & 3**].
- Work on optical biosensors for non-invasive blood glucose monitor selected as a finalist in the 2012 Medipex NHS Innovation Awards; won investment from NetScientific [**Jose3**].
- £1m venture capital investment has been secured to establish a company (Rare Earth Technology Ltd.) to exploit IP developed for enhanced rare-Earth recovery technologies [**Jha4**].
- Modelling of the processing of improved Ni-based catalyst to replace Pt in hydrogen fuel cells [**Mullis**] aided the IMPRESS project being rated as one of the top 10 projects from FP5, 6 & 7.
- World leading, basic research on industrial process tomography [**Wang M 2**] has been successfully transferred to UK company, ITS, with a significant increase in sales (case study 3).
- New piezoelectric materials with twice the strain and 200°C higher operating temperature than market leaders; formation of spin-out Ionix Advanced Technologies Ltd [**Bell3**].
- Sensitivity analysis tools developed by the school [**Tomlin4**] for environmental applications have found worldwide application in fields as diverse as machine vision and brain research.
- Application of electron microscopy to inorganic materials in biological systems [**Milne3**, **Brown1 and Drummond-Brydson2**].
- Incorporation of actives into diblock copolymer micelles to produce multifunctional nano-delivery systems [**Biggs2, 3 & 4**].

c. People, including:

i. Staffing strategy and staff development The School's academic staff profile is well matched to the teaching programmes and research strategy of the School and presently comprises (as FTE) 23.5 Professors, 12 Associate Professors (incl. Readers & Senior Lecturers), 12 Lecturers and 2 5-year Research Fellows (including RCUK fellows, Royal Society Fellows, EPSRC Fellows, etc.).

The School's strong financial position and the University's policy of making key investments to support Schools' research and teaching strategy (Leadership Chairs Initiative) and to intensify interdisciplinary research (Transformation Fund projects) have facilitated significant recruitment. Virtually all the new recruits were in response to the initiatives resulting from our 2009 review. The level of appointment for each of the positions was determined by whether the relevant initiative required leadership (i.e. Chair level) or strengthening of existing activity (Senior Lectureship/ Lectureship/ University Research Fellow). Key recruits, referenced to initiatives in section b, are:

- Creation of 3 Senior Lectureships in the ETII (**Hughes, Ma, Nimmo**, 2011) [S1]
- Recruitment of Chair in Sustainable Energy Systems (**Taylor**, 2011 ex International Energy Agency), joint with the Sustainability Research Institute (UoA7) [S3]
- Recruitment of Chair in the Engineering of Sustainable Energy Systems (**Cockerill**, 2013 ex Imperial College) joint with School of Mechanical Engineering (UoA12) [S3]
- Creation of two University Research Fellowships, filled by **Wadud** (2011, integrating energy technologies for sustainable transport) and **Upham**, (2011, public acceptance of energy technology); the fellowships are joint appointments with the Institute for Transport Studies (UoA14) and the Sustainability Research Institute (UoA12), respectively [S3]
- Appointment of two Chairs in Energy in the Built Environment (**Heyes** (ex Imperial College) and **Jaworski** 2013) jointly with the School of Civil Engineering (UoA14) [S5]
- Appointment of two RCUK Fellows transport emissions in the fields of aviation combustion and emissions (**Li**, 2008) and algal biofuels (**Ross**, 2008). [S6]
- Appointment of a Chair in Functional Materials (**Jose**, 2013) [S8]
- Award of RAEng Bragg Centenary Chair jointly with Diamond Light Source (2013) [S11]
- Appointment of a Chair in Reaction Engineering in IPRD (**Muller**, 2011 ex AstraZeneca), joint with the School of Chemistry (UoA 8) [S12]
- Appointment of a Chair in Nuclear Process Eng (**Hanson**, 2012 ex National Nuclear Labs) [S14]
- Appointment of a Chair in Petroleum Engineering (**Wen**, 2013 ex QMUL) [S15]
- Appointment of a Lecturer in Petroleum Engineering (**Hassanpour**, 2010) [S15]
- Appointment of a Chair in Structured Particulate materials (**York** 2012 ex P&G) and Lecturer in Chemical Engineering (**Cayre** 2012) to further develop the exploitation of colloid science in life science and personal care. [S17]
- Appointment of a Chair in Chemical Engineering (**Bayly** 2013 ex P&G) to replace Prof. R.A. Williams (now Dean of Engineering and Physical Sciences, Birmingham University).

Planned recruitment over the next two years includes: two lecturers in Aviation [S2]; two lecturers in Nuclear Engineering [S14]

Since RAE 2008, the following academic staff have entered full or partial retirement: Birch, Fowell, Gibbs, McIntosh, Hoyle, Wilkins, Gee and Edmonds. **R.A. Williams** has left (see 14 above); **Ding** has taken up a Chair of Chemical Engineering at the University of Birmingham.

The University has a policy of encouraging career progression from post-doctoral research to independent researcher through externally funded 5 year personal fellowships (e.g. EPSRC Postdoctoral and Early Career, Royal Society). A specific probation process applies to 5 year fellows to develop them through the fellowship to become full academic members of staff. During the audit period the School and the following submitted academic staff have benefitted from this development process: **Crook**, **Li**, **Ross**, **Scott**; **Brown**; **Westwood**, **Bourne**.

Academic staff enjoy a collective culture that directly links their career aspirations with the School strategy. This is facilitated through an Annual Academic Review, in which each academic staff member meets with the Management Group. The meeting is aimed at ensuring that staff workload is balanced to satisfy personal aspirations and those of the School. All academic and support staff members participate in the annual, campus-wide, Staff Review and Development Scheme (SRDS) in which each member of staff identifies their development needs through a review of their achievements and future plans with their line manager.

Recruitment is critical to the sustainability of the School and all staff are treated in a fair and equitable manner in accordance to the Faculty Equality and Diversity regulations ensuring that we treat all individuals fairly with dignity and respect, the opportunities we provide are open to all, and we provide a safe, supportive and welcoming environment to staff, students and visitors. In recognition of our commitment to equality, the Faculty has been awarded the Athena Swan bronze award for supporting career development of women in SET disciplines.

ii. Research students SPEME is host to a thriving cohort of postgraduate research (PGR) students which is well-balanced across all activities of the School, currently comprising 94 Home/EU and 76 International students.

The Doctoral Training Centre (DTC) in Low Carbon Technologies [EP/G036608/1, £6.5m] was established in 2009 and by 2017 will have trained 50 PhD students. The centre offers an integrated MSc and PhD. Taught modules are followed in the first two years with short research projects to allow students an insight into potential PhD topics. In year two, students are allocated to PhD

supervisors who are drawn from both SPEME and the Faculty of Earth and Environment.

Centre Director (Prof PT Williams) was a key figure in establishing the UK Network of Energy Centres for Doctoral Training (comprising 13 centres, £60m expenditure by the RCUK Energy Programme, 600 PhD students). Prof Williams is now the co-Director of the Network (EPSRC Grant EP/I036608/1, £174k), of which the Public Engagement Manager is based at Leeds.

The above model provides significant added benefit over the conventional 3 year PhD. In addition to the academic benefits of a clearly identifiable and relevant collective programme of research, the Centre provides for additional pastoral and outreach activity, which encourages an *esprit de corps* and enhances the student experience. In view of the benefits of this approach, the School decided in 2011 to allocate the majority of its future EPSRC Doctoral Training Account, supplemented by internal funds, to create inter-Institute Centres for Doctoral Training (CDTs) in 3 areas: Nuclear Process Engineering, Advanced Particulate Materials and Process Research and Development. As a consequence virtually all UK PhD students entering the School in 2013 are following the CDT model. A proposal to succeed the Low Carbon Technology Centre with a CDT on Bioenergy and a proposal for a CDT on Particulate Technology, both hosted by SPEME, are currently progressing through the second round of the EPSRC call.

The School has strict eligibility criteria for PG research based on academic achievement and English language ability. In addition to marketing PGR opportunities to undergraduate and taught postgraduate students on campus, the School works with the Faculty of Engineering Marketing Unit to attract both Home/EU and International students to undertake PG research within SPEME. This includes representation at graduate fairs overseas, advertising of specific project opportunities and participation in the University's well publicised scholarship schemes, such as the Full International Scholarships, or the Leeds-China Scholarships Council scheme. Prospective PGR students have a single point of application and contact through the Faculty Graduate Office.

It is the norm that the supervision of each PGR student is shared by two or more academic staff, approved by Research Institute Postgraduate Tutors on behalf of the School, ensuring that the combination is appropriate in terms of available resources and fit to the School's strategy. In this way, the majority of candidates are able to pursue their first choice of research topic.

All PGR students are allocated their own desk and personal computer. For each non-Research Council ("self-funded") student, the School makes a nominal allocation of £1000 p.a. to the lead supervisor for consumables, small equipment and travel associated with the project. In addition, access charges to the Small Research Facilities for PGR students are charged directly to the School and are treated as being covered by the tuition fees income.

PGR students benefit from carefully designed induction and training programmes provided by a combination of dedicated Faculty staff and the University's Staff and Departmental Development Unit. The training encompasses both skills essential for completion of a PhD (e.g. "Speed PhD", Public Communication of Science, poster and oral presentation, ethics) and transferable technical skills (e.g. Health & Safety, Technical Writing, Project Management, Statistics, Programming).

An on-line system for monitoring the progress of PGR students has been established ensuring that there are at least 12 formally recorded meetings between students and supervisor(s) each year and that short academic progress reports are jointly filed by student and supervisor at 6 monthly intervals. PGR students are only registered as PhD students on completion of progression, in which they submit a short report comprising an initial literature survey, a summary of their initial research and a detailed research plan. This is examined orally by two academic staff, at least one of which is not associated with the student's research. The School's postgraduate tutoring team monitor performance to identify any systematic shortcomings in supervision.

Supervisors are strongly encouraged to ensure that PGR students are involved in publishing and presenting their work at an appropriate stage and it is recommended that all students be afforded the opportunity to attend at least one international conference during their PhD studies.

Many of our PGRs are outstanding, an example being Tim Stevenson winning the Best Young Engineer Gold Medal Award at SET for Britain Awards 2011.

d. Income, infrastructure and facilities

Research Infrastructure The School occupies the Engineering and Energy Buildings on the northern perimeter of the main campus. The Engineering building is well maintained and continued investment has ensured that it continues to be fit for purpose and offers state-of-the-art facilities. During the audit period a sum of over £20m has been spent on improvements to the infrastructure.

A number of specific related investments are worthy of note:

- The University opened a new £12.5m Energy Research Building in autumn 2011 to create 3,400 m^2 of new space contiguous with the Engineering Building. The new building brings together SPEME energy-related research (ERI, CIER and ETII) under one roof with sector-leading facilities for combustion, renewables and carbon capture research.
- In 2009 the basement of the Engineering Building was refurbished at a cost of £1.2m to provide state-of-the-art facilities for Functional Materials research and X-ray diffraction.
- In 2010 a new £3.45m process laboratory was established jointly with the School of Chemistry with funding from Yorkshire Forward and the European Regional Development Fund. The laboratory is operated by IPRD and provides pilot scale facilities for process development.

Planned Infrastructure Activities The School has recognised the renaissance of the nuclear industry within the UK. In addition to a recent appointment of Chair in Nuclear Process Engineering, two further appointments have been made in this important research area. Over the audit period the School has established two strategic research partnerships with nuclear companies and initiated an industry funded nuclear Centre for Doctoral Training. The sustained growth in the School's nuclear profile over the past 5 years has provided sufficient confidence to commit to invest in refurbishing over 250 m^2 of space to provide a suite of state-of-the-art nuclear process research laboratories, with funding resource derived from internal and external sources, including Government and industry.

Research Facilities Over the audit period the School has invested £2.7m in large research equipment through full economic cost recoveries. This has included improvements to the electron optic facilities (a new field emission gun transmission electron microscope and an environmental scanning electron microscope) plus a suite of new analytical equipment for energy research. As current coordinators of the National Facility for Aberration Corrected Scanning Tunnelling Electron Microscopy (SuperSTEM; PI: **Drummond-Brydson**), the University has invested £250k of its own funds in the new, world-leading £2.2m Nion microscope. Carbon capture research is benefitting from the £3.4m capital investment (DECC) and £5.5m donation by RWE in the PACT national facility for research into the scale-up of carbon capture methods.

The School operates a number of shared analytical facilities for customers both inside and outside the University. These facilities have dedicated technical support to ensure they are operated in an efficient and professional manner, providing analytical support and/or training to internal and external customers. This provision is offered through four Centres, namely:
Leeds Electron Microscopy and Spectroscopy Centre (LEMAS), which offers state-of-the-art electron optic facilities including transmission electron microscopy, dual-beam focused ion beam and scanning electron microscopy, supported by 3 technical staff. The Centre acts a Small Research Facility (SRF) for academic users with an annual turnover of £600k, approximately 6% of which is derived from industrial consultancy.
X-Ray Diffraction (XRD) This facility hosts two state-of- the art XRD instruments (Panalytical MFD and Bruker D8) and is run as an SRF (Turnover £65k p.a.). The facility provides analytical services such as qualitative and quantitative phase identification and sophisticated research techniques, such as reflectometry, stress & texture analysis and temperature & atmosphere controlled studies. It is the main conduit for access to national and international large diffraction facilities, worth approximately £1.5m as in-kind income during the audit period.
Analytical Laboratory With a recent investment of £500k through HEFCE (SRIF 4) the ERI Analytical Laboratory offers state-of-the-art sample preparation and analytical instrumentation to researchers across the University and to outside organisations.
Particles Centre for Industrial Collaboration (ParticlesCIC) Opened in 2003, the ParticlesCIC has operated through the REF2014 audit period and has provided analytical services in particle characterisation to the University and external customers. ParticlesCIC also delivers CPD short courses, consultancy and provides services such as expert witness for legal matters. With an industrial customer database in excess of 500 this Centre has been the outward facing profile for IPSE for the past 10 years with an annual income of over £100k in analytical services.

Investment by the School in facilities and infrastructure has targeted priority areas identified within the research strategy. The facilities highlighted above are based within particular Institutes but are generally utilised by the School as a whole. During the audit period, facilities were decommissioned that had gone beyond their useful lifetime. Originally built in the 1960s the School 'Pilot Plant' building, which had been used to house teaching and large scale research equipment,

was demolished to make way for the new Energy Building.

Average annual research expenditure has risen to approximately £5.5m p.a. during the audit period, with just over half of this coming from the UK Research Councils, predominantly EPSRC. Income from industry, TSB and EU account for between 12 and 14% each with regional government sources accounting for the majority of the remainder. The distribution of sources has remained approximately constant throughout the period, however, the current strategy is to reduce the reliance on Research Council income in favour of industrial and EU funds; to this end, specialist teams of facilitators both at the University and Faculty levels have been established to aid with large, particularly EU, proposal preparation.

During the audit period 24 staff were involved in 144 consultancy projects, covering 65 separate companies, worth £1.71m; with income split into research sectors Energy 25% (47 projects, 8 staff), Materials 5% (6 projects, 4 staff) and Particles 70% (92 projects, 12 staff). Growth of consultancy and thereby engagement with the industry sector is viewed as a critical factor for the School to maintain a leading role in research.

The School also has a substantial portfolio of Continuing Professional Development short courses. Examples of these include, '*Introduction to Colloids and Surfaces*' (**Biggs**), '*Royal Microscopical Society - Electron Microscopy*' (**Brown**, **Drummond-Brydson**, **Scott**), '*Energy form Biomass*' (**Dupont**, **Jones**), '*Chemical Plant Commissioning*' (**Fairweather**), '*Formulation Science and Technology*' (**Hassanpour**), '*Powder Sorbants for CO_2 Capture*' (**Milne**), '*Thermal Treatment of Municipal Solid Waste*' (**Williams P**). Over the REF audit period there has been 77 annual short courses, generating a total income of £1.8m. These courses have resulted in over 1,700 delegates coming to the University of Leeds from the UK, EU and international locations thereby facilitating new lines of enquiries being opened generating additional consultancy and research.

e. Collaboration or contribution to the discipline or research base

SPEME staff are active in external activities that contribute to the development of their discipline: 20 staff are EPSRC college members ; 40 staff peer review for over 100 other funding agencies; 50% of staff regularly review for a total of over 150 international journals; 15 staff have editorial board responsibilities for 25 international journals.

National Collaborative Programmes The School has a broad base of research collaborations:

- **"***UKCCSRC - The United Kingdom Carbon Capture and Storage Research Centre"***,** [**Pourkashanian**] Edinburgh, Imperial, Leeds, Cambridge, Newcastle, Nottingham, Cranfield Universities and BGS, EPSRC £10.1M, Leeds £1.3M
- **"***CPPilot 100+, UK demonstration project* [**Pourkashanian**] Sponsor: SSE (Scottish and Southern Energy), in collaboration with Doosan Power Systems and Vattenfall, has been awarded £6.3 million by DECC, the Technology Strategy Board and Northern Way.
- *"PACT –CAPSULE (CO_2 Capture Solvents for Ultra Low Energy), Carbon Clean Solutions"* [**Pourkashanian**] an SME establishing a new technology hub in the UK, working with Imperial College and Leeds (the UK CCS Research Centre's Carbon Capture Pilot Scale Advanced Capture Technologies facility), Department of Energy & Climate Change £3.3M
- *"DIAMOND, Decommissioning, Immobilisation and Management of Nuclear Wastes for Disposal"* – RCUK Energy Programme / EPSRC, £4.2m, [**Biggs**]. Consortium of 6 universities with financial and in kind support from 20 companies including the National Nuclear Laboratory, Nuclear Decommissioning Authority and Sellafield Ltd. 35 researchers with 50 academic and 35 industrial supervisors across the membership.
- *"SuperSTEM Consortium"* – EPSRC, £5.8m, [**Drummond-Brydson**]. EPSRC national facility hosted at Daresbury with Leeds as the lead, with Liverpool, Glasgow, Oxford and Manchester.
- *EPSRC Nanoscience and Nanotechnology Equipment Facility (LENNF)* [**Drummond-Brydson**] *(awarded 2008 and renewed 2013-2016 with Physics and Elec. Eng at Leeds) provides free at point of access use of equipment and expertise to external EPSRC users.(EPSRC £1.1M). 2009-2012 served a total of 156 users, from > 25 institutions supporting over 110 EPSRC grants of facility users and producing almost 50 journal publications.*
- "*City Energy Futures*" – EPSRC, £1.1m, **Gale**. Interdisciplinary collaboration of researchers in energy engineering, energy policy, socio-technical systems design and applied mathematics/ computer science of complex systems.
- "*I4T, Innovation In Industrial Inkjet Technology*" – EPSRC, (£5.24m / £1.6 to Leeds), [**Biggs**] Universities of Leeds, Cambridge, Durham;

- "*New and Improved Electroceramics*" EPSRC (£4.75m / £0.58 Leeds), [**Bell**], with U. Sheffield;
- "*Sandpit: Mobile Energy Harvesting Systems*" – EPSRC/DSTL (£1.1m), [**Bell (PI)**], Universities of Bristol, Cranfield, Essex, Leeds, Liverpool, Sheffield, Southampton;
- "*Next Generation Visualisation & Metering Technology for Multi-Phase Flows*" – EPSRC (£1m), [**Wang M (PI)**], Universities of Leeds, Huddersfield, Cambridge, with Schlumberger and ITS Ltd

International Collaborative Projects International collaborations accounts for approximately 15% of the School research portfolio. Approximately 5% comes from non-EU industrial collaboration, with the remainder being mainly via EU Framework Programme 7. Exemplars include:

- "QNano" (www.qnano-ri.eu) – EU FP7, 13 countries and 27 partner institutions supporting the EU's nanosafety community. Project value €7m (€355k to Leeds), [**Drummond-Brydson**].
- "Nanomotion" – EU FP7 Marie Curie ITN, €3.4m 16 partners; Value: £280k [**Bell**].
- IMPRESS (www.spaceflight.esa.int/impress/) – EU FP6, €41m, 40 EU partners, 150+ scientists from 15 countries, in the top 10 FP5/6/7 projects (out of 900+), [**Mullis**].
- **"***RELCOM—Reliable and Efficient Combustion of Oxygen/Coal/Recycled Flue Gas Mixtures***"**, Glamorgan, Abo Akademi, E.On, TUM, EDF, IEN, IFK, Leuven, Doosan Power Systems, ENEL, IFRF, Ciudad, Leeds. EU FP7**,** €10M (Leeds £628k) [**Pourkashanian**]
- "*OxyCoal Combustion Processes through Numerical Modelling and 3D Flame Imaging*"**,** (RCUK-China)**,:** BOC Ltd, Electric Power Research Institute, ANSYS UK, Mitsui Babcock Energy Ltd, RWE Npower, South China Power Company, University of Technology Zhejiang, Leeds. EPSRC: £490.610 (Total for consortium £1.1M led by Leeds). [**Pourkashanian**]
- Danone "Characterisation of Mixing Behaviour in Industrial Vessels", £128k [**Wang M**]
- Wuhan Iron and Steel Corp. "Microstructure of Steels" £282k [**Westwood**]

Leadership in the academic community Members within School have leading roles within their field of expertise and are recognised as such both nationally and internationally, through awards, roles within industry, conference chairs, invited lectures etc. A summary of these is as follows.

Awards and Prizes: Bell: IEEE Ferroelectrics Recognition Award (2012) **Biggs:** Fellow of the Royal Academy of Engineering (2010); IChemE Core Chemical Engineering Prizes jointly with Sellafield Ltd (2011 & 2012) **Drummond-Brydson** IoM3 Pfeil award (2009). **Gale:** US FAA Outstanding Leadership award, (2008); **Fairweather** Frank Lees Medal of IChemE (2009). **Mullis** Metal Powders Industry Federation prize at PowderMet (2007); **Wang M** awarded the "Outstanding Contribution Medal 2008" from Nihon University, Japan. **Williams P**, awarded Distinguished Guest Lecture Medal by the Environmental Chemistry Group, Royal Society of Chemistry (2012).

Advisory Board Appointments: Bell: US Office of Naval Research Piezoelectric Materials and Transducers Programme (2012/13); **Drummond-Brydson:** Scientific Advisory Board of Limerick University Materials Institute, Ireland; Steering Group for the National Centre for Surface Spectroscopy, Daresbury, UK (2006-2011); **Jones:** advisor to the Department of Business, Innovation and Skills (2009); **Mullis:** UK Space Agency Space Environments (Microgravity) Working Group. **Pourkashanian:** Member of EERA for EU SET-Plan, 2015 vision (UK representative for CCS Capture); Department of Energy and Climate Change Energy CCS Roadmap UK-2050; All Party Parliamentary Renewable Transport Fuels Group **Taylor:** Steering Group to UK Energy Research Centre; advisory board on Accelerating Energy Innovation at the International Energy Agency. **Tomlin:** Air Quality Expert Group, **Williams P**.: NERC Programme Advisory Group for the Resource Recovery From Waste programme.

Learned Society Participation The following are members of committees of international organizations: **Bell**: IEEE UFFC Society Admin Cmmtt, Elected Member, Deputy Vice-President, Ferroelectric Cmmtt (2008-12); **Drummond-Brydson**: Exec. Board member of European Microscopy Society; **Fairweather**: Computer Aided Process Engineering Cmmtt of European Federation of Chem. Eng. In addition, 11 staff serve on committee of UK-based societies

Conference Participation: UoA15 academic staff made over 20 plenary and keynote presentations at international conferences serving on more than 30 conference organizing committees, including the following as Conference Chairs: **Bell** 19th IEEE ISAF (2012). **Biggs** UK Colloids (2011) **Fairweather** 22nd Symp. Computer Aided Process Eng. (2012) **Nimmo** UK-Pakistan Coal Conference (2012). **Wang M** 6th World Congress of Process Tomog. 2010.