Institution: Ulster - Unit of Assessment 13: Engineering Research Institute - ERI

Overview: Engineering materials research at Ulster was initiated less than 25 years ago and due to substantial growth and effectiveness over that period, the University sought to create a solid foundation for future expansion by formally establishing the Engineering Research Institute (ERI). This followed a series of new investments via SRIF & RCIF grants (£5m) and 3 new professorships over the past 5 years. ERI now offers a more integrated environment of shared facilities and resources to encourage inter-group collaboration and foster high-impact interdisciplinary and innovation-based approaches. Our new industry-led centres as well as pioneering technology transfer via seven successful spin-outs, high levels of consultancy (over £3m) and international collaborative R&D, reflect our strong position in linking the academic and commercial worlds. Our new centres include the £6m **Northern Ireland Advanced Composites & Engineering Centre** (NIACE), the associated £5m competence centre (NIAECC); the £5m Connected Health Innovation Centre (**CHIC**); the £3m **AVX-INI Ceramics Centre of Excellence** (CEE); our collaborative EPSRC-**MATCH** National Centre (£6.3m); two cross-border centres, **DEL Centre for Intelligent Point of Care Sensors** (CIPS-£2m); **DEL Collaborative Centre for Functional Biomaterials** (CCFB-£1.4m) and the Centre for Advanced Cardiology Research (CACR). Our collaborative culture helps ensure that new and early career research staff are given every opportunity to fulfil their potential via access, training, mentoring and seed-funding.

Research Structure: Engineering research at Ulster is directed and managed via ERI (Director-McLaughlin), one of 16 such institutes established to enhance the University's reputation for research excellence, create critical mass within high impact research areas and to make effective and efficient use of resources. ERI has now consolidated the foundation for engineering, materials and devices research and provided a solid platform to develop and expand the research capacity and proactive research culture in the future. ERI manages the research activities of the School of Engineering which comprises 120 people (academics/ research staff/PhD's/admin). The three main research themes and associated research centres are outlined in Table 3.

TABLE 3: Research Structure	Associated Research Centres	Academic Staff Members	Sub-Groups
Functional Materials and Devices	NIBEC, CHIC and CIPS	McLaughlin, Davis, Maguire, Escalona, Byrne, Lemoine, Finlay, Dunlop, Mariotti, Papakonstantinou,	Connected Health Sensors; Plasma Technology; Nano- and Photocatalysis Materials
Biomaterials	NIBEC, MATCH, CCFB	Meenan, Boyd, Dixon, Brown and Burke	Tissue Engineering
Structural Materials	ECRE, AMFoR & NIACE	McIlhagger, Archer, Quinn, Leacock	Composites; Metal Forming

2.0 Research strategy: The University's vision is "to be a model of an outstanding regional university with a national and international reputation for quality". Within ERI's research strategy its key aims are: to deliver high quality international research and to promote the exploitation and application of science and engineering-based research through technology transfer. This includes licensing, spin-out company formation, support for existing industry, and through incubation, innovation and the science research park development (NISP). This, in turn, enhances the recruitment of very high calibre academic, research and clinical staff with demonstrable research and teaching achievements. Our core strategy is aligned with major EPSRC themes (advanced materials, manufacturing the future; healthcare technologies) as well as EU FP7 and Horizon 2020 research programme (focussing on challenges in nanotechnology, e-health, clean technology, composites) and the industry and societal challenges of health and demographic change as identified by TSB, BIS, EU Horizon 2020 and MATRIX NI. Our strategy in detail seeks to increase research staff and student numbers, to improve our publication rankings & citations, grow funding and further international links. We also aim to improve our building resource infrastructure, enhance the nanotechnology, composites and bioengineering capability and develop additional industry and clinical MoU's, to enhance impact via technology transfer and outreach.

Our targets have been achieved by consolidating our basic materials science research and driving

application streams via collaborative projects involving industry, key universities and other stakeholders. In particular our vision is to be one of Europe's leading engineering-led innovation centres underpinned with a strong and vibrant material science and engineering devices fabrication capability. This strategic approach has already delivered significant benefits for ERI in the reporting period. Compared to the 2008 submission, our staff return is up by 58%, external research funding is up by 86% (over £10m in the year 2013), UKRC funding spend is up by 163% and EU by 314% as indicated in Table 4. The number of PhD student graduations has increased by 28% and is complemented by substantial growth in Masters level awards (160). Journal publication, conference and patent outputs have improved in quality (3 front covers: J. Phys. D (DM), Eur. Phys. J. Appl. Phys. (DM), Analytica Chimica Acta (JD)); an improved impact factor average; increased in quantity (up 30%). Collaboration with major industries via our new centres (e.g. GE Healthcare, AVX, Seagate, GSK, Bombardier, Rolls-Royce, Veeco) and SME companies (e.g. Heartscape, EnBIO, Randox) continues to be a major strength with commercialisation of research outcomes the main objective. This success is also evidenced by the increase in Cross-Border Fusion Industry Projects (NI-ROI) and KTP projects (£1.5m across 40+ projects), over 30 patents, consultancies (over £1.7m); licensing (£200k) and the establishment of three new spin-out companies, Axis Composites (AMcI), Surf-Spec (BM) and Lenis Aer (AL).

TABLE 4: Research Evaluation Metrics (up to RAE 2008 and since mid-2008)

	2008	2014	Percentage Change
UoA Staff Numbers	12	19	58%
Overall Funding Attracted	£14,000,000	£26,000,000	86%
Funding Spend	£8,014,145	£11,516,221	44%
RC Funding Spend	£947,346	£2,487,209	163%
EU Funding Spend	£315,095	£1,305,307	314%
Research Students Qualified	42	53.83	28%
Consultancy and Royalty	£500,000	£1,900,500	280%
Fusion and KTP	19	41	115%

As we develop our industry links further and expand our connected health, composites, nanotechnology and bioengineering expertise, our capability to make a significant global impact through innovation will be enhanced. ERI's culture of fundamental and applied research, both interdisciplinary and multi-disciplinary, is reinforced by the many collaborative projects within and across groups, as cited in RA2/RA3. A new rapid proto-typing laboratory is near completion. This will deploy new project managers (e.g. CHIC business manager (McComb)), increase our technology transfer drive, encourage new spin-outs and collaborative projects and create international networks via EU (National Contact Point, Horizon 2020 (Davey)) and UKRC funding.

3.0 People: Staffing strategy and staff development: Day-to-day ERI management is the responsibility of the Director, in partnership with the Head of School and Centre Directors. Regular performance review meetings are held with the PVC of Research and relevant research office personnel to assess current performance, set future targets and address resource issues. ERI also reviews research progress via quarterly reports and an online database (ERI Activity Monitor) and all outputs are collated via the Ulster Repository.

In 2008, the Institute received an RAE profile of 5:45:45:5 with 12 staff. This has now increased to 19 category A staff, with 17 high-calibre research associates/fellows employed at present (60 employed in REF period showing a 67% increase on last REF period). There have been 7 new staff appointments in the period (Prof. Davis and Drs. Brown, Archer, Burke, Dunlop, Finlay and Mariotti) resulting in a relatively low age-profile (average 42 years) which, although encouraging, has impacted on PhD studentship numbers. To remedy this, supervision by new lecturers is prioritised. Promotions during the period have included: Papakonstantinou and Byrne to Professor, McIlhagger and Leacock to Reader; and Quinn and Boyd to Senior Lecturer (all externally refereed). We are currently recruiting four new academic staff, including a new Royal Academy of Engineering Bombardier Professor to further enhance our overall engineering capability with a particular emphasis on design, composites, materials science, electronics and sensor systems. ERI has appointed academic staff from South America (OE); Italy (DM); Greece (PP); France (PL) and throughout the UK and Ireland. Research Staff are appointed following strategic links with

India (IIT Mumbai), China, Taiwan, South America and EU. The centre also has 15 active visiting Professors – Campbell (Bombardier); Apsley (NISP); McMillan (Rolls-Royce); Adgey (Royal Victoria Hospital); Andonie (Washington Central University); Baikie (Strathclyde); Chen & L Chen (NTU-Taiwan); Hardeman (Seagate); Jossinet & McAdams (ENSA-Lyons); Misra (IIT Mombay); Robertson (Robert Gordon University); Velusamy (Bulgaria) and McEneaney (Southern Trust, NI).

Contract research staff and early career researchers are supported by a University Concordat Coordinator (Concordat on Research Careers, 2000). The Ulster strategy and action plan determines the ERI research budget (£70k pa). A centrally administered element has been used to fund 4 lecturing posts in 2010 and promote contract researchers (PD, AB, EA, GB) to maintain research vitality and develop exciting new areas. New staff are encouraged to establish and lead their own research area, and to submit their EPSRC first grant applications. They are attached to an established research group to be mentored by the senior researcher and are given priority for PhD supervision jointly with experienced colleagues. They are strongly encouraged to participate in international collaborations and support is provided to attend meetings with potential consortium partners. Developing research profiles and accessing successful funding are the basis of our Mentoring Programmes which are delivered as modules via our PCHEP programmes. Funding applications are reviewed by our ERI Proposal Review Committee and at our ERI away days funding agencies are invited to update staff on guidance and new opportunities.

The University has put in place an Organisational Development Strategy for the period 2011 to 2015. There are three stands to the Strategy: People Management; Leading and Developing Employees; and Valuing Employees (through engagement, recognition and equality). The Strategy acknowledges that staff are key to maintaining, enhancing and developing Ulster's excellence in research. The University has put in place a comprehensive suite of HR policies and practices to support the recruitment and career development of our research staff. In recognition of these HR policies and practices the University has recently gained the 'HR Excellence in Research' award from the European Commission. The University researcher CPD framework incorporates all the domains and sub-domains of VITAE UK's Researcher Development Framework.

This Unit of assessment endorses the university's equal opportunities policy, the code of practice on the selection of staff for the REF 2014 submission and the principle that staff who are eligible for return are not excluded for a non-traditional career pattern. Staff in this UoA who are involved in selection decisions have received or undertaken equality and diversity training in relation to REF 2014. The university carried out equality screening on the code of practice and conducted regular equality analysis of staff following each REF review. An equality impact assessment will be carried out on the final selection of staff. The university is a member of the Athena SWAN charter (PP represents ERI and also participates in 'Woman in Science Programmes'). Ulster recognises the outstanding scholarly accomplishments of staff members and assists in the development of staff as excellent researchers. One indicator of recognition is the annual award of 'Senior Distinguished Fellowships' (awarded to JMcL, BM and PM), or 'Distinguished Research Fellowships' (awarded to PP and DM). PP received a 'Leverhulme Senior Fellowship' and DM received a 'Japanese Society for the Promotion of Science Invitation Fellowship' and a 'Bridge Fellowship'.

Standards of research quality and integrity are set by the university's code of practice for professional integrity in the conduct of research, which covers research in all disciplines and is underpinned by a series of policies and procedures relating to the ethical review of research involving human participants and the governance of areas which are subject to specific regulation, including human tissue, radiation and vulnerable populations (complying with Universities UK concordat to support research integrity). Research students and newly-appointed staff are introduced to the requirements of the code of practice during their university induction.

Research students: Research student affairs are the responsibility of the Faculty Research Graduate School (RGS) which allocates studentships through fair and transparent competition, via interview. These include: Vice Chancellor's Research Studentships (VCRS), those gained through external grants and Department for Employment & Learning NI (DEL) awards, (accepted by HEFCE as the equivalent of RCUK awards, since all NI universities are excluded from applying for RCUK DTAs). Each student is provided with his/her own PC and work space in a dedicated area within the facility with access to world-class equipment, managed jointly by ERI academic staff. Student progress is monitored by the RGS through faculty-based seminars, annual student and

supervisor reports and presentations as well as 100 day and 9 month viva voce. RGS also monitors student feedback, issues concerning supervision and student resources. The generic and research skills training (GRST) programmes support the students' 'personal development portfolio system' and ERI postgraduates also focus on key skills associated with practice-based vacuum-technology, electron-microscopy, surface-science, programming, analytics, modelling and scientific presentation as managed via our own DTC manager (DM). Mentoring workshops and a weekly ERI lecture series (TB organises guest talks supported by IET, RSC, IOP, IMechE and IOM3) keep students appraised of the latest research trends and breakthroughs. Three prizes for ERI research students are presented annually at the faculty's RGS dinner for best PhD confirmation, best student published research-paper and best overall thesis. The QAA institutional audit (2010) commended Ulster for the 'comprehensive support, training and supervision of research students'.

Since 2008, 53 PhDs have been awarded, with the majority of graduates now holding technical or academic positions in UK/EU industry. DEL CAST awards have been awarded jointly with Seagate, Bombardier, DSTL; Rolls-Royce, AVX-Kyocera, Intel and GSK. Other key Studentship Awards include Cross-Border DEL, Marie Curie and British Council-UKIERI. High quality applications continue to grow, especially from Asia (up 40%) and India in particular. EU-ESF, DEL and BIS Aerospace funding has supported Masters Studentships with 160 graduated since 2008, which includes elements of multi-disciplinary, German-NI and all-Ireland university collaboration.

d. Income, infrastructure and facilities: With over £26m of externally funded project success, key capital investment in infrastructure includes £5m SRIF & RCIF grants, £6m NIACE (jointly owned with QUB) and other specific equipment grants (£2m EU; EPSRC, Royal Soc., Leverhulme). This has resulted in the establishment of £15m high-impact laboratories (3000sq.m) in a new purpose-built building that houses state-of-the-art materials and nano-device fabrication facilities (e.g. Graphene and nanoparticles by ECR-MECVD), characterisation (e.g. dual beam FIB) and surface science equipment (e.g. HR-TEM-EELS, TOF-SIMS). In addition, ERI boasts fully integrated cell-biology and microbiology laboratories that directly enhance interdisciplinary activities. To further our targeted engagement with the bioscience area, a new £1.5m (philanthropy) biomaterials/devices led Centre for Advanced Cardiovascular Research (2008) has been established jointly with the Royal Victoria Hospital, Belfast. The Facilities are managed by the ERI resources co-ordinator (PD), whereby maintenance, access and funding are controlled and sometimes outsourced to STFC: SRS Daresbury Laboratory 2008 (£73k-PP). Functional, Structural Engineering and Biomaterials research is spread across three main centres, namely the Nanotechnology & Integrated Bioengineering (NIBEC); Engineering & Composites Research (ECRE); Advanced Metal Forming (AMFoR) and the new NIACE Centre located at Bombardier.

Functional Materials and Devices (FMD). The core of the FMD group is based within the NIBEC facilities and incorporates the following new well-staffed Industry led- £5m INI CHIC; the DEL-£2m CIPS and the £1.5m CACR (Philanthropy).

Sensor Materials and Connected Health: The Sensors Group is an international leader in electrode-electrolyte interface impedance and their ability to successfully develop technology and transfer into industry has been demonstrated over the past 20 years with 35 patents and 3 spin-out companies [see Ref3b]. JMcL has developed a range of connected health initiatives that has led to the establishment of a Northern Ireland and European based connected health eco-system. Areas of study include: electrical properties of tissue and of the electrode-tissue interface, electrical impedance spectroscopy, novel sensor transduction mechanisms (e.g. non-linear dielectric spectroscopy). The group has vast experience in sensor design for a wide range of diagnostic and therapeutic applications; including self-management platforms for connected health [1, 2] smart algorithms for predictive health monitoring [3, 12]; Point of Care telemetry sensor integration [4, 8], microfluidics [5, 6], wound-monitoring and point-of care monitoring. The cornerstone of their success has been the ability to fabricate devices such as nano-electrodes [7], micro plasma-based electronic-nose [13], nano-templating and immobilisation of proteins [4] and implant sensor development [9]. The sensors activity has led to a range of collaborations in USA (3 MoUs with Lowell, Illinois and North Eastern); India (MoU-IIT Mumbai) [5]; France (INSERM, INSA, CNRS Lyons) [12]; throughout the EU and also very strong industry collaboration which led to CHIC [12].

Photocatalysis Materials focuses on semiconductor photocatalysis (TB, PD) via UV or solar activated metal oxides for water purification (e.g. solar disinfection of water in developing

countries) [14, 15], solar energy conversion and surface sterilisation e.g. medical devices. Photocatalyst preparation routes include sol-gel, plasma and, more recently, electrochemical anodisation for self-organised titania nanotubes. Material quality is characterised by the measurement of physico-chemical properties and correlated to photocatalytic efficiency for specific applications e.g. degradation of organic pollutants in water [16] or for water splitting. Recent projects include the decontamination of prion material from surgical instruments [17] and inactivation of pathogenic biofilms [18, 19, 20]. The group's fundamental and applied research is also channelled into commercialisation with two RDA-funded Proof-of-Concept projects completed. International links have been developed with e.g. Solar de Plataforma, Spain; University Joseph Fourier, France; EAWAG, Switzerland; Royal College of Surgeons, Ireland; NGOs, Kenya, Zimbabwe and South Africa; Groningen University Netherlands; Ben Gurion, Israel.

Nanomaterials: Over the last 10 years, the group has built a solid track record in the preparation, analysis and processing of mainly carbon-based materials including ultra-thin hard diamond-like carbons (DLC), graphene and carbon nanotubes (CNT), as well as silicon alloys and metal oxides / ceramics and has obtained direct support from EPSRC, Royal Society, Leverhulme, the EU and industry (Seagate-Veeco Labcoat, Intel, Glaxo-Smith-Kline, SiSaf, AVX, Medtronic, Boxmore).

The group collaborates on developing a fundamental understanding of plasma, CVD or solution-based materials processing and its impact on resultant properties, with the strategic aim of enabling the fabrication of advanced devices, e.g. impediometric biosensors, and the integration of new materials into industrial manufacture. A new Nanoparticles Laboratory was opened in 2012 for analysis of pilot scale manufacturing processes and materials [20]. This compliments over £10m of capital investment in Nanotechnology since 2004 (RCIF-SRIF-EPSRC) leading to the creation of one of the most advanced academic laboratories in Europe for nanoparticle based fabrication which includes a suite of advanced multi-functional plasma systems with integrated diagnostic tools for concurrent measurement of plasma and materials properties during growth. Research on graphene [21, 22, 23] and carbon nanotubes [7] investigates plasma and electrochemical functionalisation and is currently focussed on controlling the growth and properties of active high surface area structures for biomedical and biosensor applications. Based on the original Astec system for diamond growth, and in partnership with Seki (Japan), a custom-designed microwave and ECR plasma-enhanced CVD system provides one of the most advanced facilities for the growth of precisely tailored carbon nanostructures. Applications include electrochemical platforms for bio-sensing (5 successive Royal Society/GSK-Cast Awards, PP, DM & JMcL). Research into nanomaterials growth is accompanied by advanced process diagnostics (e.g. mass & energy spectrometry, IR absorption spectrometry) and high resolution materials analysis via an extensive in-house suite (e.g. TOF-SIMS, XPS, TEM) and enhanced by access to synchrotron and neutron diffraction facilities through CCLRC awards (PP). Materials functional testing has encouraged the industrial uptake of research through multi-technique (AFM-SEM-Nanoindentation) industrially applicable nanometrology protocols for accurate determination of nanohardness, thickness, stress and adhesion on ultra-thin (1nm–50nm) carbon layers (Lemoine) and a number of carbon-based processes (DLC nanofilms) are now integrated into industrial manufacture (e.g. Seagate).

New directions include plasma systems design for large area/low cost atmospheric pressure plasma coatings [24] as well as precision three-dimensional coatings for medical implants, particularly inner tube surfaces of coronary stents. Patent licensing and commercialisation are in progress (US 6,638,569/GB 2338716B, US-7,361,514). Advanced concepts include microscale high density plasma devices [25] and mixed plasma-liquid phase non-equilibrium chemistry for studies at the biological physics – biomaterials interface [26]. Thin film and quantum-confined nanoparticle generation (Si, C, metal oxides) is under development to drive innovative approaches to 3rd generation photovoltaics via all-inorganic heterojunction devices [27, 28]. This work dovetails well with highly successful industrially driven research on nanoparticle barium titanate (sub-100nm) in collaboration with AVX Capacitors, where 2 successive INI-AVX Ltd collaborative projects of over £1.6m were awarded [29], with a new £4m grant to be announced shortly. Here the focus is on nanomaterials processing and device fabrication and test for near-term integration into volume manufacturing [see Ref3b]. Other commercially focussed projects now avail of this enhanced facility and expertise in nanoparticle has led to collaboration with SiSaf Ltd. (spin-in) and Si nanoparticles [29] with enhanced dissolution in human tissue/fluids for targeted drug delivery.

[1] £220k–EPSRC-1EP/I01179X/1EP/G001049/1 & EP/I01764X; [2] DEL-70517-£623k; [3] £410k-Wellcome Trust-084593/Z/07/Z; [4] £2m DEL & £800k-UU-DCU-HEA-Res-Prg.-2; [5] £100k-British Council; [6] £460k-NSF-US-Irl; [7] £205K-FP6NMP4-CT-2004-505626-DesynIT; [8] £235k-IST-FP7-216592 DiAdvisor; [9] £206k-INI POC-118&303; [10] £245k-ESRC RES/353/25/0004; [11] INI-Capital-£482k; [12] £5m-INI-Industry CHIC and ESRC-RES/353/25/0004 [13] £580k-EPSRC EP/K006088; [14] £350K-FP7-SME2011-1-286641 [15] £300k-NSF-US-Irl, [16] £145k-FP6-31650-Sodiswater; [17] £133k-DOH-0070090; [18] £103k-INI-PoC 060 [19] ESP-MD CLG 9833 44–NATO-£5k [20] £12k-Royal Soc. JP090423. [20] £1m-DEL-RCIF; [21] £19k-EPSRC-EP/I01764X/1; [22] £30k-Leverhulme Fellowship; [23] £40k-RAEng/Leverhulme-10226/41; [24] £100k POC 003; [25] £103k POC-325; [26] £645k-EPSRC-EP/K006088/1 Microplasmas-Glasgow.; [27] £692k-Plasma Sensing EPSRC-SUPERGEN-EP/K022237/1-St. Andrews; [28] £124k Leverhulme Int. Network, Rapid IN-2012-136; [29] £1.6m AVX ST5274 and 70073; [30] £150k-INI-SiSaF-Gift.

Biomaterials & Tissue Engineering: BTERG, based at NIBEC, is undertaking internationally leading research in the development of functional biomaterials for applications in medical implant technologies, tissue engineering and regenerative medicine. The main focus is on directing and controlling early-stage bioprocesses at the material-tissue interface via surface engineering strategies. Specifically, chemical and/or topographical effects at the sub-micron to nano-scale (≤100 nm) that can interact with biological systems at the sub-cellular molecular level are being investigated. The group is recognised for its innovative atmospheric pressure plasma processing technologies and experience of calcium phosphate thin-film sputter deposition. A recent focus on exploiting the groups IP in this area has led to the formation of a spin-out company (Surf-Spec BM Founder and Director). An additional strength of BTERG is expertise in surface analysis techniques (XPS, ToF-SIMS, AFM, etc.) as applied to biomaterials research. Direct assessment of the bio-functionality is facilitated via dedicated in-house cell culture facilities. New institutional support for the area has been forthcoming with the appointment of two new blood lecturers (GB & ABr).

Core funded projects within the reporting period include EPSRC-Grand Challenge REMEDI, joint with Kings College London on real time characterisation of cells in a dynamic cell-culture/bioreactor environment [31] and the role of ionic-buffer and protein sheet on the toughness of mature enamel [32] The group is actively engaged in funded collaborative interactions most notably with NUI-Galway in the establishment of an all-Ireland R&D Centre for Functional Biomaterials [33] and in the USA with the U. of Mass. in printing of active matrices for tissue engineering applications [34]. Expertise developed within the group has received funding for three Proof of Concept awards [35 - 37]. BETRG is also a core partner with the Brunel, Nottingham and Birmingham in the EPSRC-MATCH Innovative Manufacturing Research Centre (IMRC) for the assessment of healthcare technologies. MATCH (Ulster) obtained substantial renewal funding within the period [38, 39].

[31] £325K-EPSRC-IMRC-Grand Challenge REMEDI-EP/C534247/1-collaboration- Loughborough, Nottingham, Cambridge, Birmingham and Liverpool; [32] Leverhulme, F/00 430/J; [33] £1.3m-UU05-DELNI; [34] £84k-INI; [35] £105k-INI-POC300; [36] £94k-POC 305 [37] £94k-POC 319; [38] £1.4m-EPSRC-EP/F063822/1; [39] £355k-EPSRC-EP/G012393/1.

Structural Materials: Structural Materials research is based at the Advanced Materials Research Centre linked to the new £6m NIACE Centre [40] and will be led by the new Royal Academy of Engineering Bombardier Professorship. In 2012 an Ulster - QUB consortium set-up the jointly owned NIACE centre which was opened by Vince Cable, MP**.** This is a technology hub for the research and development of advanced engineering and advanced materials technologies across a range of industrial sectors. Member companies (Table 3) are co-located with academic staff working together to develop world-class technology solutions for a breadth of manufacturing applications. NIACE promotes the development of skills and rapid knowledge transfer between the universities and industry, ensuring the development of innovative new product and manufacturing technologies. The Centre currently hosts up to 120 research and technical staff from participant organisations and it provides a collaborative office environment, a composites research laboratory, materials analysis laboratories, meeting rooms and a lecture theatre, as well as a wide range of laboratories and workshops equipped by Bombardier and the two universities. A joint £5m-Ulster-QUB Composites Competence Centre has been awarded in 2013 [41] along with new EU funding [42]. Within Ulster the two main Structural Materials groupings are:

Engineering Composites Research (ECRE): is the leading UK-based research centre studying

the development of technical textiles, principally 3D woven preforms, for use in the aerospace and other transportation sectors. The main focus of the work is the science underpinning the design, development, manufacture and testing of composite structures. An investigation of the compressibility of such reinforcements has led to the development of an empirical relationship between the applied pressure during processing and the overall fibre-volume fraction. The group has specific interests in parallel-plate dielectric analysis [42] in monitoring and control during the curing of composites, particularly for liquid-moulding processes. Dynamic collaborations with industry include Bombardier Aerospace [44], Rolls Royce [45-47] and Dowty in the development of 5-axis textile preforming technology (SpaRC) and the group are recognised as leaders in this field. ECRE has developed a strong relationship with Rolls-Royce, working closely on the DTI-funded 3DSIMCOMS programme [45] via 2 CAST Awards. Other consortium members include BAE Systems, ACG, Dowty Propellers, DSTL and Sigmatex. Private Venture funding totalling £129k has been secured from Rolls Royce to further develop unique 3D-weaving/preforming capability [46], manufacturing/processing, modelling and appropriate test standards. This relationship forms an important strategic partnership with one of the UK's flagship companies. Notable consultancies include: novel 3D woven preforms for Dowty Propellers for inclusion in the DTI funded IPSOFACTO study and AMRC Sheffield/Boeing (£29k feasibility study-InvestNI) on the development of Hybrid Fabrics for smart composites. Composite Waste studies include a new Proof of Concept [48] and an industry based KTP [49]. Future strategy involves the use of nano-composite materials and, in particular, the role of nano-particle loading in polymers. Academic collaborations include with the universities of Cambridge, Oxford, Bristol, Nottingham and Waterloo (MoU). AMcI is a Founder and Director of a new spin out called Axis Composites.

Advanced Metal Forming Research (AMFoR): Research includes; springback compensation in stretch forming, hydro-forming, phenomenological characterisation and modelling of yield behaviour in the aerospace sheet-metal forming process. The first significant international breakthrough for 15 years in the development of the Hill-yield criteria family was made by Leacock leading to the development of new roll-bending processes (PCT/EP2009/004434). The incorporation of nano-crystalline materials is currently under evaluation [49]. AMFoR collaborate with leading researchers in the field including Professor Banabic (Visiting Scholar Cluj-Napoca-Romania), Professor J. Bressan (U. of Santa Catarina, Brazil), Airbus and Caterpillar. A close working relationship with Bombardier Aerospace [50-52] has provided mutually beneficial advancement in mechanical metallurgy and forming process development. Highlights include stretch-forming process optimisation [53], resulting in savings of £30k per annum and more recently, discovery of key compensation treatments for springback in the sheet-metal hydro-forming process [54]. Leacock has formed a spin-out called Lenis Aer in 2009, with NISP 25k and Seed Funding success. The AMFoR laboratory facilities are unique within Europe.

[40] £6m-NIACE-BIS-INI-Bombardier-Ulster-QUB; [41] £5m INI-NIACCE-Competence Centre; [42] £540k-EU Marie Currie-MARINCOMP-612531; [43] £97k POC 11a; [44]£750k-Composite Skills; [45] £130k-Rolls Royce; [46] £244k-DTI/Rolls Royce; [47] £56k-R-RAEPS2001 DPC6227 Rolls Royce; [48] £97k-POC-313; [49] KTP-009239; [50] £103k-INI-POC149; [51] £103k-gift; [52] £60k-KP/MPE/2655; [53] £10k-PAMSTAMP; [54] £62k-INI-POC-113, [55] £107k-KTP 009321Star Inst.

e1. Collaboration: Our International Engineering Advisory Panel, chaired by N. Apsley (NISP), addresses industry engagement, collaborations, user needs, STEM initiatives, training, skills requirements, IP management and access to Ulster's engineering expertise. The international profile of ERI's researchers has grown as we have established a number of strategic alliances and joint research-funding. Many of these collaborations are interdisciplinary and include end-users, heads of industry, clinicians, computing scientists, biologists, social scientists and modellers. With 6 new EU projects and a range of EPSRC, INI and DEL funded collaborations, this has led to over 40 industry partnerships [see Ref3a] and 12 funded international academic collaborations, focused on internationally leading industry-relevant research. Our broad portfolio of collaborative, national and international projects is driven and supported by our close integration with centres such as MATCH, CHIC, NIACE, and CACR and through developing synergistic ROI-Cross Border collaborations through the Centre for Intelligent Point of Care Systems (Ulster-DCU) and the Centre for Functional Biomaterials (Ulster-NUI Galway), both funded by DEL(NI)-HEA (RoI).

Other national and international university collaborations include funded engineering projects with

Glasgow, Cambridge, Strathclyde, St Andrews, QUB, Nottingham, Brunel, Birmingham, Queen Mary London and also: in US, Scripps Oceanography UCSD, Stanford, Connecticut; Pennsylvania, MIT, Massachusetts, Case Western Reserve, Texas; TIT (Japan), IIT Mumbai (India); ESEM & Joseph Fourier (France); Solar de Plataforma (Spain); EAWAG (Switzerland); RCS (Ireland); Groningen (Holland); Ben Gurion (Israel); Bochum (Germany); CISRO & Sydney (Australia); Havana (Cuba); Nanyang (Singapore); Cluj Napoca (Romania); Santa Catarina (Brazil); NTNU-SINTEF (Norway); Kyong Hee (Korea); Inst. Physics (Serbia); NGOs (Kenya). **Cluster Collaborations:** CHIC: 35 companies including BOSCH, Intel and GE Healthcare; NIACE: 10 companies including Thales, Bombardier, Caterpillar; Membership of SuperSolar Network and EPSRC SuperGen Solar hub, COST Actions TD1208 (Electrical Discharges with Liquids:) and MP1101 (Bioplasma); MATCH – 4 Universities and 10 companies; **New university MoU's**: Massachusetts (Lowell & Dartmouth), Illinois, Northeastern in US; Waterloo and Alberta (Canada); IIT Mumbai (India); Nat. U. of Taiwan; DCU & NUI Galway (Ireland); Surrey (UK).

e2: Contribution to the research base: ERI contributes substantially to the international direction of functional, structural and biomaterials and devices. JMcL was awarded an OBE for research and enterprise and conferred with a Fellowship of the Irish Acad. of Eng., BM the UKSB Presidents Prize for 2010 for his contributions to the subject and PP the Leverhulme Sen. Fellowship 2011. ERI has 3 Fellows of the IOP; 2 Fellows of the RSC; a Fellow of the RAM in Ireland; a Fellow of the IOM3; a JSPS Bridge Fellowship-Japan, JSPS Invitation Fellowship, a D&T Rising Star. Staff have Visiting Professorship/Researcher roles in various universities in the EU, Japan and USA.

ERI has a wide range of **Advisory/Organising Committee contributions** over the period including: *Hosted At Ulster:* Comp. in Cardiology 2010 Int. Conf., 2010; ICMAC; ICCM18; SheMet 2007 & 2013; ECH Leadership Summit 2011 and the EuMHA MHealth Symp. 2011/2012/2013; EPSRC Tech. Plasma; *Externally:* ESB 2012 (joint-NUI-Galway); Chair of Symposium L -MRS 2009; ICCM17 Edinburgh 2009; UKSB 2009; 2nd SP2 2007 Aberdeen; NBM-3 -IC4N 2008 (chair), ISNEPP 2007, Euro Nanoforum 2013; Inst. Physics Belgrade Western Balkans Project; SSBII 2010; Solar'10 2010; IEEE 2012, Ecuador, 2012; ICPIG 2011; ISNEPP 08.

Panel/Council Membership: Royal Irish Acad. Chem. and Phy. Sci. Com. (2007-2010 PP and PM); EPSRC Peer Rev. Coll. (AMcI, PM, JMcL, BM, PP); Int. Soc. for Comp. Electrocard. (DF); Royal Soc.- Int. grants (PP 2006-09); Nat. Acc. Prog. (2007-09 PP); Mats. Theme Coord.–EPSRC Net-Non-Thermal Plasmas, 2006–09 (PM); Reg. of Experts for Health Res. Activities EU FP7 (OE, JMcL); Sci. Advisor for SFI (PM, JMcL); MATRIX-NI S&T Foresight plus Chair Adv. Mat. (JMcL); UKSB (AB). SSBII (AB); Nat. Sanitation Found (TB). RSC Photochemistry Spec. Int. Group (TB).

Company founders/ Directors: **JMcL:** Intelesens, ECHA, ECHC (chair 2010) SiSaf, (chair 2009) **BM:** SurtSpec, **AMcI/EA:** Axis Composites; **AL**; Lenis Aer: *Board Members:* NORIBIC; INSPIRE (TCD); CCAN-ROI; CHIC; MSSI-Limerick; MATCH; ADL; Comp. in Cardiology and winners of 9 Proof of Concepts Awards, Seed Corn and 25k Awards (PD, TB, PP, AMcI, EA, AL, JMcL, DD).

Keynotes and Invited Talks include: **JMcL:** SAS-IOP; 2008; SPIE-2008; SAS IEEE 2010; ICMP 2013; NBM-2, IC4N 2008; Smart Surface 2012; Inventing our Future RIA 2012; IOP Connected Health Summit in London 2009; 24th ESB 2011 ROI; ICSFS-14-2008; **BM:** 24th ESB-2011; IOM^3 Innovation in Polymers; **OE:** (SEEIC) 2010; **ABr:** 24th ESB-2011 **AL:** ESAFORM 2008 France**; EA:** ECCM15 **AB:** 24-ESB-2011; SSBII-11, **TB:** PPTC'09, Portugal 2009; EuroNanoForum 2009, 2009; Nanomaterials 2009, UK Nanoforum-2009; **PD:** SODIS Brazil-2011; PHONASUM 2010; ICPC-NanoNet-2009; **DM:** ICRP-8; SPP-31, 2013, Japan; iPlasmaNano-II,III,IV, Australia/Singapore/USA; 7th Int. W'shop Microplasmas, 2013 China; 69th IUVSTA- 2012 Slovenia; 13th-PSE, Germany; 221st ECS, 2012, USA; 5th Int. W'shop on Polymer/Metal Nanocomposites - Nanoworkshop 2011, Italy; 30th-Gases-ICPIG, 2011, UK; 18th-CIP 2011, France; 2011-ESA, USA; 2nd Int. Conf. on Adv. Plasma Tech. & 1st Int. Plasma Nanoscience Symp., 2009, Slovenia; Workshop on non-equilibrium synthesis of nanostructures and nanoarchitectures, 2008, Australia; **JD:** 10th ECRICE, Poland 2010; J&J Nano-Healthcare Select Symp. US 2010; **PM:** W'shop on Microfluidics and Microsensor Tech.; 2013; EPS 38th Plasma Physics Conf., 2011; 15th CPPA, Romania, 2010; 61st Gaseous Electronics Conf., USA 2008; **PP** IC4N 2008, Greece; 14th ICSFS, 2008 Ire.; Hot nanotopics TMCN 2008, Slovenia; NNO9-2009, Greece; 3rd Int. Sum. Sch. on Nanosciences & Nanotech, Greece; IC4N 2009 (PP); **DD** Thermec 09 Germany.