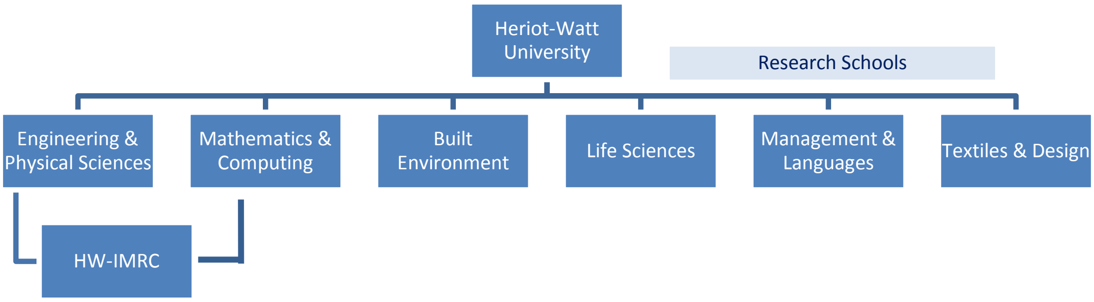
Heriot-Watt Innovative Manufacturing Research Centre

Key Data	
Time Period	**10 Years total** Phase 0: 2000 - 2005 (IMRC from 2003) Phase 1: 2003 - 2008 Phase 2: 2008 - 2013
Total Value of EPSRC Grant	**£11.5m total** Phase 0 - £2.1m Phase 1 - £3.5m Phase 2 - £5.9m
Other Funding *(Direct leverage of additional research funding specific to IMRC)*	**£9.59m total** (83% of EPSRC funding) – of which • Research Councils (non-IMRC) - £5.10m • UK Public sector (non-RC) - £1.66m • UK private sector - £1.25m • Overseas - £1.58m
Projects	56 projects funded to date Average size: £215k (EPSRC funding); £433k (All funding)
Current Staff	38 staff funded by IMRC grant (21 investigators; 17 PDRs)
PhD Students	34 PhDs completed to date + 34 current PhD students *(funded by IMRC grant or supervised by staff involved in IMRC)*
IMRC journal publications	112 journal publications; 195 conference presentations
Patents granted	20 filed; 11 licensed
Key Sectors of Focus	Aerospace, automotive, retail, semiconductor electronics, machine tools, software, packaging, textiles and bio-medicine
Research Themes / Specialisms	**Digital Tools** (DT) - development of highly intuitive tools to manage information and knowledge in the design and manufacture of 3D products **Microsystems for Manufacture** (MM) – development of innovative technologies that underpin the integration and packaging of Micro-Electro-Mechanical Systems (MEMS) **Photonics-based Manufacturing** (PM) – research on technologies for industrial laser tools, optical sensing measurement, fibre delivery, novel beam-forming optics and industry-led high power laser applications.
Examples of key economic impacts	1. **Contribution towards $1billion sales across global laser market** - IMRC funding has supported Heriot-Watt maintain its position as a world leader in laser technologies. 2. **Supporting Renishaw plc as world leader in specialist measuring equipment** – multiple projects over the last 7 years generating increased sales in automotive & aerospace 3. **Groundbreaking 3D-Mintegration Grand Challenge programme** – this has generated strong potential impacts with Zeiss, National Physical Laboratory & Renishaw plc.
Key value added aspects demonstrated by the IMRC	• More strategic focus for research • Flexible and fast response to industry needs • Continuity of research – long vs. short term perspective • Multi-disciplinary working –within HW-IMRC & University • Reducing risk and increasing R&D in the private sector • Building and retaining industrial partnerships 1-2-1

Overview of the Heriot-Watt IMRC

University Structure – HW-IMRC was established in 2003 as an integral part of Heriot-Watt University. It focuses on research, knowledge transfer and teaching and is embedded in the University's institutional structure: see diagram below. There are six Schools, two of which provide the investigators for IMRC: Engineering & Physical Sciences and Mathematics & Computing.



Vision – the vision of the HW-IMRC is to capture relevant technological innovation from the University and its professional networks, to channel it into manufacturing technology research and to transfer the resulting knowledge into and for the benefit of UK manufacturing industry.

Philosophy – the HW-IMRC is based on research groups in Digital Tools (DT), Microsystems for Manufacture (MM) and Photonics-based Manufacturing (PM), which represent the strongest clustering of manufacturing research in the University. However, the most important problems facing manufacturing industry are no longer amenable to mono-disciplinary solutions. Hence, the HW-IMRC portfolio is intrinsically inter and multi-disciplinary, spanning electrical and mechanical engineering, computing and physics.

Impact Examples – to date, HW-IMRC has leveraged in £ for £ funding from the private and public sectors, amounting to £9.59m in March 2010. It has also worked with > 60 UK and multi-national manufacturing companies and research institutes, which has generated the following impacts:

- 3 successful spin-out companies – Totallytextures Ltd from DT theme; MicroStencil Ltd from MM theme; and PowerPhotonic Ltd from PM theme;

- Multiple Knowledge Transfer Partnership (KTP) projects with strong industrial outcomes. Of particular note is the KTP with Caledonian Alloys Ltd, which was the winner of the Royal Academy of Engineering KTP Excellence Award (2010). This has contributed to making Caledonian Alloys the world leader in super alloy recycling services and improved its profits by £6m p.a.; and

- Knowledge transfer through HW-IMRC's leadership, in partnership with the University's Technology Transfer Unit, to secure £6.4m of EU and Scottish Government funding for the "Converge" programme. This supports effective knowledge exchange across Heriot-Watt University.

- Development and delivery of postgraduate education and training programmes, both on campus for graduate students and postdocs, and off campus for research engineers involved in the highly successful Engineering Doctorate Centre in Optics and Photonics Technologies centred at Heriot-Watt University.

IMRC Research Strategy

Throughout the 10 year programme (2003-20013) HW-IMRC has been focused exclusively on three research themes:

- **Digital Tools** – the research objective of DT is to provide tomorrow's engineers with highly intuitive, person-centric tools that will help them easily record, locate, manipulate and exploit information and knowledge concerning the design and manufacture of 3D products;
- **Microsystems for Manufacture** – the main goal of MM is to research new packaging solutions of Micro-Electro-Mechanical Systems (MEMS), optoelectronics and microelectronics that are low cost, mass manufacturable and easily adoptable by industry; and
- **Photonics-based Manufacturing** – the research focus of PM is to deliver academic and commercial outputs in laser and optical measurement hardware, process technology and production applications.

The success of HW-IMRC's research strategy has been based on the following:

- Building upon its established international standing in DT and PM – this gave continuity and a robust platform upon which to build;
- Enriching Heriot-Watt's offer through the formalisation of the MM theme, which capitalised upon this emerging market opportunity
- Exploiting the extremely strong industrial relationships for which Heriot-Watt University is renowned;
- Maintaining focus and not getting distracted. HW-IMRC is committed to maximising its performance and contribution over the long term.

The strategic drivers and performance indicators for these three research themes are summarised in the table below:

Strategic Drivers	Description
World class research	As measured by quality of publications; peer review; benchmarking against world-class competitors e.g. Fraunhofer Institutes
Industrial and economic impact	Through the uptake of research outputs by industry and the resulting commercialisation and economic benefit
Talent development	To develop talented engineers and scientists via PhDs, EngD, MSc and Post Docs.
Academic & industrial network	To extend HW-IMRC's network of industrial and university collaborators, both in the UK and overseas
Manufacturing research at Heriot-Watt University	To exploit synergies across the different academic areas at the university – both internal and external to HW-IMRC

The table below provides a breakdown of projects and EPSRC funding by research theme. It also shows that funding was split approximately 35% design-related, 50% technology-related and 15% management-related.

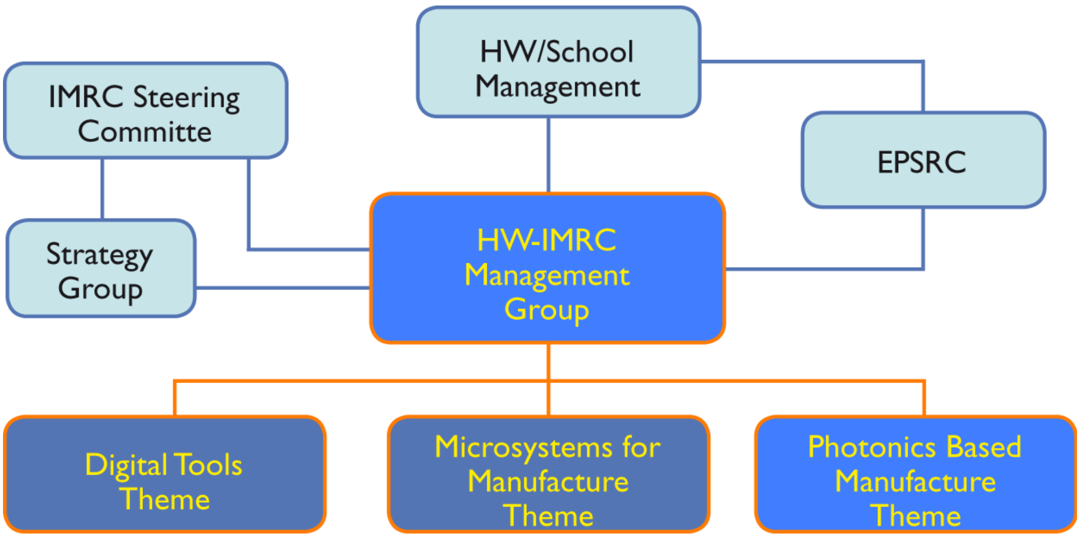
Theme	Number of Projects*	EPSRC Funding (£)	Design %	Technology %	Management %
Digital Tools	16	3,472,200	70	15	15
Microsystems	8	1,728,600	15	70	15
Photonics	20	4,252,900	15	70	15
Total	44	9,453,700	35	50	15
Note: *Data as at March 2010. Current projects now 56 and allocated funding £10.5m (Jan 2011)					

Performance – EPSRC's initial five year funding block of £4.2m (2003 – 2008) was extended for a further five years (2009 – 2013) through an additional award of £7.3m. This was influenced by the very positive 2006 International Review of the Centre, which rated the three research themes:

- DT and PM – "Internationally Leading" (note: both were established themes at the University when HW-IMRC was launched)
- MM – "Internationally Competitive" (note: this theme was formed around the time of the HW-IMRC launch in 2003, so it has less time to establish its international reputation)

IMRC Programme Management

The overall structure of management and governance for HW-IMRC is illustrated in the Figure, which is explained below.



Management Group (MG) - The HW-IMRC is managed by its 9 person MG, which is chaired by Prof Denis Hall. The members of the MG are the Principal Investigators, of which there are seven (including Prof Hall), the Deputy Principal of Heriot-Watt University (Strategy & Resources) and an Administrator. The MG is responsible to the University for ensuring that in all academic respects, the conditions of the EPSRC grant are complied with. This includes responsibility for:

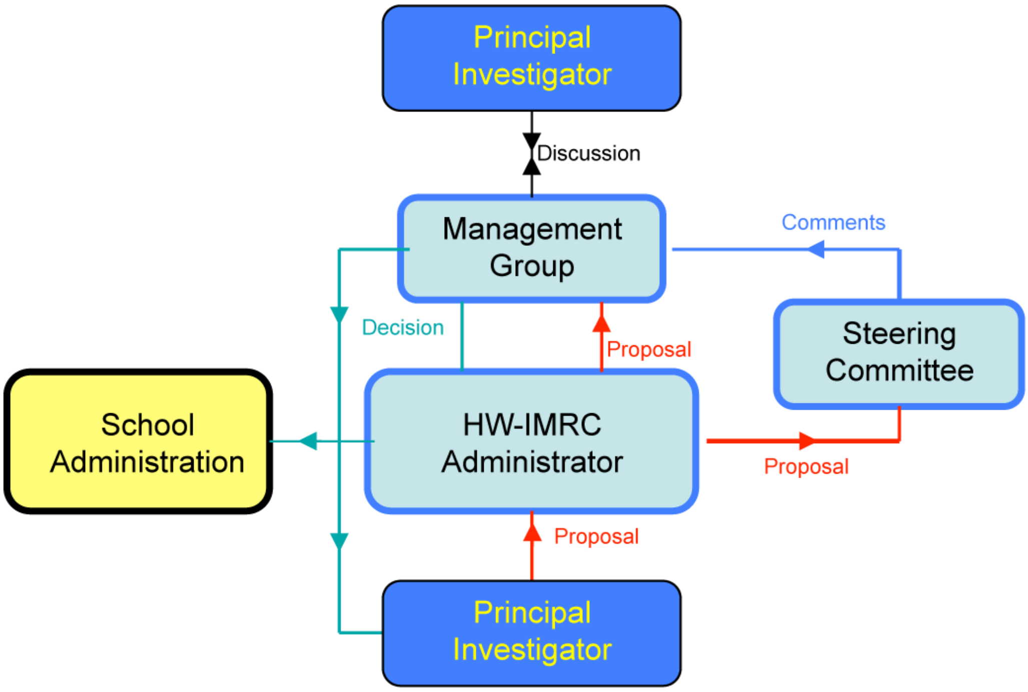
- Reviewing the use of funds;
- Developing and evaluating strategy; and

- Managing interfaces and reporting.

The latter interfaces include IMRC staff and students, other University staff, committees and groups; and internal and external collaborators.

Steering Committee (SC) – this Committee is industrially led by Prof Geoff McFarland, Group Engineering Director of Renishaw plc. The 14 strong SC membership is comprised of representatives from leading industrial companies in the UK, such as QinetiQ and Rolls Royce, strong SME technology intensive businesses, leading academics and a representative from EPSRC. The principal role of the SC is to act as a source of independent guidance and advice for the MG on the development of the HW-IMRC vision, the alignment of its strategy, and progress towards its objectives.

Project Assessment – the MG serves as the coordinating focus for all HW-IMRC opportunities. The figure below illustrates how the research project assessment process works. In addition, the MG introduced a 'roadmapping' technique towards the end of the first five year funding period to ensure a structured and coherent approach to the future development of HW-IMRC research focus and projects. Using an external consultant specialising in 'roadmapping', and drawing upon the latest foresighting documents a Strategic Research Roadmap was finalised at the beginning of 2008 to



inform and guide the second five year block of research funding.

Sustainability of HW-IMRC Model – given that EPSRC funding will run out in 2013, the HW-IMRC reviewed options in 2008 for the maintenance of the IMRC operational model for the period 2008 – 2018. The MG, with the strong support of the SC, has initiated a new pan-University Research Institute focused on promoting internationally-leading research in topics and technologies that underpin high value manufacturing industry. The new Institute, which has been designated the **James Watt Institute for High Value Manufacturing**, incorporates both the existing members of the HW-IMRC and 20 plus additional independent academic colleagues across 4 Schools, who are not currently part of HW-IMRC.

IMRC Impact Model

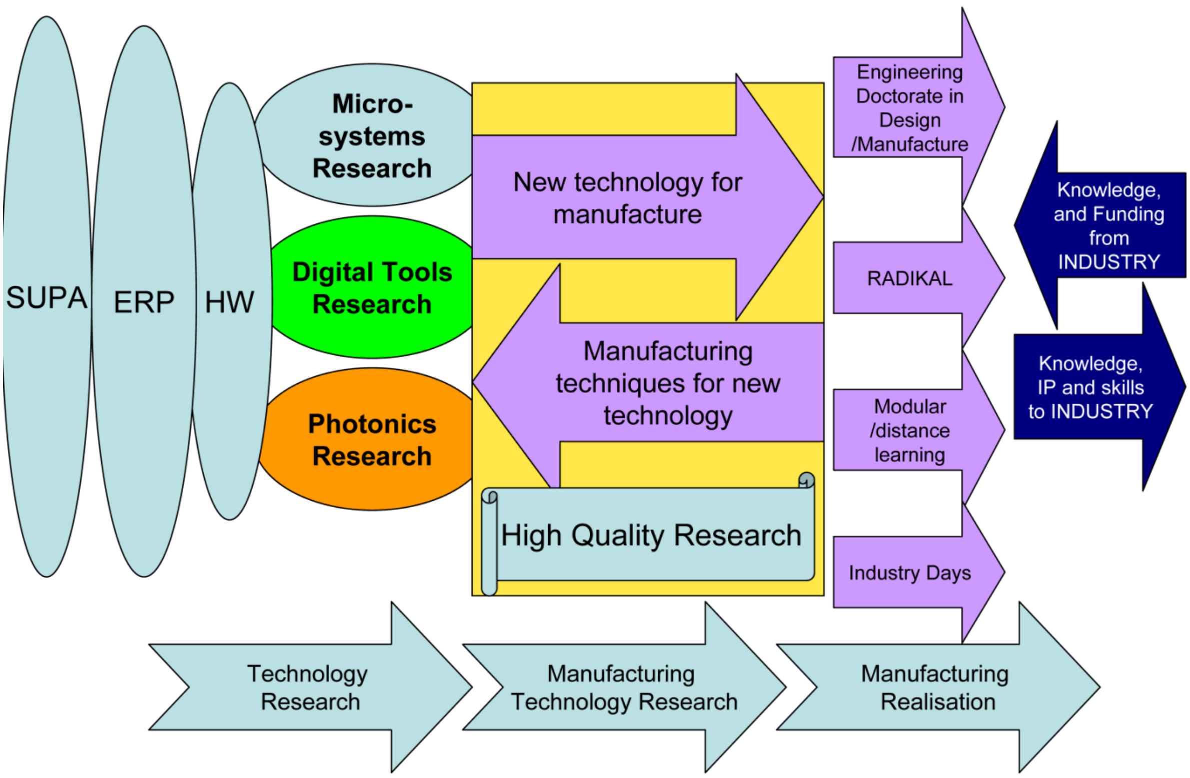
HW-IMRC achieves its outputs and impacts through the way in which it has structured its internal and external relationships with academia and industry. These routes to impact are illustrated in the figure below, with each of the three 'activity strands' being described.

- **Technology Research** – this relates to relevant applied science and technology research carried out across Heriot-Watt University (outside HW-IMRC). This provides the foundation platform for widening the 'reach' of HW-IMRC;

- **Manufacturing Technology Research** – this involves HW-IMRC tapping into manufacturing technology research not just in its three research themes (DT, MM and PM), but also through:

  - The wider university – new technology for manufacture – providing new tools and techniques for novel products using technology from other areas of the University; and
  - Inter-university pooling initiatives such as Edinburgh Research Partnership (EPA), a pooling of engineering expertise and resources with the University of Edinburgh; and the Scottish Universities Physics Alliance (SUPA), a pooling of physics expertise;
  - Other IMRCs; and

HW-IMRC Model – Routes to Impact



- **Manufacturing Realisation** – achieving impact through the following:

  - Increased industrial engagement through its SC, research partners, industry bodies and Government; including secondment of staff between the University and industry;
  - Joint and collaborative research projects with industry partners;
  - Supply of skilled graduates and postdoctoral engineers to industry;
  - Training – now consolidated in a simple structure comprising three MSc programmes, one MRes programme, CPD, Industry Days and Graduate School;
  - Generating IP licensing and IP transfer; and creating spin-out companies;
  - Providing a two-way portal for UK manufacturing industry and all the IMRCs;
  - Maintaining close supportive links with the University's Technology Transfer Unit; and
  - Engaging with regional knowledge transfer activities.

Economic Impact Analysis

Funding and Leverage

HW-IMRC's "7 Year Review Report 2010" gives a detailed breakdown of additional external funding which has been leveraged from the public and private sectors:

- As at March 2010 a total of £9.59 million (cash and in-kind contributions) had been provided by partners to support the research work of HW-IMRC. Thus, for every £1.00 of committed EPSRC funding (£11.5m), £0.84 has been leveraged from sources outside IMRC, as at that date.

- The public sector accounts for a high proportion of the leveraged funding (70%) – in particular, the Research Councils, EPSRC being the most important. Other sources include the private sector (13%) and overseas contributors (17%).

- Excluding EPSRC, important public and private research collaborators and co-funders are Renishaw, Airbus, BAe, BCF Designs Ltd, Exception PCB Ltd and Logitech Ltd.

Leveraged Funding		
Source of Funding:		
- Research Councils (non-IMRC)	£5.10m	53%
- UK Public sector (non-RC)	£1.66m	17%
- UK Private sector	£1.25m	13%
– Overseas	£1.58m	17%
Total	**£9.59m**	100%
Split by Research Theme:		
– Digital Tools	£2.21m	23%
– Microsystems Manufacture	£3.44m	36%
– Photonics-based manufacturing	£3.94m	41%
Total	**£9.59m**	100%

Delivering Human Capital to the Labour Market

The HW-IMRC staff complement is currently 38, split 21 investigators and 17 post-doctoral researchers. For those staff and post-docs which leave the HW-IMRC, a very high proportion goes into industry (71%). This reflects the strong relationships which Heriot-Watt develops with its industrial partners and the positive outcomes this gives rise to for post-docs in particular.

Approximate proportion of former staff/researchers in:	
Academia	21%
Industry	71%
Government	8%

HW-IMRC has a very strong doctoral programme and, from the start of the funding period in 2003, it has achieved 34 PhD completions and a further 34 are in progress. Of particular significance has been the highly successful Engineering Doctorate Centre in Optics and Photonics Technologies centred at Heriot-Watt University.

There are a number of strong examples which illustrate how skills have been transferred into industry through research staff and students – either by KTPs or through recruitment:

- *Rofin-Sinar Ltd Case Study*– the IMRC model has fostered a long term commercial relationship between academia and the company, which facilitated a very strong two-way knowledge exchange process:

  "*The process of transferring technology to the company has been either direct with our staff acquiring the knowledge directly or we have employed PhD students who were active on the project. We have actually employed 3 PhD students from Prof Denis Hall's group*."

  Managing Director, Rofin-Sinar UK Ltd

- *Balfour Beatty Rail KTP* - due to improvements generated through the acquisition and implementation of a new machine tooling, developed in conjunction with HW-IMRC, it is expected that the company will be able to fully machine and process roughly an extra 520 cast manganese crossings a year. This will mean a substantial increase in annual sales of approximately £4.2m p.a.

- *Caledonian Alloys Ltd KTP* – through this award winning KTP, the PhD student was instrumental in the development of a new "Optimised Logistics Process for the Metal Recycling Industry". The commercial benefit to Caledonian Alloys was substantive, with net operating profit increasing by £6m p.a.:

Caledonian Alloys KTP – Commercial Impact p.a.		
Net Operating Profit	Expected (£'000s)	Actual (£'000s)
During KTP	145	2,100
Following KTP	2,150	3,900
Total	**2,295**	**6,000**

Research Impact

In consultation with the Director of HW-IMRC, EPSRC and the Principal Investigators six research areas were selected initially for case study review: see Table on the next page. These case studies were selected on the basis of the agreed shortlisting criteria, as follows:

- **Demonstrate a range of types of economic impact as defined by BIS** – the case studies selected demonstrate Improvements to Existing Businesses, New Business Creation, Human Capital and Improvements to Public Policy/Public Services. HW-IMRC was not able to identify any significant impacts in relation to leverage of inward investment; hence this impact category has not been covered. Human capital impacts have been picked up through discussion of the six case study research areas and the HW-IMRC as a whole (considering the overall number of PhDs and Research staff involved).

- **Offer convincing evidence of significant tangible impact** - All of the case studies identified offer convincing evidence of significant tangible impact – although not all of this is quantifiable, given that some impacts are latent or potential and others by their very nature are difficult to quantify.

- **Demonstrate the added value of the IMRC model** – the case studies highlight a number of added value features of the IMRC model such as high levels of collaboration with industry, other UK institutions, and government; and critical mass.

- **Coverage of the different research themes within the HW-IMRC** – two case studies per research theme have been selected, which are representative of the research work and contribution of HW-IMRC.

- **Sector coverage** – the case studies have widespread coverage of the UK manufacturing sectors including general industrial manufacturing; health sector/pharmaceuticals, electronics, photovoltaics, wallpaper manufacturing, retail/wholesale distribution and defence sector.

Overall, the selection of case studies is representative of the types of work which the HW-IMRC is engaged with, whilst focusing on the examples which demonstrate significant impact and added value.

Case study	BIS Impact Headings	Added Value aspects	IMRC research theme	Sector
1. Pioneering Laser Research	Formation of Rofin-Sinar UK Ltd et al - $1billion of sales Productivity benefits	Critical mass of knowledge Industry collaboration	Photonics	Industrial manuf. Health sector
2. Optical Shape Measurement	Improving existing business – Renishaw Public sector impact – Atomic Weapons Establishment	Industry partnership approach Inter-disciplinarity	Photonics	Health Defence Industrial manuf.
3. 3D-Mintegration	Human capital Improving existing businesses (latent – 4 patents)	Leader of £4.2m Grand Challenge Prog. Innovative thinking Disruptive technologies Inter-disciplinarity Industry collaboration	Microsystems	Wide-ranging application to manufacturing sector
4. Manufacture of High Performance Stencils	Spin-out – Microstencils Ltd Productivity benefits for electronics sector	Industry partnership internationally Critical mass of knowledge	Microsystems	Electronics Photovoltaics industry
5. Surface Texture Characteristics	Spin-out – Totallytextures Ltd Improving existing businesses Public benefit through web application – 'open to all'	Industry collaboration; www – major potential via shoogle.com application – generic public good	Digital Tools	Wallpaper industry Retail /wholesalers Auction houses
6. Exploiting KTPs	Commercial benefits to Caledonian Alloys - £6m p.a. Also Balfour Beatty Human capital benefits	Inter-disciplinarity Industry collaboration The top award in UK rated 'outstanding' out of c. 1,000	Digital Tools	Logistics Manufacturing

However, during the course of the case study work it was agreed that the number of case studies should be reduced to a maximum of 3 – 4. Consequently, we have selected case studies 1 – 3, shaded in the table above. Clearly, this reduction reduces the level of representativeness, but we believe the selection is still strong in terms of coverage of two out of the three research themes; the range of impact headings covered; added value dimensions and sectoral coverage.

Added Value of the IMRC Funding Model

The IMRC funding model has been rated very highly by the Chair, Director and Principal Investigators of the HW-IMRC, as well those industrial collaborators we have spoken to. The key added value features highlighted include:

- **Rolling 5 year funding profile** – the commitment of funding for a sustained period – which will be 10 years for HW-IMRC – is highly beneficial in sustaining research effort and achieving critical mass. This is more likely to generate research impact than a series of unconnected three year research projects. It also allows the University to adopt a ‘portfolio approach’ in the pursuit of its research interests, whereby it can speculate on emerging areas whilst also supporting its core research projects. Feedback from Rofin-Sinar UK Ltd and Renishaw plc endorse this point, as they have been engaged with HW-IMRC on a long term series of research initiatives each one building on the achievements of former research work (see case studies numbers 1 and 2);

- **Flexibility of IMRC funding** – EPSRC funding approval under broad research themes and then allowing HW-IMRC to make the decisions on which research areas to fund within each theme is highly beneficial. The key advantages are:

    - **Speed of response** – the University can respond quickly in the exploitation of opportunities identified with their commercial and academic partners. The traditional approval route for EPSRC funded research projects could take up to 12 months, whereas HW-IMRC can submit its case and have it approved by the Steering Committee within a matter of weeks;
    - **Authority over spend** – the HW-IMRC appreciates the devolution of decision-making from EPSRC over which specific research projects it will allocate funding to. It believes its Principal Investigator Team is best placed to make these decisions, in partnership with its Steering Committee;

- **Internal knowledge exchange** – the HW-IMRC has brought together a range of skills from different academic schools which would not otherwise have happened. This has been helpful in allowing them to:

    - Bring together multi-disciplinary teams more effectively than would otherwise have been the case;
    - Identify, tackle and exploit research areas more effectively through a multi-disciplinary approach. “You have a much bigger pool of expertise to draw upon – colleagues you can bounce ideas off”;
    - Share research staff, resources and ideas within themes and between themes much more effectively
    - Exploit economies of scale through the larger critical mass of HW-IMRC

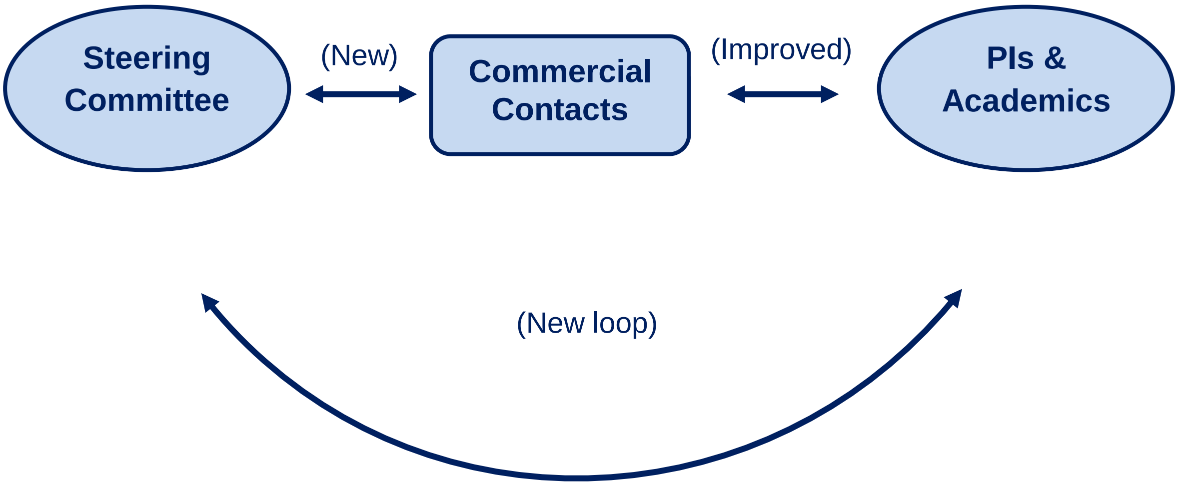
- **Commercial Linkages** – notwithstanding the pre-existing strong commercial partnership philosophy of Heriot-Watt University, the HW-IMRC has built upon this further and derived the following benefits through:

    - The Steering Committee which provides an invaluable conduit to the private sector through its private sector structure. It is chaired by the Director of Engineering at Renishaw plc and comprises a further 9 scientists and engineers at Director/ MD level from leading edge firms across the UK, including Rolls Royce and QinetiQ; and

- The research proposals from HW-IMRC have to demonstrate a strong ‘market-connect’ to secure approval by the Principal Investigator Team and Steering Committee.

- The benefits of the HW-IMRC model are illustrated graphically below, showing where new or stronger commercial relationships have been established. According to the Chairman of HW-IMRC, *“It is now second nature for academics to ‘think commercial’”*

HW-IMRC’s Commercial Linkages

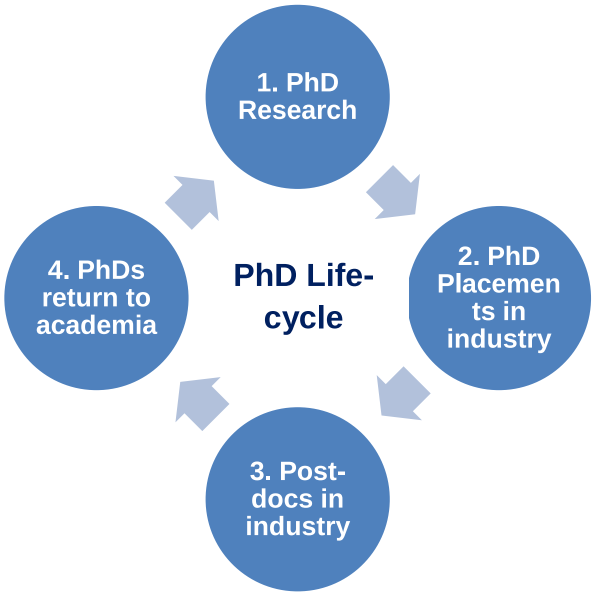


In one example quoted, HW-IMRC undertook a TSB project which “.......*involved the bringing together of IP, people, skills and equipment with the commercial expertise and resources of the private sector. This has been a ‘micro-industrial revolution’ – ‘transformational’*”

- **Human Capital Benefits** – the strong industrial interface which underpins the HW-IMRC research work confers direct benefit to doctoral students engaged in this work. They have the opportunity to work with leading industrial businesses operating at the forefront of their technology. This experience prepares students for industry and improves their chances of securing leading edge research and commercial positions in industry. This is an important value added element of the IMRC model. In this regard there are strong parallels with the Fraunhofer model in Germany. The view of the Principal Investigators is that this applied doctoral training is markedly superior to the more traditional PhD route.

- Further benefits are also derived from this model, due to:

  - The commercial linkages which post-docs can bring to the University when they take up positions in industry – they act as gateways to either open up new relationships or deepen existing ones (both Rofin-Sinar UK Ltd and Renishaw plc have recruited postdocs from HW-IMRC – see case studies 1 and 2); and
  - The fact that a number of post-docs will return to academia bringing their industrial experience with them, which again benefits the university.



This represents a very strong human resource life cycle, whereby the investment in PhD education confers strong research and commercial benefits at all stages: during the PhD education, during employment in industry and when such staff return to academic research functions.

From the perspective of Rofin-Sinar UK Ltd (see case study), principal benefits of the IMRC model are:

- **High Additionality** – the funding enables research projects to proceed which would not otherwise happen, and also helps to enhance scale and performance for committed research:
  "*It allows SME companies to explore opportunities that are on the leading edge of technology: riskier projects but with potentially higher rewards. The gearing that is available encourages larger projects with higher returns."*

- **Knowledge Exchange** – the IMRC model fosters long term commercial relationships between academia and industry, which facilitates a very strong two-way knowledge exchange process:
  "*The process of transferring technology to the company has been either direct with our staff acquiring the knowledge directly or we have employed PhD students who were active on the project. We have actually employed 3 PhD students from Prof Denis Hall's group*."

- **Virtuous Circle** – the transfer of PhD students from academia into industry creates a virtuous circle, with important feedback loops from industry to academia:
  "*Again this cycle is self generating. They train, we employ, the new guys develop and we enter new product territory that poses new opportunities that require academic input that need PhD students and so the cycle turns again."*

The Research and Development Manager at Renishaw's Edinburgh facility sums up the key attributes of the IMRC funding model as:

"*Without the responsiveness of IMRC model, we could not have built up this strategic academic-commercial relationship with Heriot-Watt University. We would have had to resort to the 'old model', based on short, focused, small pieces of work. Renishaw's contribution would have been less and the returns would have been modest. We would have been scratching the surface rather than achieving a major impact in 5 years time."*

Specific added value aspects of the Grand Challenge Programme are:

- **Collaborative Working within Academia** – the nature and scale of the academic partnership working was driven by IMRC funding and the Grand Challenge process. It involved seven universities and the intensity and commitment over a four and half year period is atypical of partnership working in the UK university sector;

- **Industrial Engagement** – 24 companies have engaged with the programme and a number of 'deep' research and commercial relationships have been established; and

- **Novel Research Thinking** – the IMRC funding has provided the level of resources and time-frame to allow a novel approach in facilitating 'blue sky' thinking. This was a real 'challenge' for all of the academic team members: "....*it took us 18 months to stop thinking incrementally and to start thinking outside the box.*" This sea-change in their research methodologies could not have been achieved under the more traditional research funding route.

Case Study 1: Pioneering Laser Technology

<table>
<tr><th colspan="2">Key Facts</th></tr>
<tr><td>Time Period</td><td>2001 – 2010 →</td></tr>
<tr><td>EPSRC Funding</td><td>Three IMRC projects funded:
- Pioneering Industrial Laser Technology (ref P0.06) - £356k
- Fibre Optic Delivery for High Power CO2 lasers (P1.15) - £133k
- Novalase – Solid State Laser Programme (P2.12) - £180k

Total EPSRC funding - £669k</td></tr>
<tr><td>Other Funding</td><td>Contributions from Rofin-Sinar UK Ltd amounted to £97k for Pioneering Industrial Laser Technology:
- Cash £9k (£120k)
- Equipment £77k (£40k)
- Other in-kind £11k (£45k)
The additional contributions for Novalase are in brackets in red.</td></tr>
<tr><td>Collaborator(s)</td><td>Rofin-Sinar UK Ltd; Exitech Ltd; CoorsTek Ltd; Nottingham University</td></tr>
<tr><td>IMRC Research Theme</td><td>Photonics</td></tr>
<tr><td>Key Economic Impacts (Against BIS Impact Headings)</td><td>Contribution to Rofin-Sinar UK Ltd – supporting commercial development of earlier spin-out company (pre-IMRC) – improving an existing business:
- Sales impact – contribution to the growth of Rofin-Sinar UK Ltd:

<table>
<tr><th>Rofin-Sinar UK Ltd</th><th>2003</th><th>2010</th><th>Growth</th></tr>
<tr><td>Turnover</td><td>£6.5</td><td>£16m</td><td>£9.5m</td></tr>
<tr><td>Employment</td><td>70</td><td>120</td><td>50</td></tr>
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- Rofin-Sinar has achieved a 6% growth in sales during the recession compared to a 24% decline across the worldwide laser market (by far the worst downturn since the laser market formed in the early 1960s). It has also won a Queen's Award for Innovation and has applied for a Queen's Award for Enterprise (International Trade) - 2011.
Wider benefits of this technology to the global laser industry which has achieved sales of >$1 billion since the commercialisation of the original pioneering work in the late 1980s, exploiting key breakthroughs:
- Development of high power density radio-frequency discharge planar waveguide lasers (revolutionary business card shape rather than conventional cylindrical laser shape)
- Development of unique laser marking systems

Majority of this commercial benefit flows outside the UK given the global nature of the industry.</td></tr>
<tr><td>Sector Focus</td><td>Applications for manufacturing processes in:
- Industrial manufacturing (materials processing, sheet metal cutting, automotive, textiles, electronics, aerospace, product marking
- Health sector applications</td></tr>
</table>

Context

This area of research originated in the 1970s with work at Hull University and the spin-out company Laser Applications Ltd developing novel radio-frequency lasers for health applications. The company was acquired by Coherent Inc in 1986. A history of buy-outs of UK spin-outs by US and German firms followed, leading to Rofin Sinar GmbH acquiring the spin-off company Palomar Technologies Ltd, after a ten year joint venture. However, the creation of new companies in the UK has continued over the last three decades. The common themes have been:

- The continuity of the same core academic research team in the UK leading the pioneering research, which is characterised by its strong desire to see the commercialisation of its research breakthroughs
- The consolidation of Heriot-Watt's role in the global photonics industry with the transfer of Prof Denis Hall and Prof Howard Baker from the Hull University to Heriot Watt (1987)
- The commercial exploitation of pioneering laser technologies by international players with the marketing resources and economies of scale to be successful
- The refocusing of the academic research effort at key junctures to meet changing technological challenges and commercial opportunities. This has included:

    - Development of several generations of planar waveguide lasers (revolutionary THIN 'business card' shape rather than conventional cylindrical laser shape)
    - Development of unique crystal lasers rather than gas lasers

The IMRC Project

The IMRC funded research represents an extension of Heriot-Watt's longstanding research programme on laser and photonic technologies. The market failure is assessed to be high as is the level of additionality. This reflects two factors:

- The research focus is transformational and not 'near-market'. The strategy has always been to develop leading-edge IP and know-how at which point the private sector is used to bring it to commercial reality; and

- The specialist nature of the research knowledge and skills embodied within the HW-IMRC is unique and not replicated in the private sector [Note: Heriot-Watt is recognised as a world leader in research on laser technologies by the world centre for laser manufacturing in the West coast of the United States.]

The impact assessment focuses on **Pioneering Laser Technology Research (P0.06)** which built on earlier pioneering planar waveguide architecture developed at Heriot-Watt and applied it to ultra-compact high peak power (USP) CO_2 lasers for industrial and medical applications.

The following outputs can be attributed to the IMRC funded research project:

- 2 new workstations
- 27 journal and conference papers
- 10 invited talks at international conferences
- 5 PhD completions; 4 PhD students writing-up

The outputs of the research have been applied as follows:

- Development of USP laser technology which is under commercial development
- Maximising the commercial performance of spin-out company Rofin-Sinar UK Ltd (formed in 1997 prior to IMRC funding)

The IMRC Photonics Research Theme has subsequently committed funding to two further research projects to continue its laser research work:

- Fibre Optic Delivery for High Power CO2 lasers (P1.15) - £133k (2006 – 2008)
- Novalase – Solid State Laser Programme (P2.12) - £405k (funding recently approved by IMRC Steering Committee)

The strong finding from this case study has been the sustained application of research effort over a period of 30 plus years. The current IMRC funding programme is complementary to, and supportive of, this research philosophy.

Assessment of Economic Impact

For the IMRC funding period the focus of economic impact at the UK level is through HW-IMRC's contribution to Rofin-Sinar UK Ltd. Gross impacts over the period 2003 – 2010 have been:

- Turnover growth of £9.5m, from £6.5m to £16m (150%increase over 7 years)
- Employment growth of 50 staff, from 70 to 120 (70% increase over 7 years)

It is important to point out that these value-for-money metrics understate the long term impact from IMRC funding due to the following factors:

- The impact is based on commercial contribution to date. It is likely future exploitation of the technology will continue to support the growth and development of Rofin-Sinar UK Ltd;
- The fact that multiplier and supply chain benefits have not been calculated; and
- The legacy effects of this research. For example, we know that this project forms an important foundation for follow-on applications in the area of fibre optic delivery of high powered lasers and the development of solid state lasers.

Regarding the latter point, the Managing Director of Rofin-Sinar UK Ltd estimates that if you integrate the revenue of the companies that trace back to the original start up Laser Applications Ltd then you get c. £250 million turnover with the majority exported.
"*This has provided, and provides, knowledge based employment and a continuing export revenue stream to UK Ltd.............. exactly what this country needs to compete in the evolving economic market*."

Consultees

The following people were consulted:

- Professor Denis Hall
- Dr Ken Lipton, Managing Director of Rofin-Sinar UK Ltd

Case Study 2: Optical Shape Measurement

Key Facts	
Time Period	2007 – 2011
EPSRC Funding	IMRC project: "Free form shape engineering": July 07 – March 08 (ref P1.17) - £130k
Other Funding	Industrial collaborative funding from Renishaw plc – £334k: - Supporting the building of prototypes - Use of Renishaw equipment to test them - Allocation of EngD student time
Collaborator(s)	Renishaw plc
IMRC Research Theme	Photonics
Key Economic Impacts (Against BIS Impact Headings)	Improving the commercial performance of an existing business (Renishaw). It is projected that this will result in the following employment impacts by 2015: • 17 additional jobs in research and manufacture in the UK • 20 safeguarded jobs in research and manufacture in the UK
Sector Focus	Applications for manufacturing processes in: - Industrial manufacturing (specifically aerospace and automotive) - Health sector applications

Context

This is a 100% IMRC project in terms of its timing – the first tranche of funding was allocated in July 2007:

- Free form shape engineering – July 07 – March 08 (ref P1.17)

It arose from meeting the technical challenges facing their industrial partner Renishaw plc, a specialist manufacturer of measuring equipment based in Gloucestershire. This research work provides the focus of this case study.

Commercial Partnership – Renishaw plc has a longstanding research relationship with Heriot Watt University. The firm has a 'Metrology Department and Innovation' facility on the Heriot-Watt Science Park employing 22 staff. They have also funded laboratory space in the Heriot-Watt Engineering and Physical Sciences building. The philosophy underpinning this relationship is based on the following principles:

- Renishaw is a source of industrially relevant research problems to be solved, both for their own products and their customers' requirements. This ensures that the HW-IMRC research effort is market facing with the certainty that there is commercial relevance

- HW-IMRC focuses on what it does best – leading edge research to help its industrial partner crack the technological problems

- A partnership model which is one based on openness and equity. All staff involved in the HW-IMRC research work at Renishaw and Heriot-Watt are covered by a Non-Disclosure Agreement which ensures genuine sharing of information.

- There are no problems over IP, as Renishaw takes out patents where appropriate, and if commercially successful there is an open discussion on the financial returns to the University.

The University considers such relationships to be "......*like gold dust – highly valuable to both partners and underpinning a 'knowledge rich environment'*". This model replicates other such relationships which Heriot-Watt has helped to foster with leading public and private sector organisations such as AWE, Selex, BAE and Rolls Royce.

The IMRC Project

The project was to improve the efficiency and cost-effectiveness of measuring shapes. The problem was highlighted by Renishaw plc, which is a world player in the production of measuring equipment for industrial and medical manufacturing processes – most of its measuring equipment is exported worldwide. Developing the research expertise or know-how to crack this problem would have been costly and time consuming. However, they were interested in pursuing a collaborative research project which combined the IP and research skills of HW-IMRC with their production skills and resource base. This had proved a winning formula in the past. The rationale for public sector research funding is therefore based on:

- **Sharing Risk** – given the speculative nature of this research area and its unknown commercial potential (at the outset of the research), Renishaw would not have committed to undertaking this work. The IMRC funding combined with the acknowledged expertise at Heriot-Watt University represented the 'tipping point' for convincing their Board to invest in this technology. Sharing the investment costs, the risks and returns is a successful formula to bring forward research that has real commercial potential.

- **Exploiting Window of Opportunity** - there is also a timing factor in that it quite possible for the market window for technology such as this to be missed altogether with the consequence that the commercial opportunity is lost altogether. The IMRC funding model enables a prompt response to be made to the initiation of the research project.

- **Technology spillovers** – whereby the roll-out of the research outputs have the potential to contribute not just to Renishaw but also the wider industry – the counterfactual being a lower level of investment by the private sector than would otherwise have been the case. This can be due to the problems of 'free riders', companies which prefer to under-invest in research because of the difficulty of internalising such benefits, especially where the know-how becomes a public good.

The context for this research is the application of optical techniques to take measurements for engineering applications. The current measuring equipment technology is based on Co-ordinate Measurement Machines (CMM) which are based on a point-by-point measurement over the whole surface of the object using a probe that touches the surface. This can be very slow as outline co-ordinates have to be input as part of the set-up process which can take half to a full day. To speed the set-up process HW-IMRC have focused on the development of Optical Shape Measurement (OSM) technology which allows the shape to be measured over extended regions of the object to provide the co-ordinates for the CMM equipment in a fraction of the time. They explored two OSM techniques in parallel: fringe projection and photogrammetry with specific innovations required to be compatible with CMM technology.

An EngD student at Renishaw built the prototype with the support of the Principal Investigator at HW-IMRC, a postdoc and two research staff at Renishaw. The following outputs can be attributed to the IMRC funded research project:

- A laboratory prototype of the novel optical scanner was built and its operating principles verified
- 4 patent applications submitted:
    - 3 completed, but not granted (in examination phase)
    - 1 pending completion

- 3 journal papers (in preparation); 3 conference papers

The outputs of the research have been applied by Renishaw as follows:

- 2 products in active development by Renishaw
- 2 further products being considered by Renishaw

The IMRC Photonics Research Theme has subsequently committed funding to two further research projects to continue its OSM work:

- Shape measurement for laser material processing: Jan 09 – Dec 11 (ref P2.10) – EPSRC funding £419k and Renishaw support valued at £189k
- Speckle reduction in optical sensors for manufacturing processes (which funded 2 PhD studentships for 3.5 years): Oct 09 – March 13 (ref P2.07) – EPSRC funding of £132k.

This follow-on research focuses on areas that build on OSM mounted to CMM, with the specific objectives to:

- Develop novel optical arrangements; and
- Investigate effect of speckle contrast (for both coherent and incoherent illumination sources) on shape measurement accuracy and investigate speckle reduction techniques consistent with fringe projection and CMM-mounted optics.

It also tackles a new research area which is investigating the potential for a novel high-accuracy optical scanner (<5um).

The strong finding from this case study has been the sustained application of research effort over a period of 5 plus years. It has been rated highly by both Renishaw and HW-IMRC:

- Contribution to industrial partner – Renishaw plc – has been rated as 'major value'. Their Director of Engineering has assessed the research project as 'very successful'.

    - *Adventure rating of project* – classified as 'breakthrough research'

Furthermore, this research work has contributed to the assessment of Heriot-Watt's Photonics Theme to be deemed "*Internationally Leading"* at both the five and seven year reviews of the HW-IMRC, the highest grade that can be awarded.

Commercial Benefit – the application of the OSM technology has very strong commercial potential for Renishaw in improving the performance of its Industrial Metrology Tools in three main areas:

- *Product* – where you have to re-engineer or modify a product for which you do not have the digital data
- *Process* – to establish the set-ups in the manufacturing process, so the machine tool cuts in the right place
- *Quality* – to check that you have made the product to the exact tolerances that were planned, i.e. quality control.

Examples of the benefits which the new OSM technology will confer include:

- Measurement of products where touch measurement using CMM technology is not appropriate e.g. car seats due to the fact that they are soft

- Surfaces with cosmetic or optical properties e.g. high gloss finishes. At present this is checked 'manually' by the human eye as CMM technology could damage the paintwork. The OSM technology would overcome this problem
- High temperature coatings on aero-engine blades are very brittle. CMM technology could easily crack them.
- Speed of checking – it is much quicker to operate OSM technology saving time and money for the manufacturer.

Assessment of Economic Impact

The economic impact at the UK level is through HW-IMRC's commercial contribution to Renishaw plc, an existing UK business. The estimation of potential impact is based on:

- The roll-out of the OSM technology to the aerospace industry, projected to be within the medium term. It is not a case of 'if' but 'when'. The technology will be adopted by all of the major aerospace manufacturers worldwide; and
- A second phase roll-out across the automotive industry in the longer term. Again, all major automotive companies will be using this technology in their production plants.

The economic impacts are estimated to be:

- R&D employment at Renishaw's R&D facility at Heriot-Watt increasing from 22 to 35 by year 5;
- Manufacturing employment of high value products at its Gloucestershire plant from 5 to 15 staff by year 5.
- Safeguarding employment of 22 staff at Renishaw's research and development facilities at Heriot-Watt Science Park and manufacturing employment of 5.

	Current Employment 2010	Future Employment 2015	New or Safeguarded Jobs
R&D	22	35	13
Production	5	15	10
Total	27	50	23

Consultees

- Professor Andrew Moore, HW-IMRC
- Professor Geoff McFarland, Technical Director, Renishaw plc
- Nick Weston, Manager, Edinburgh Research Facility, Renishaw plc

Case Study 3: 3D-Mintegration – the Design and Serial Manufacture of 3D Miniaturised Products

<table>
<tr><th colspan="2">Key Facts</th></tr>
<tr><td>Time Period</td><td>Oct 2005 – March 2010</td></tr>
<tr><td>EPSRC Funding</td><td>Contribution from IMRCs
HWU £429K, Cranfield £500K, Loughborough £429K, Nottingham £730K, Cambridge £250K

Funding from the EPSRC
HWU £692K, Cranfield £781K, Greenwich £405K, Loughborough £621K, Nottingham £893K, Cambridge £773K

Total contribution from IMRCs £2,337K
Total funding from EPSRC £4,167K</td></tr>
<tr><td>Other Funding</td><td>- Industrial funding and in-kind support > £2.3m during the programme
- Future funding of £9.1m achieved by academic, industrial and public sector partners as a result of the project</td></tr>
<tr><td>Collaborator(s)</td><td>- Leader – Heriot-Watt
- Other IMRCs – Cambridge, Cranfield, Loughborough, Nottingham
- Non-IMRC Universities – Brunel and Greenwich
- Large companies - National Physical Laboratory, Syngenta, Sun Microsystems, Unilever, MBDA, BAe Systems, Astra Zeneca & Glaxo SmithKline
- SMEs – 16 small and medium sized companies covering a wide range of industrial sectors and whole value chain in manufacturing</td></tr>
<tr><td>IMRC Research Theme</td><td>Microsystems</td></tr>
<tr><td>Key Economic Impacts (Against BIS Impact Headings)</td><td>Many across several universities</td></tr>
<tr><td>Sector Focus</td><td>Not sector specific. The research has involved applications across the whole manufacturing domain. Specific applications being investigated from this research include:
- Automotive sector
- Industrial manufacturing
- Health sector – diagnostics, medical devices, etc.
- Microelectronics/nanotechnology
- Aerospace</td></tr>
</table>

Context

This is a 100% IMRC project in terms of its timing – funding commencing in October 2005 although non IMRCs such as Greenwich and Brunel were invited to join. As part of the 'Grand Challenge' initiative, the IMRCs were challenged to come up with research themes. From the long list of 45 – 60 ideas, the Directors of the IMRCs shortlisted down to eight, of which EPSRC funded four. The HW-IMRC led '3D-Mintegration' programme was ranked first equal at the final approval stage.

IMRC Project

The 'Grand Challenge' faced by the 3D-Mintegration (abbreviation for 3D Minaturised /Integration) project was a complete revision of 'traditional' manufacturing practice at the micro-scale, moving away from the no-expense spared mindset of the semi-conductor industry over a 50 year period. This required visionary research based upon fundamentally new ideas and consequently taking unexpected paths into totally uncharted territory. The funding gave them the 'permission to dream', to investigate disruptive technologies and genuinely 'think outside the box'. The rationale for funding such an approach is based on:

- Information failures – whereby the dissemination and sharing of knowledge between the UK's research base and industry was highly imperfect. This project enabled a much more joined-up and integrated approach.
- Additionality – given the pioneering approach, the avenues being explored can be considered to be 100% additional and new territory. This explains the high level of interest from industry – they all wanted to share in the potential upside and not 'lose out'.
- Technology spillovers – this also provides strong evidence for positive externalities and technology spillovers i.e. industry is not willing to invest individually in such research work, but they are prepared to join a subsidised collaborative effort. Given the groundbreaking nature of the research topics, if the research outputs are successful commercially, then they are quite likely to have widespread adoption and uptake across a range of industries and applications.
- Transformational Impact – given the pioneering nature of the research the impact could well be transformational in its range and scale across industry and the public sector (e.g. health benefits).

The research was organised into five themes, which were then further subdivided into work packages with multiple tasks:

- Design & Simulation: Leader – Greenwich University; partners – Brunel, Nottingham and Heriot-Watt
- 3D Processing: Leader – Cranfield; Partners – Cambridge and Heriot-Watt
- Micro-assembly: Leader – Nottingham; Partners – Cranfield, Cambridge, Greenwich and HW
- Packaging: Leader – Loughborough; Partners – Greenwich & HW
- Test & Measurement: Leader NPL; Partners – Cambridge, HW, Loughborough, Greenwich and Nottingham

This research effort equated to 50 man-years of effort over the four and a half year programme. It was also complemented by three demonstrators which provided tangible test beds to focus the research, to validate developments and to promote discussion with the industrial collaborators:

- Health and Usage Monitoring System (HUMS)
- Miniaturised flexible microprobe
- Micro-fluidic delivery system

Outputs & Outcomes from Research (illustrative only):

- 3D-MINTEVISION – a software framework that knits together conceptual design and manufacturing to facilitate the manufacture of new products using newly created technologies.
- Risk Mitigation – a breakthrough product and process introduction methodology that mitigates risk by comparing the similarities between new manufacturing techniques and a cohort of previously techniques
- Design Methodology – which can transform physical principles in 2D diagrammatic form directly into beneficial 3D structures

- ‘Similitude’ – a special application to help designers visualise and debate micro-behaviour at everyday macro-scale
- Manufacturing Processes – a portfolio of 32 processes which are relevant to 3D miniaturised integrated products
- Focused Ion Beam Technology – the development of this as a manufacturing tool rather than its conventional use in measurement and analysis, with particular application to the creation of low-cost precision tooling for high volume manufacturing
- Demonstrators – the demonstration of the validity of the academic research through the production of three test prototypes.
- Dissemination:

  - 71 journal articles
  - 163 conference proceeding articles
  - 23 MSc/PhD theses
  - 4 patents filed
  - 1 software created
  - 118 separate dissemination activities

This wide-ranging research programme with its active industrial partner engagement has yielded a wide range of commercialisation activities, including:

- SLI Ltd moved to the Heriot-Watt Science Park, which enabled a strengthening of their collaborative research activities with the University, and resulted in the creation of two additional research projects targeted at the design and manufacturing of Microsystems;
- Ultra Electrics increased their contribution to the Consortium threefold as a consequence of winning a £1.2m contract with SEEDA
- Tecan Ltd contributed to a significant market survey on the current leading edge technology in stencil printing
- Epigem Ltd increased their contribution to the programme and entered into license negotiations with Heriot-Watt University for the commercialisation of the micro-fluidic demonstrator. The company benefited from this work through the award of two additional research projects under TSB funding.
- NPL contributed so much to the project that they became, along with BCF Designs Ltd, the industrial leaders for the micro-phobe demonstrators. Negotiations have started with NPL to commercialise the microprobe with the company Carl Zeiss
- Renishaw plc is very interested in the processing work package in terms of the novel technologies it may spawn and the contribution to lowering the manufacturing cost of their encoders.
- Fiat Group identified the programme as being of seminal importance. As a result, they have contributed to the content of 3D-MINTEGRATION Annual Conferences.

Finally, Heriot-Watt University is in negotiations with four Fraunhofer Institutes for the set-up of a Centre for low cost micro-manufacturing. The Centre will be financed by the German Government, University and public sector contributions in the first instance, with the objective of translating the research outputs from 3D-Mintegration into industry technical outputs to support their commercialisation.

Assessment of Economic Impact

In general terms it is too early to see the economic and wider societal benefits flow through from this Grand Challenge Programme. However, there is strong evidence of potential economic and health impacts – in the UK and internationally. The ‘Success Stories’ include:

- **University, Greenwich – WP1 – Development, Integration and Deployment of Simulation Tools.** The research outputs have wide potential for impact:

    - Products and manufacturing processes that are not incremental developments of what has gone before
    - Products with tightly integrated functions, yet highly predictable interactions between those functions
    - Products with ever accelerating market introduction and downward pressure on price

    The application of this work is now a topic for the European Technology Platform EPoSS which recognises that 'Smart System Integration' based upon holistic design will provide competitive advantage for European industry.

- **University, Nottingham – WP1 – Risk mitigation Engine.** This research demonstrated a world first in the definition of 'Manufacturing Readiness Levels' to ascertain the risk of introducing new manufacturing technologies, akin to NASA's 'Technology Readiness Levels', which have become currency worldwide.

- **University, Brunel – Conceptual Design**. NDA has been signed with The Medical Device Company Ltd to pursue commercialisation of the blood plasma separation device conceived during the work. The successful deployment of the device would enable low-cost highly effective diagnosis of disease and its treatment, away from supporting infrastructure. This would have also significant health and social welfare benefits, in addition to the economic returns.

- **University, Cambridge – WP2 – Laser Print Forming.** The research outcomes have been applied directly in the production of a range of demonstrator projects:

    - 3D Microprobe for a new nano coordinate measuring machine manufactured by Zeiss and designed by the NPL;
    - 3D Micro-fluidic cell separator for white blood cells – a preliminary stage in the development of a genetic testing kit; and
    - Wiring loom diagnostic system for current carry systems in aircraft.

    This work has the potential to provide radically new production capabilities that will be employed to develop high value products necessary to maintain the competitiveness of the UK economy.

- **University, Cranfield – WP2 – Microinjection Moulding of a Demonstrator Minifluidic Blood Plasma Separation Device.** In order to avoid invasive techniques of extracting cells from pregnant women to detect genetic abnormalities such as Down's Syndrome, an attempt is being made to detect an abnormality by analysis of foetal cells contained within maternal blood. The small number of foetal cells requires concentration of the mixed maternal/foetal red blood cells prior to analysis. The demonstrator indicated ways forward for the practical implementation of such a separator.

- **University, Nottingham – WP3 – Pneumatic Micro-feeder System.** The long term impact of this technology is significant as the research output will provide radically new production capabilities that will be employed to develop high value products relevant to the UK manufacturing base.

- **University, Loughborough – WP4 – Localised Polymer RF Joining**. Making reliable contamination free seals in fluid interconnects and hermetic device packaging, at low cost, is an essential enabler for the adoption of advanced Microsystems.

- **University, Loughborough – WP5 – Advances in Interferometry**. Industry will immediately benefit from the publication "Guide for the Measurement of Rough Surface Topography using Coherence Scanning Interferometry, National Measurement Good Practice Guide." (Crown Copyright 2010).

Consultees

- Professor Marc Demulliez, HW-IMRC