| Institution: University of Bolton |
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| Unit of Assessment: 15, General Engineering |

## a. Context

The major research activity in this unit is to develop novel materials or precursors for products with a major focus on their potential end-use applicability. Hence, most of research is carried out in collaboration with industrial partners and stake holders, keeping also in mind interests of the public at large. The unit is a key partner in the Knowledge Centre of Materials Chemistry (KCMC), based in the northwest (and now operating as a national centre) to facilitate transferring knowledge to industries including via spin-offs. As an example, FibrLec Ltd was set up in 2013 through which internationally patented hybrid piezoelectric and photovoltaic fibres developed at Bolton will be commercialised. The modeling approach for developing "designer" materials is a key element in formulating innovative materials for a sustainable economy with industrial partners in UK/EU and worldwide. For example, the Fire Materials Group with a history extending over 35 years has worked with and continues to work with the major UK, European and US flame retardant manufacturers as well as providing advice and assistance to UK and EU government interests.

In addition to the above, the UoA's research strategy includes education and training and public awareness. Thus, research generated is also used in teaching modules and training industry-based workers, one example being involvement of Aircelle and BAe systems through the Royal Academy of Engineering Outreach Programme. The work on energy harvesting devices has led to opening of a new research institute (Institute for Renewable Energy and Environmental Technologies - IREET) through which industry-based Masters and PhD students will be taught and trained. University and unit scientists/engineers also go to local schools for science days to talk about their work (at the appropriate level) and the wonders of the scientific world. In 2012 and 2013 over 1000 adults and children took part in numerous events put on by IMRI/IREET at the University and Bolton Museum. The unit is also part of the National Primary and Secondary Engineer Programme engaging school children in composites and textiles particularly.

## b. Approach to impact

The university has taken several steps to maximise the impact through the KCMC, where it has a research manager liaising with academia and the industry. This has helped in bringing new companies to the university and linking them with academics of relevant expertise, to help improve their products. A KTN manager has also been appointed and specific examples are included within each research group's activities.

**Innovative materials for environmental technologies (IMET)**

**Fire materials:** Here research has been concentrated on developing / exploring synergism between two or more flame retardants present in polymers in a manner specific to polymer type and form. Since 2002 the group has been working with Camira fabrics, UK to develop novel FR formulations for polypropylene fibres, one of which has been commercialised (see Case Study 1) and been responsible for generating over £15m worth of exports. The work has continued since then through the Development Director (Ms Cheryl Kindness) of Camira fabrics by her enrolling as a PhD-by-publication candidate. In parallel the group was approached by ICL –IP Europe in 2008 to understand the function of their recently developed products applied to cotton, polyester and polyester-cotton fabrics. The results are being used by the company in their technical datasheets defining their novel range of TexFron® products.

In 2007 William Blythe Ltd, a speciality inorganic chemicals manufacturer, approached the Fire Group for help in understanding the flame retarding function of their metal salts in engineering polymers. Through KCMC and by direct funding, the research continues on different polymer systems, which has helped the company to launch their products in different applications and result not only in generating increased sales but also in their being identified as recognised suppliers to major industries such as aerospace. In parallel, with the help of KCMC, the company was

successful in securing EPSRC CASE award to develop novel, non-toxic, environmentally benign, synthetic inorganic compounds which impart fire retardance and smoke suppression to selected high performance polymers without use of halogenated synergists. Extending this strategy to fibre-reinforced composites, the current EPSRC- funded project on marine composites, has collaborators from all sectors of the marine market – from materials suppliers (Scott Bader), ship builders (BVF) and boat yards (BVT) to operators (RNLI and MoD/Dstl/Royal Navy) and involves regulators (Lloyd's Register and MoD) and statutory agencies (Maritime Coastguard Agency) from which. One patent application [GB1222468.9] has already been made. A similar position exists with the TSB-funded project on Fire Retardant Bio-Composites for High Performance Applications, which has six industrial partners (NetComposites Ltd, Drake Extrusion Ltd, Tilsatec, Sam Weller & Sons Ltd, Ove Arup & Partners Ltd and Exel Composites Ltd). Both project outcomes are expected to have high a impact in the marine, automotive and construction industries, respectively.

**Composite systems:** The group has developed novel slash and cut resistant fabrics and garments with enhanced hygiene properties for protective garments worn by police and defence personnel. These lightweight slash proof materials are integrated with a barrier against both gram positive and gram negative bacteria, which have been commercialised as SARK Technology by Future Textiles, UK. Revenue is anticipated to be as high as £200kper annum.
In the mechanics area, a nanocoating technology (nickel, copper and chromium films incorporating nanoparticles) has been developed to protect and enhance the performance of large machinery and mining equipment. This development has been taken up by MSC Coating Technology, UK and is currently under qualification for production with the company estimating an increase in turnover ~£1m and associated £100k profit for the first year with subsequent annual increases of 20%.

**Biomedical engineering and devices**
The work and therefore impact of this group falls into two distinctive categories, **Medical Device** and **Bio-functional Materials**. Examples of the first category include development of a revolutionary single-layer bandage to replace the current four-layer bandaging system used in the NHS for the treatment of venous leg ulcers. Baltex Ltd, UK is currently conducting clinical trials with an expected revenue of £100K in year one and £1m in subsequent years (see the Case Study 2). Relief from pressure ulcers and spinal disorders that wheelchair patients currently experience has been achieved by the development of novel foam-free pressure-relieving cushions (AIROPSPRING). Baltex has just started selling the products and the sales figures are expected to reach £6m by 2018. Aburnet Ltd, UK has benefited by the KTP-supported project that has led to the development of hygiene products (KleenCap, StayCool and HairGon) for food and allied hygiene industries and has initiated marketing these products in Europe with a projected turnover of £6m within the next five years. Furthermore, negotiations are underway with ConvaTec, UK and Crawford Healthcare, UK for licensing and marketing all-in-one collagen booster composite wound dressings and medical devices for wound debridement respectively.
Two new hybrid biomaterial fibres intended for wound dressing applications have been developed, the first as "Alchite" fibre which uses alginate and hydrolysed chitosan in a unique combination with inbuilt attributes such as antimicrobial, haemostatic, natural healing properties. Sumed International, Himedica and Chembiotech have been the prime sponsors and promoters. The related IP has been patented worldwide and Sumed International through University of Bolton has exclusive rights to market the product, which is expected to be on the market later in 2013 with estimated sales in the range of $250m to $500m.
The second biomaterial uses Psyllium mainly comprising a natural polysaccharide has exceptional absorption and uses 1/6$^{th}$ of normal quantity of silver used in modern dressings while being potent against all types of gram positive and gram negative bacteria including MRSA. Xiros, who has exclusive rights from Bolton to commercialise this product, has invested £70k in the project and within the last 6 months has received £150k from TSB to commercialise it with Advanced Medical Solutions, UK as the larger commercial arm. The estimated market could reach £200m in first couple of years. This low dose silver fibre having reduced cost per unit allergenic property would challenge all silver dressings in the market, including the number 2 world leader, Aquacel.
The group is also active in developing medical and healthcare devices using nanotubes, graphene, graphene oxide and ZnO nanomaterials. Bolton has led a consortium of three universities (Cambridge and Manchester) to develop surface acoustic wave (SAW) and film bulk acoustic wave

resonator (FBAR)-based sensors using CNTs and graphenes. A UK / PCT patent has been filed for one FBAR with discussions with Nokia for their commercialisation underway. Seed corn funding (£50k) from Cambridge University for developing prototype single FBAR-based temperature /pressure sensor products for use in cars for environment monitoring and control is complemented by plans to set up an SME for FBAR sensors for the automotive industry. If successful, the expected annual market value is several millions pounds.

**Renewable energy**

This recently evolved group focuses on advanced and sustainable technological solutions for renewable energy generation and clean/hygienic environments. The development of oxide- and silicide-based thin film solar cells has led to 3 patents and collaboration with national and international industries is the norm. The work on oxide solar cells with the Teer Coatings Ltd (MIBA) has led to additional technological achievements such as indium-free transparent conducting oxides (TCO) and subsequently a current EU project on organic large area photonics, which involves one of the UK's leading innovation company, CPI, and MIBA Austria. The consortium aims at providing industrial solutions for transparent electrode and barrier layers that are essential for printable large area organic PV and photonic devices for a 900m square metre TCO market worth $10bn annually.

Other potential impacts of the future lie with:

(i) The close collaboration with Plasma Quest Ltd. (inventor of the remote plasma sputtering system (HiTUS) crucial to energy harvesting, functional thin films) has won a recent TSB competition for sustainable manufacturing in order to scale-up the research-level sputtering system to one with capacity for roll-to-roll coating of novel TCOs. The consortium was selected for the October TSB China Mission, wherein collaboration with China has been established with sales projected to be around £30m pounds in 5 years.

(ii) The research on hybrid PV/piezo materials for energy generation applications which has led to a unique process for the continuous production of piezoelectric polymer fibres for energy harvesting, has been patented and the IPR licensed to a spinoff company FibrLec Ltd. A complete supply chain from fibre manufacturing to piezo fabric product retailing has been established with interest shown by Marks & Spencers and Brighter Futures.

## c. Strategy and plans

The University encourages world class innovative research in collaboration with industry and leading academic institutions, aiming at advanced and sustainable engineering solutions in line with its commitment to deliver research-informed, educational programmes for engineering that address the needs of students and the society. The University encourages the UoA's continuing commitment to support knowledge transfer through proactive engagement with KT networks and KT centres, with ring-fenced funding being in place to sustain the KCMC and KTN partnership. It provides funds to cover IP filing and protection, by covering the initial Patent application, and tries to keep promising patents until they are licensed to companies for commercialisation.

Internationally, the University encourages staff to interact with overseas centres of excellence for research and technological development. It has also established various collaborations for joint provision of educational programmes particularly on advanced engineering subjects, through its off-campus division.

## d. Relationship to case studies

The Fire Material and Medical Textiles groups, both having been established for more than 30 years, have generated more impact in commercial terms as compared to other areas, where many new products have been developed and the IP assigned to companies. However, because of the inevitable time delays from research and proven concept to development of an acceptable prototype at full commercial scale, their commercial gains cannot be quantified until some years after in many cases. Because of the nature of the fire retardants and its user industries, most applied research gives rise to incremental changes in product character typified by the example in the Case Study 1 supplied here.