Institution: University of Warwick

Unit of Assessment: B15 General Engineering

a. Context

The School of Engineering and WMG have collaborated with over 1,000 non-academic users, enabling exploitation of knowledge and major impact in engineering, manufacturing and service sectors. Collaborators range from global corporations to innovative SMEs and from government departments to health trusts. Both departments structure their research to ensure '*excellence with impact'* using carefully complementary approaches and working across all technology readiness levels to enable economic, international, environmental and social impact. This single joint REF submission represents the holistic approach, drawing on examples and case studies from WMG and the School of Engineering. The significant contribution of research to the 'body scientific' is applied to inform an active programme to enable public understanding.

b. Approach to impact

Our approach at Warwick is to undertake internationally leading research in conjunction with non-academic users and to *take responsibility* for impact, transferring our knowledge into a form and environment to ensure maximum exploitation. Academic staff are recruited based on academic excellence, coupled with a wish to engage effectively with non-academic users. Full training is provided to give staff, particularly early career researchers, the confidence to do this, together with the provision of dedicated support to achieve impact through the approaches described below:

Collaborative Research

At Technology Readiness Levels 1 – 3 (basic principle – proof of concept) activities to enable and deliver research to address stakeholder challenges (Case Studies B15.1, B15.2, B15.3), include:

- **EPSRC research grants** - e.g. Interdisciplinary Centre for Storage, Transformation and Upgrading of Thermal Energy (*Critoph*) - £5.2M with 23 industry partners; Integrated, Market-fit and Affordable Grid-scale Energy Storage (*Wang*) - £3M with 9 industry partners; and Knowledge Driven Configurable Manufacturing (*Harrison*) - £1.9M with 6 industry partners.
- **EPSRC / industry co-funded programmes** – e.g. EPSRC: Jaguar Land Rover (JLR) Programme for Simulation Innovation visualisation research theme (*Chalmers*) - £0.9M.
- **EPSRC Warwick Innovative Manufacturing Research Centre** (£8.2M, 2008 - 2011) - involved over 108 partners in industry and healthcare, with wide exploitation: e.g. capturing customer requirements in new products exploited in UK companies including Bentley and non-competing sectors internationally e.g. the TVS Wega scooter (*Williams*).
- **EU Framework** – pan-European projects with 160 current collaborators include: AESOP (*Harrison*), ENLIGHT (*Dashwood)*, RLW Navigator (*Ceglarek*) and SOI-HITS (*Gardner*).
- **Research Networks** – active membership of academic-industry networks, e.g. EPSRC Energy Storage Network (*Jennings* and *Marco*), Medilink West Midlands (*Chappell*) and UK Research Centre in Non-Destructive Evaluation (*Billson*, *Dixon* and *Hutchins*).
- **Science City Research Alliance (SCRA)** – a union between the universities of Warwick and Birmingham with collaborative projects in Advanced Materials and Energy Futures.

At Technology Readiness Levels 4 – 6 (laboratory validation – technology demonstration), major programmes exploit understanding from fundamental research (Case Studies B15.4 and B15.5).

- **Technology Strategy Board** – 16 current Technology Strategy Board R&D projects involving 58 company collaborations (e.g. *Covington*, *Chalmers*, *Gibbons* and *Goodship*) – Warwick research value £2.9M. One completed project (Roy – retired 2012) with GSK, Newcastle and Surrey Universities created a new tablet production process which won the IChemE's Outstanding Achievement in Chemical Engineering Award 2012.
- **Demonstrator Programmes** - showcase research outputs in application based scenarios. The Premium Vehicle Customer Interface Technologies Programme (*Williams*) impact reported to ERDF is 46 new products, £6.6M Gross Value Added (GVA) and 237 jobs

created/safeguarded (2009-2013). The Premium Vehicle Lightweight Technologies Programme (*Dashwood*) impact reported to ERDF is 35 new products, £6.1M R&D investment, £31.5M GVA and 582 jobs safeguarded (2009-2013). The Wilson Review of University: Business Interactions (BIS, 2012) highlighted the Warwick led 'Low Carbon Vehicle Technology Project involving academic: industry core collaborators with over 25 smaller local companies involved'. 41 new products/processes were created (*Dashwood*).

- **Defra** – research to inform policy about the generic efficacy of detention ponds for mitigating pesticide transport, in collaboration with pesticide manufacturer Lonza (*Guymer*).
- **High Value Manufacturing Catapult** – WMG is one of 7 members of the Catapult, with an £18M spend in 2012-13 'bridging the valley of death' between research and exploitation in Low Carbon Mobility Technologies. Companies involved include: Drayson Racing, Holovis, Hyde Group, Johnson Matthey, Koolkwik, Level Energy, Mujo Mechanics, Nissan Motorsport, Oleo, Porous Power, Remotec, RML, Sharp Labs, Simpact, Techna International and Qioptiq.

Direct industry contracts range from JLR's £1.5M p.a. research funding (*Dashwood*), Horticulture Development Council tomato yield predictions (*Hines* and *Iliescu*), energy saving devices with E.ON (*Wang*), solar refrigeration with ATMI (*Critoph*) to consultancy e.g. Aaquis & Aaquis (*Tamainot-Telto*), Metal Rax (*Oram*) and definitive texts e.g. Handbook of Surface and Nanometrology (*Whitehouse*) selling in over twenty industrialized countries.

Development of Start-Up Companies

Academic staff benefit from strong support in the creation of companies. Facilitated by Warwick Ventures, there have been 24 patent filings, 16 granted national and international patents and 10 companies created by staff in the assessment period: e.g. Anvil Semiconductors (*Mawby* SiC devices – 2010); goHDR (*Chalmers* and *Debattista* video compression algorithms – 2009) and Sorption Energy (*Critoph* solar refrigeration – 2009). Impact is promoted by significant venture capital funding, e.g. Warwick Audio Technologies (*Billson* and *Hutchins* – 2001: Case Study 15.6). Impact is also achieved through assignment of IP, e.g. to a start-up company at Cambridge (*Gardner* – 2010: Case Study 15.7) and IP Licensing including infra-red imaging (*Hutchins*) and condition monitoring (*Bryant*). (Case Study 15.8 also refers).

Strategic Partnerships

Building on the strength of automotive research at Warwick, JLR, Tata Motors and Tata Steel have co-located advanced research teams of 200, 250 and 30 staff respectively in University buildings; bringing strong synergies, research alignment and accelerated pull through of Warwick research into products. This has led to the National Automotive Innovation Campus, currently under construction (see Strategy and plans). Already, this vision has drawn new R&D intensive companies onto the University Science Park e.g. Bosch and FEV. Strategic industry partnerships include Arup, Buro Happold, DRB-HICOM (owners of Lotus and Proton) and IBM. NHS West Midlands created a £4M Institute of Digital Healthcare (IDH) to enable technology and process understanding initially exploited in automotive/aerospace to be transferred to healthcare. Building on this, Bosch has sponsored a Learning Laboratory to design, deploy and evaluate emerging digital healthcare technologies. Industrial Chairs and Secondments enable research across technology readiness levels, these include - Elster Chair in Industrial Ultrasonics (*Dixon*); RAEng / Converteam Chair (*Mawby* – Case Study 15.8); RAEng/Tata Steel Chair (*Seetharaman*); Royal Society Industrial Fellowship (*Chalmers* with Johnson Tiles); Royal Society Industrial Fellowship (*Debattista* with JLR); and RAEng Industrial Secondments *Ni* (Arup) and *Covington* (Alphasense).

Facilities Usage

Unique R&D facilities have been created through strategic investments, for example via the SCRA. Dedicated business development teams have brought new companies to the University to access these facilities. As an example, SME Bladon Jets brought their innovative micro gas turbine to the £2.3M Vehicle Energy Facility for test. From this initial contact, a TSB research programme, Validation of Automotive Micro Turbine Range Extender was developed and funded (£366k). HEIF funding has been strategically allocated, for example to support facilities managers and to develop a web based database (Warwick Scientific Services) to make equipment readily accessible to users in industry. http://www.m5universities.ac.uk/facilities/results/?q=warwick&c=Find

Knowledge Transfer Programmes
Dedicated programmes have enabled growth in SME's, e.g. the International Digital Laboratory (IDL) programme (2008-2013) with tailored support for: Late Adopters (basic technology, e.g. workshops); Mainstream SMEs (advanced technology, e.g. demonstrators and guilds); Leading Edge SMEs (strategic thinking, e.g. Knowledge Transfer Partnerships (KTP) and doctoral projects); Feasibility to Full R&D (new product development with support from TSB, EU etc.). Impact audited by the Homes and Communities Agency included: 288 jobs created/safeguarded, 368 new collaborations with the knowledge base, 548 individuals gaining new skills and 169 new products/processes. The national Manufacturing Advisory Service is delivered by four partners, one of which is West Midlands Manufacturing Consortium (WMMC) Ltd, a special purpose vehicle set up by WMG, EEF and Business Link West Midlands. Extensive use has been made of KTP programmes, e.g. De Puy, Det Norske Veritas, First Utility, FTI Communication Systems, Metalysis, NAREC, Nissan, Prestige Plastics, RTC Electronics and Seat Design Co..

Education Programmes for Industry
Academic staff develop new Masters-level teaching modules from research. These are presented as stand-alone short courses, through Awards and Certificates to a full Masters and delivered to companies (e.g. BAE Systems, Health and Safety Executive, Network Rail and Rolls-Royce). WMG created with SEMTA, IET and IMechE, the Masters-level Advanced Skills Accreditation Scheme announced by the Secretary of State for BIS in June 2012. It draws research-based content from leading universities, enabling participants in industry to take the '*best courses from the best sources*' within a single qualification framework. Warwick has delivered modules to 750 individuals to date (Case Studies 15.4 and 15.5). The BIS publication Tunnelling: A Capability Analysis (April 2012) highlighted the School of Engineering's new Masters in Tunnelling and Underground Space where industry sponsors, e.g. Balfour Beatty, London Bridge Associates and Halcrow 'offer UK students both a cost-neutral option and the security of employment upon completion'. Global reach is facilitated through centres in China, India, Malaysia, Singapore, Thailand and Turkey. For example, over 170 people from companies including Godrej & Boyce and Larsen and Toubro are taking a Masters in Mumbai – a partnership with the Confederation of Indian Industry. Between 2008-2013 over 2,488 individuals from 170 companies were awarded qualifications through WMG's programmes. WMG was awarded the Queen's Anniversary Prize for Further and Higher Education 2009 in recognition of the impact of industry education programmes.

Industrial Doctorates
An Engineering Doctorate Centre has operated throughout the assessment period with 21 new starters (each with industrial sponsorship) and 26 EngD graduates. In October 2011, an additional EPSRC sponsored EngD (international) was launched with 25 new starters to date. Warwick Collaborative Postgraduate Research Scholarships match institutional and industry funding. The IMPACT project applies innovative modelling to pharmacology through an AstraZeneca: Warwick partnership training Early Stage Researchers in systems modelling (EU Marie Curie European International Doctorate). EPSRC Industrial CASE Studentships have included ABSL Power Solutions, Ford, JLR, NPL, MEL Chemicals, Olympus, QinetiQ, Ricardo, SensaPharm, Tata Steel, Thales and Unilever. Industry and Charity funded PhDs include Alzheimer's Society, Binding Site, Delphi Diesel, Gambro, GE, Horticultural Development Council, Lonza, National Semiconductors, Potato Council, Torver Environmental and Toyota. These enable the forging of strong links with partners and enhance the training experience. The transfer of knowledge and expertise is often completed by the recruitment of PhD/EngD graduates by collaborating partners.

Influencing Policy
Research has been incorporated into standards e.g. construction (European Codes of Practice: Case Study 15.9), materials (Standard for Load Resistance Factor Design of Pultruded Fiber-Reinforced Polymer Structures: ACSE Pre-standard – November 2010, developed as consensus standard process by the ANSI (2014) and automotive – the draft international standard for Interior Air of Road Vehicles (*ISO/TC 146/ SC 6/ WG 13 – ISO/FDIS 12219-3: 2011*). Academic staff are members of bodies developing technology roadmaps informing government and industry policies, e.g. automotive: *Dashwood* – UK Automotive Council Lightweight Structures Group; electronics: *Mawby* - Power Electronics: A Strategy for Success (BIS – 2011: Case Study 15.8); energy:

Wang - British Coal Utilisation Research Association; materials: *Mottram* – Network Group for Composites in Construction; metrology: *Chetwynd* – UK National Measurement Scheme - Working Group of Engineering Measurements; telecommunications: *Green* – Infrared Data Association; and water: *Guymer* – ICE Water Experts Panel.

Public Understanding

A regular programme of events for schools and other organisations, with partners including the British Computer Society, helps to develop creativity, risk assessment and an interest in science and technology in individuals e.g. WMG's involvement in *Scratch at MIT 2012* with a 'sensing our world' workshop involving 400 teachers and educators from 30 countries, Royal Institution Masterclasses 2013 and *Collingwood's* role as a STEM Ambassador, the Royal Society Summer Exhibition 2010 and Big Bang Fair 2012. Annual participation in Imagineering Fairs for 8-16 year olds, have included demonstrations in rapid manufacturing. (Case Study 15.10 discusses the impact of Warwick's World F_3rst racing car, Case Study 15.3 also refers.)

Support to Staff to Develop Impact

By working closely with users of knowledge, anticipating future needs and supporting staff to develop cutting edge solutions from our research, we have been able to translate and deliver broad reach, significant economic impact and benefit to society. A Development Director, two Research Development Officers and three team members, together with an 8 person SME team, help identify partners, enable efficient and effective collaborations and identify and achieve pathways to impact. This is augmented by specialist support from the University's Corporate Relations Unit and Research Support Services. A comprehensive web presence is visited by an average of over 7,000 external visitors a week, with access from 191 countries in the first nine months of 2013. Every year, thousands of individuals visit our facilities which are configured to demonstrate research. Many visits are direct company requests; others come via intermediaries e.g. UK Trade and Investment. A Communications Manager, Marketing Manager and Assistant work with the University Communications Office to ensure publicity for innovations. Regular press releases are made, with 35 in the first nine months of 2013, together with website news stories. These led to 553 stories in print and online media, 32 TV/radio broadcasts and press release pages shared over 675 times on social media channels. An example is world-wide interest in *Denissenko's* research in spermatozoa migration. Industrial chairs and secondments together with a number of recently retired senior executives from aerospace, automotive and other sectors are employed to facilitate exploitation in that sector, helping avoid cultural/language barriers and providing contacts.

Incentives to Staff to Develop Impact

Research impact is a key element in the assessment criteria in staff annual reviews, merit awards and the selection of staff to propose for promotion. Matched funding is offered to staff that can obtain part funding from industry, healthcare trusts etc. to support new PhD students, with 20 studentships supported over three years.

Institutional Support

In addition to specialist support from the Corporate Relations Unit and Research Support Services, impact is enabled through the University's constructive approach to IP, with the most appropriate organisation driving exploitation. Where a start-up company is created, the University provides excellent support through Warwick Ventures and access to seed and venture capital funding. Initial space for start-ups is available in IDL and the International Institute for Product and Service Innovation (IIPSI); with grow-on space at the University Science Park. The University has been instrumental in facilitating major initiatives e.g. the SCRA that has provided leading-edge research equipment in Advanced Materials and Energy Futures, together with a network of business development managers. The University has enabled access to the HEFCE Strategic Research Infrastructure Fund, UK Research Partnership Investment Fund and Catalyst fund for collaborative R&D facilities and industry education programmes. Land has been made available for strategic new capital investments, with facilities created through Estates programme management.

c. Strategy and plans

'Impact through Research' is at the heart of our strategic direction and is achieved with input from Research Committee and Industrial Advisory Panels (e.g. in Civil Engineering). Each major project

has an academic/industry Steering Group. Interdisciplinary research is enabled through research themes including: Sustainable Cities, Energy and Warwick Engineering in Biomedicine; each has a strong outward facing profile, e.g. Sustainable Cities is enabling new discussions with the MoD and Thales. Themes support the University's Global Research Programmes, three of which are led by Engineering/WMG – Energy (*Mawby*), Innovative Manufacturing (*Kirwan*) and Sustainable Cities (*Guymer*) and supported by University pump-priming funding. The 'Impact through Research' goals are refreshed annually - current strategic initiatives include:

- ***Increased Industrial Engagement*** - To enhance the impact of our research through our relationships with industry, developing strategic partnerships and participating in industrial secondment schemes, international partnerships and collaborative research, to increase industrial income to 20% of research grant income. Industrial Advisory Boards will be constituted for Sustainable Cities, Energy and Warwick Engineering in Biomedicine.
- ***Automotive: National Automotive Innovation Campus*** – Opening in March 2016, it will provide a critical mass of research capability, combining expertise from the University, industry, supply chain companies and SMEs. A 30,000 m^2 (£94M) environment funded by HEFCE's UKRPIF (£15M) and industry (£79M) will foster collaboration, cohesion and cross-fertilisation of knowledge, enabling academic/industry teams to work together in facilities with state of the art equipment to create breakthrough technologies, e.g. the recent award of £3.2M through EPSRC's 'Great Technologies' Capital Call to create drive-in driver simulator facilities for research into smart and connected vehicles.
- ***Energy: UK Energy Storage R&D Centre –*** Construction of Phase 1 (£13M – BIS/TSB and Industry) commenced October 2013 of a unique facility to enable battery scale-up, creating processes to take new chemistries from laboratory to power pack in a range of application sectors. Industrial and academic collaborators include Imperial College, Johnson Matthey, Morgan Crucible, Oxford University and SMEs (Axeon and Nexeon).
- ***Healthcare: West Midlands Academic Health Sciences Network*** - Announced in May 2013. It links University Hospitals in Birmingham, Coventry and Warwickshire and N. Staffordshire. WMG and Warwick Medical School are developing the Digital theme, which will enable healthcare exploitation in areas including clinical connectivity, stratified care and e-trials.
- ***SMEs*** - The IIPSI Programme (until 2015) tailors research knowledge to enable exploitation by micro and small companies. WMG case studies (hard copy/website) include: Han Dynasty (cloud based systems) and Digital Native Academy (digital representations of historic artefacts) - http://www2.warwick.ac.uk/fac/sci/wmg/iipsi/business/casestudies/ A planned successor programme will ensure that SMEs continue to benefit from Warwick's expertise.
- ***Applied Education:*** *Applied Engineering Programme* - Addressing the chronic shortage of graduate engineers, an innovative part-time undergraduate programme to be taken by company staff at their workplace, including new Higher Apprentices. HEFCE Catalyst funding (£2.8M) will help develop processes to ease entry to higher education for new participants and return to study for existing staff. *WMG Academy for Young Engineers* - A business-focussed, business-led University Technical College will open in September 2014. Working with organisations including EEF, National Grid and Westwood Academy, it will focus on high quality relevant education in STEM subjects for 640 students (14-19 years).

d. Relationship to case studies

Three case studies relate primarily to collaborative research at low technology readiness levels with impact in healthcare, construction and automotive (Case Studies 15.1, 15.2 and 15.3). Two case studies highlight the role of strategic research, demonstrators and industry education programmes to enable impact in the automotive sector (Case Studies 15.4 and 15.5). Start-up companies, initially in electronics but with broad impact feature in Case Studies 15.6 and 15.7. Strategic partnerships feature in Case Study 15.8, together with a start-up company and influencing policy. Influencing of construction practice is highlighted in Case Study 15.9. Case study (15.10) is on sustainable motorsport, where demonstrators informed public understanding.