Impact Assessment of EPSRC's Manufacturing the Future Programme 2005-2020

Final Report 1.0

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Contents

Executive Summary 3
1. Introduction and Methodology 5
1.1 Introduction 5
1.2 Study Approach 5
2. Overview of the UK Manufacturing Sector and the Rationale for Public Investment in Early-Stage Manufacturing R&D 7
2.1 UK Manufacturing Sector Overview 7
2.2 Strategic Importance of the UK Manufacturing Sector 8
2.3 Rationale for EPSRC MtF Investment 10
3. Overview of the MtF Programme 11
3.1 Funding and Allocation of MtF Resources 11
3.2 Analysis of External R&D Investment Secured by the MtF Programme 11
3.3 New Start-Ups / Spin-Outs 13
3.4 Skills, Training and other Outputs 14
3.5 Public and Policy Impacts 15
4. Return on Investment in the MtF Programme 16
5. Insights on MtF Impacts 19
5.1 Introduction 19
5.2 New Market Opportunities for UK Manufacturing 19
5.3 Impact on Talent & Skills Development 25
6. Added Value from Critical Mass Investments (CMIs) 27
6.1 The 4 Key Added Value Benefits from the CMI Funding Approach 28
7. Conclusions and Next Steps 34

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Executive Summary

Brookdale Consulting was commissioned by EPSRC to carry out an assessment of the impact of its Manufacturing the Future (MtF) Programme. MtF supports early-stage, basic research with the goal of delivering transformative new knowledge that can be used to build new and more competitive manufacturing activities in the UK.

Market forces do not incentivise business to invest sufficiently in early-stage R&D. This is a problem because it is from this type of research that some of the most significant long-term, exponential productivity gains have been achieved, as recognised in the *UK Innovation Strategy 2021*. EPSRC's MtF Programme responds to this need.

A bespoke economic model, based on HM Treasury Green Book principles, was constructed to assess the impact of EPSRC's £975m investment in the MtF Programme over a 15-year period from 2005-2020. The key findings are as follows:

- Every £1 spent on MtF returning £63 at the UK level over a 50-year appraisal period (based on the value of economic gains and carbon reduction emissions). £41 of this can be attributed to EPSRC.
- A range of sensitivity analysis can be undertaken, but the consistent finding is a strongly positive Return on Investment (RoI) from EPSRC's MtF Programme.

Other key findings from the study are:

- The additionality of benefits is high because there is a clear market failure that discourages businesses from investing sufficient resources in early-stage R&D
- The MtF 'portfolio approach' is a feature of its success. Risk is spread across different types of interventions with an acceptance that not all will achieve significant impact. The emphasis is on the portfolio as a whole. In our random stratified sample of case studies, we reviewed some projects where there had been no tangible impacts to date, but these were more than compensated for by a small number of projects where very significant impacts had been achieved
- The direct monetised impacts from Mtf are just part of the way in which it benefits the economy. In addition to the creation of new knowledge through R&D, it builds university-business networks to support the diffusion of new knowledge into industry, and raises the absorptive capacity of industry to deploy new knowledge for economic gain (including SMEs)
- MtF has not been drawn into competitive tensions with the new innovation bodies established over the last fifteen years. Instead, there is evidence of pull-through of basic research funded through MtF into the more near-market innovation support system provided by the Catapult Network and others. MtF complements these programmes and EPSRC provides resources for outreach and collaboration, particularly through its CMI investments
- One of the most pressing needs of businesses in the advanced manufacturing sector is securing talent and skills. Part of the MtF portfolio is directed at skills provision which is an excellent use of resources where MtF funds a core academic team to both undertake research, and to recruit and train students in the emerging technology area

- The bulk of manufacturing output is generated outside London and the South East. MtF is a vehicle for addressing regional inequalities in the UK and examples are provided in the report
- MtF has been agile and responsive to new industry and technology requirements over the study period. This is one of the reasons for its success and it must continue to adapt in the future, taking account of the findings and recommendations from this study.

1. Introduction and Methodology

1.1 Introduction

Brookdale Consulting was commissioned by EPSRC to carry out an assessment of the impact of its Manufacturing the Future (MtF) Programme.

EPSRC supports the UK's manufacturing sector by funding early-stage manufacturing research up to the point where it can be developed and applied by companies or via intermediaries such as Innovate UK and the Catapult Network. In turn, EPSRC's research helps to support new technologies, products, services, and jobs in the UK and abroad.

The MtF Programme supports research across all aspects of the manufacturing sector - simulation and design, production, fabrication, systems, and services. It aims to drive innovation in high-value manufacturing activities such as aerospace, pharmaceuticals and healthcare engineering and energy as well as supporting the transition to net zero.

The MtF Programme began in 2005 and the impact assessment considers the period from 2005 to 2020. This report provides an overview of:

- **The UK manufacturing sector**, its strategic importance to the UK and the rationale for public investment in early-stage manufacturing research
- **The funding and operation** of the MtF Programme
- **The return on investment** from 2005-2020**,** based on the economic model constructed for the study by Brookdale Consulting in accordance with HM Treasury Green Book principles
- **Some of the real-world impacts** from the MtF Programme in terms of UK manufacturing productivity growth, the international competitiveness of the UK manufacturing sector, the rapid scale-up of UK manufacturing capacity for the Covid vaccine roll-out, and a pipeline of PhD and post-doc skills and talent for UK manufacturing companies
- **The value of critical mass investments (CMIs)** alongside project grants in the MtF portfolio
- **Conclusions** and lessons learnt.

A set of appendices accompany this document and provide further information on the study methodology, the case studies undertaken and the cost benefit model (CBM).

1.2 Study Approach

The study was overseen both by EPSRC staff and an Independent Project Advisory Group drawn from academics and industry.

The details of the study methodology can be found in Appendix 1. The key components of the work programme were as follows:

- **Analysis of the MtF project database -** we were given access to EPSRC's grant database and ResearchFish outputs for the 1,000+ MtF projects funded from 2005-2020

- **Review of the UK manufacturing sector –** key features of the UK manufacturing sector, and its performance over the study period, were examined
- **Consultations with EPSRC staff –** early consultations were undertaken during the inception phase of the study to develop the work programme in more detail. An Inception Report was prepared, and this was approved by the Project Advisory Group. The internal team responsible for overseeing the project were EPSRC's Head of Manufacturing, EPSRC's Head of Evaluation & Research Impact, and UKRI's Economic Advisor for Business Cases & Evaluation
- **In-depth research impact case studies –** a random stratified quota approach was employed to choose the case studies, which was overseen and agreed by the Project Advisory Group. The process for undertaking the case studies involved a desk review of project documentation, structured interviews with the lead academics and follow-up consultations with industry partners. A key feature of the Brookdale Consulting approach is to independently verify case study findings with industry and other partners. There was extensive contact with industry partners during the study and (where relevant) sign-off by industry partners for the impacts reported for each case study. The individual case studies are included in Appendix 2[1]
- **Independent assessment of the value of critical mass investments (CMIs)** alongside project grants in the MtF portfolio. CMIs are multi-disciplinary research hubs that receive more secure, longer-term funding for a period of time. Approximately a third of the MtF budget is channelled into strategic research hubs which operate at a national scale in a hub and spoke structure, and so are fundamentally different to the way that conventional project grants operate. One of the requirements of the brief was to establish whether there was added value to MtF from investing in CMIs alongside project grants, and the case for continuing to invest in CMIs in the future
- **Development of a bespoke cost-benefit economic model for MtF.** This was constructed in accordance with HM Treasury Green Book principles. The model focuses on returns to the UK economy and society. Wider global impacts are not included although substantial in some cases. The period of analysis is from 2005 onwards with a 50-year appraisal period. This gives the best representation of cost-benefits as the early-stage research funded by MtF can take an extended time to reach market.
- **Data input and running the cost-benefit analysis** – all cost-benefit analysis is critically dependent on the quality and accuracy of data inputted into the model. The data for this study is predominately from the detailed fieldwork undertaken by Brookdale Consulting and it includes only benefits that can be attributed directly to EPSRC investment. In this sense, the estimates of impact may be considered somewhat conservative. Judgements about attribution are based on consultations (particularly with industry) and our previous experience of undertaking impact studies for early-stage research. This is not an exact science, and assumptions have to be made, all of which have been recorded for quality checking purposes.
- **Study findings, final report and accompanying evidence base –** these are set out in the rest of the rest of this document.

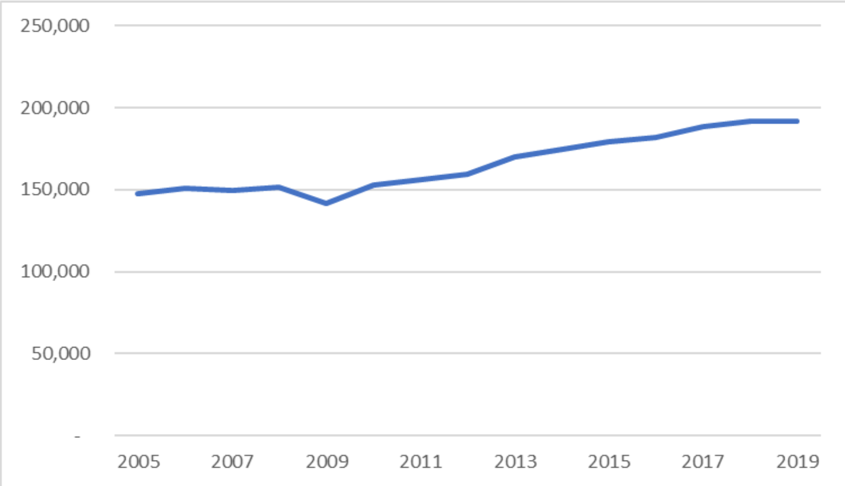
[1] Note there are NDAs and confidentiality matters pertaining to some of the case study projects, which require the contributor's permission prior to publication or wider circulation outside EPSRC

2. Overview of the UK Manufacturing Sector and the Rationale for Public Investment in Early-Stage Manufacturing R&D

2.1 UK Manufacturing Sector Overview

Office for National Statistics (ONS) data shows that Manufacturing Gross Value Added (GVA), the Government's preferred measure of economic performance, has grown 30% since 2005, reaching £191.6bn in 2019. Over the same period, however, the UK economy grew by 58%, reflecting very strong growth in the services part of the economy.

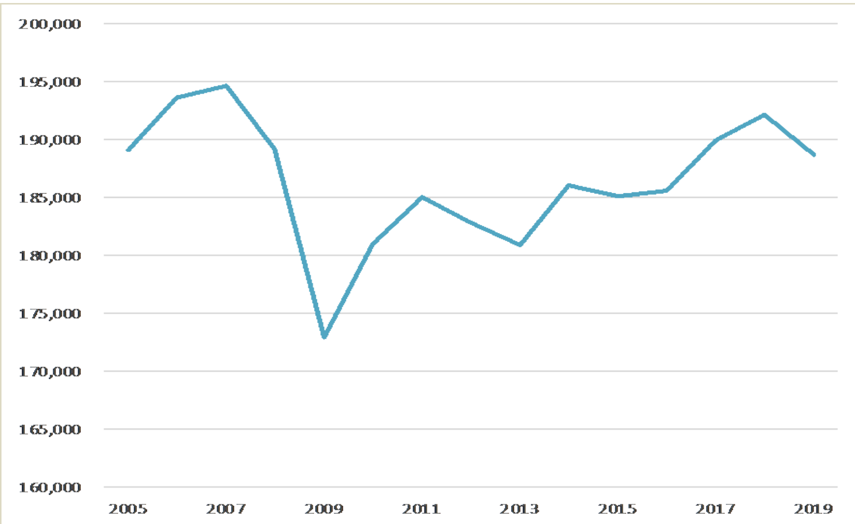
Figure 2.1 UK Manufacturing Sector GVA (£m) in Current Prices



Source: Office for National Statistics

GVA Chained Volume Measure (CVM) provides more insight into the sector as it reflects the change in value resulting from a change in volume of production as opposed to inflationary or deflationary effects. In Figure 2.2, this measure shows how UK manufacturing output was hit hard by the 2008 financial crisis and downturn in the global economy. Then how output value has recovered almost back to where it was by 2019. Over the same period, however, the UK economy achieved growth of 21% - again demonstrating the strength of the services sector.

Figure 2.2 Manufacturing GVA Chained Volume Measure (£m) in Constant Prices



Source: Office for National Statistics

2.2 Strategic Importance of the UK Manufacturing Sector

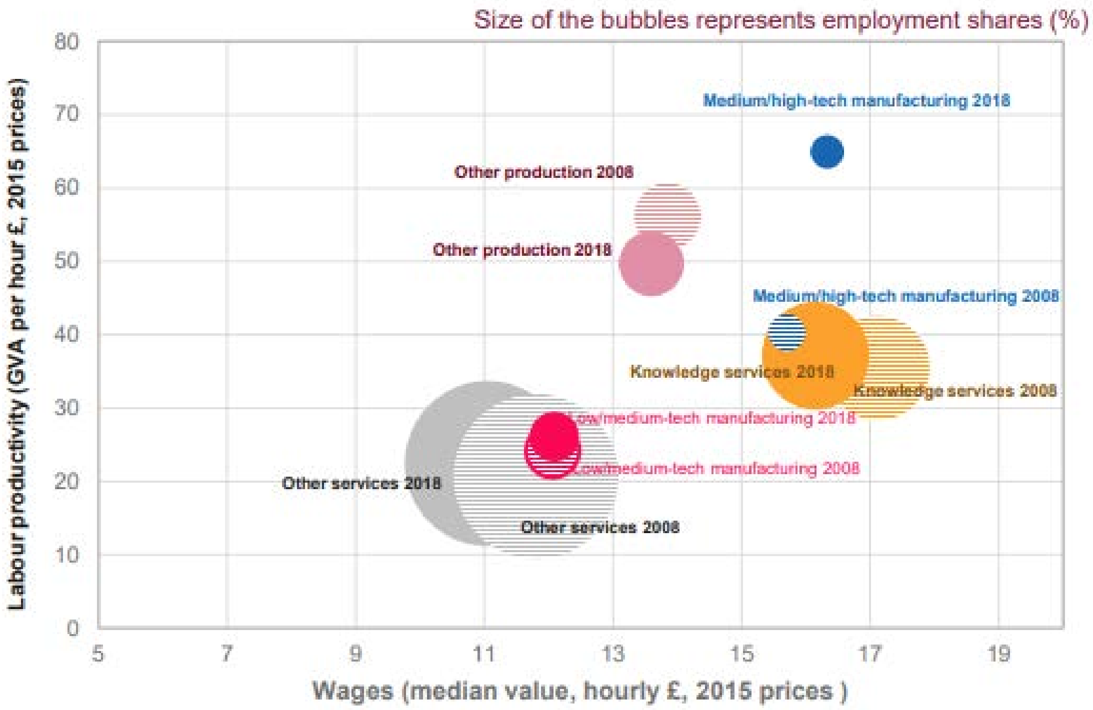
The contribution of manufacturing to UK economy GVA (CVM) £m dropped from 12% to 10% over the period 2005 to 2019. Since the manufacturing sector is relatively small in the UK, and its trend growth has been declining relative to services, it could be questioned whether it matters that much for the country and whether there is a case for any R&D support from Government?

Figure 2.3 shows UK employment shares in 2008 and 2018 in the five following industry sectors:

- Low/medium-tech manufacturing
- Medium/high-tech manufacturing
- Other production
- Knowledge services
- Other services

The size of the bubbles represents the share of employment in each sector (hatched pattern represents 2008 and solid pattern represents 2018). This shows clearly that manufacturing employs relatively small numbers of people in the UK. However, medium / high-tech manufacturing (which includes pharmaceuticals, aerospace, electronics, photonics etc) has significantly outperformed other parts of the economy in terms of *productivity growth*, with an average annual growth rate of 4.9% from 2008-2018. It is also the only one of the five sectors which has seen an increase in the real value of wages over this period.

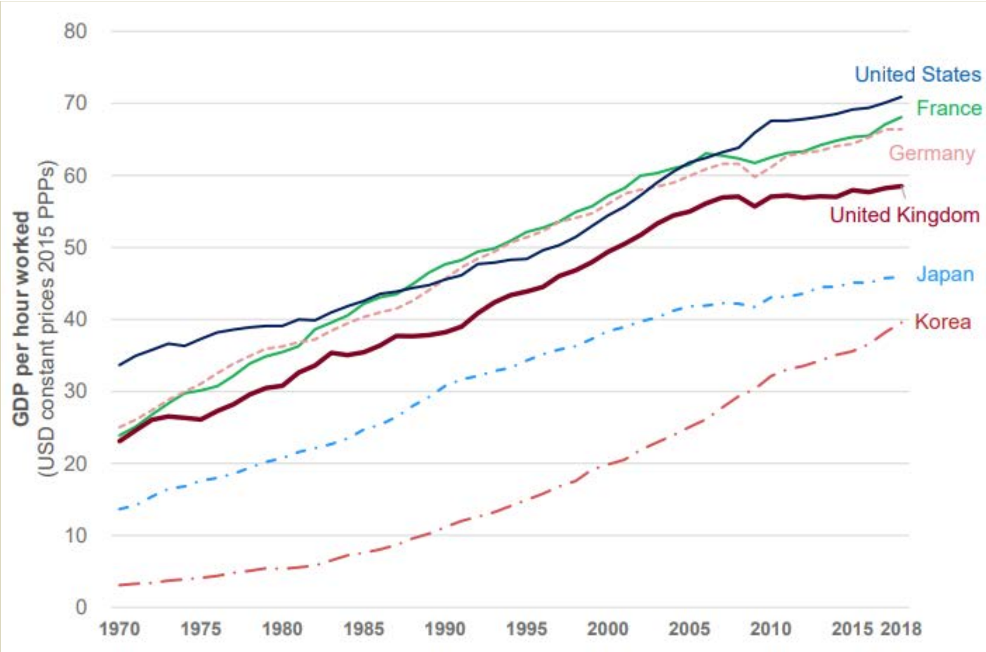
Figure 2.3 Changes in the Structure of the UK economy – Employment Levels, Productivity and Wages by Sector (2008-2018)



Source: UK Innovation Report, Institute for Manufacturing, University of Cambridge, February 2021
Note: £ values deflated using PPI (labour productivity) and CPI indices

This matters because in the last 15 years UK productivity has grown at a considerably slower rate than in the past. This trend is visible across much of the western world but is more pronounced in the UK than other comparator countries (see Figure 2.4). Since the global financial crisis in 2008, productivity growth in the UK has more or less stagnated. In turn this has held back average real wages, which is part of the backdrop to the current painful "cost of living crisis".

Figure 2.4 Labour Productivity International Comparison (GDP per hour worked, selected countries, 1970–2018)



Source: UK Innovation Report, Institute for Manufacturing, University of Cambridge, February 2021

Economic growth is the key priority of Government, and a fundamental driver of economic growth is productivity. One of the main drivers of productivity is technological development achieved through the adoption of innovations. Innovations are new ways of either reducing the inputs needed to produce goods and services or bringing completely new goods and services to market. Research and development (R&D) is fundamental to the process of innovation. Not all innovation arises from formal R&D, but it is striking that the UK's decline in productivity growth follows a period in which the overall R&D intensity of the economy declined substantially, both in its own right and relative to other comparative countries[2].

The private sector is the largest contributor to R&D funding in the UK (55%) but levels of UK business investment in R&D are below that of competitors such as Germany (66%), Korea (77%) and Japan (79%). There is a clear need to increase business investment in the UK and manufacturing industries remain the largest contributors to R&D expenditure across the world, despite the sector's relative decline as a share of the economy in most industrialised countries in the last couple of decades.

In 2018 medium / high-tech manufacturing (which includes pharmaceuticals, aerospace, electronics, photonics etc) accounted for 60% of business R&D expenditure in the UK, followed by knowledge services at 30%. Growing these industries is important for improving

[2] An Index of Issues in UK Science and Innovation Policy, Professor Richard Jones University of Manchester 2022

the level of R&D intensity in the UK economy, which in turn contributes to economic growth. Innovative firms grow twice as fast as firms that fail to innovate.[3]

2.3 Rationale for EPSRC MtF Investment

The creation and application of new knowledge is the lifeblood of innovation, The 2021 UK Innovation Strategy places innovation at the heart of Government policy. It views the UK's research, development and innovation capabilities as a critical national asset which must be grown in the future. What will make the difference is a step-change in the level of R&D investment by the business sector, and particularly by manufacturing businesses for the reasons explained above.

In 2019, 49% of business R&D was experimental development and 41% was applied research.[4] Left to their own devices, businesses do not invest adequately in basic research. This is understandable because the risks are high but at the same time, basic research has underpinned some of the major technological advances in the last couple of decades including high-speed communications, cancer treatments and COVID vaccines

The Terminology of Basic, Applied and Experimental R&D
Basic research is experimental or theoretical work directed at gaining new knowledge of fundamental phenomena without any particular application or use in mind
Applied research is new investigations directed towards a specific practical aim or objective
Experimental development is systematic work directed towards improving or producing new products and processes, drawing on research and practical experience

Source: House of Commons Library

The 2021 Innovation Strategy observes that some of the most notable long-term, exponential productivity gains from technology, which have transformed the world, have come out of basic research. And although the impact from these technologies has been global, the revenues and jobs associated with them, has accrued strongly to the geographic areas where they were developed. For example, the development and deployment of computing technology in Silicon Valley USA, which is still a global powerhouse today, and the birth of molecular biology in leading global universities in the USA and UK and the major pharma / biotech clusters which have grown up in places such as Boston, Cambridge and Oxford.

The rationale for EPSRC's MtF Programme is that:

- There is a market failure that discourages businesses from investing resources in early-stage R&D
- Manufacturing is the largest component of business R&D in the UK, so it is a sensible target for action on improving levels of business investment in early-stage R&D.

EPSRC's MtF Programme responds to this need.

[3] UK Innovation Strategy 2021

[4] Research and Development Spending, House of Commons Library Sept 2021

3. Overview of the MtF Programme

This section provides a summary of the MtF Programme drawing on analysis of databases provided by EPSRC as well as consultations with EPSRC staff.

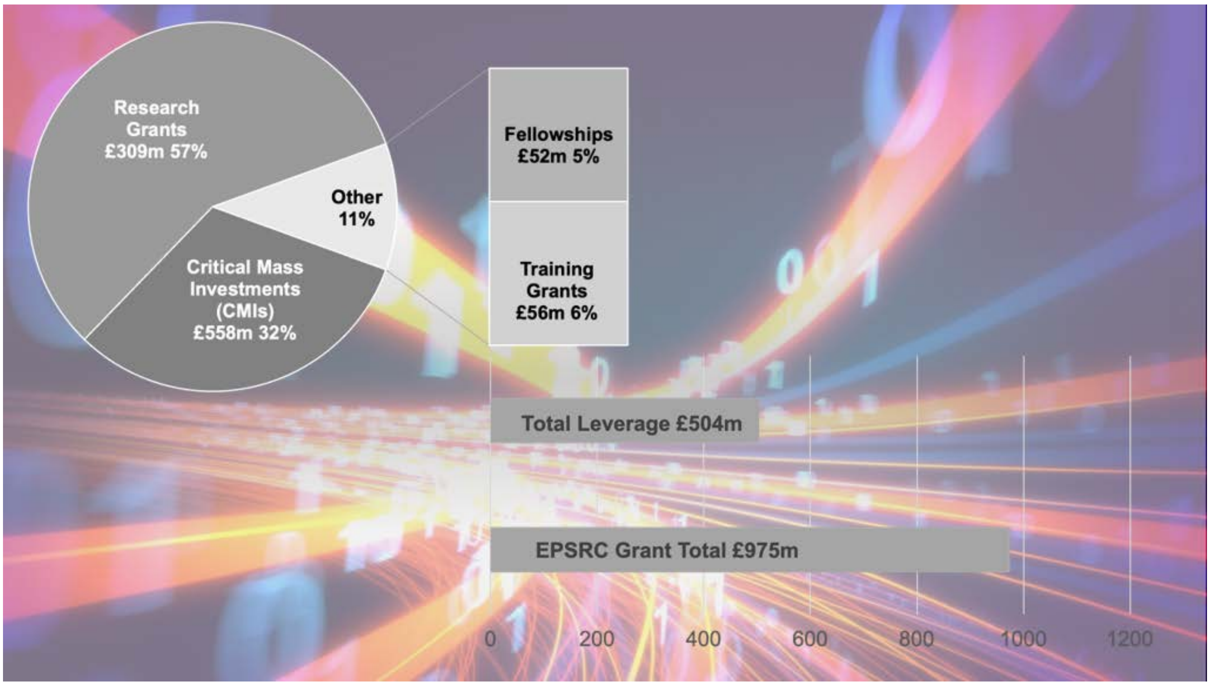
3.1 Funding and Allocation of MtF Resources

As stated in Section 1, the period under consideration is grants awarded by EPSRC between 2005-2020, with some of the later grants completing beyond this period.

Figure 3.1 provides an overview of MtF funding, highlighting £975m spend over the 15-year programme period. The largest spend category is project research grants (57%) followed by critical mass investments (32%), fellowships (5%) and doctoral training (6%).

Total leverage (cash and in-kind) from external partners is £504m. Thus, each £100 invested by EPSRC has been matched by a further £50 from partners. This is a substantial sum for basic, early- stage research.

Figure 3.1 Funding and Leverage for the MtF Programme[5]



Source: Brookdale Analysis of EPSRC Grants Database

3.2 Analysis of External R&D Investment Secured by the MtF Programme

Figure 3.2 shows the levels of leverage achieved by different parts of the MtF programme. The level for CMIs considerably exceeds the level for individual project grants, but this is to be expected given CMIs have additional resources for partnership-building and a specific sector focus.

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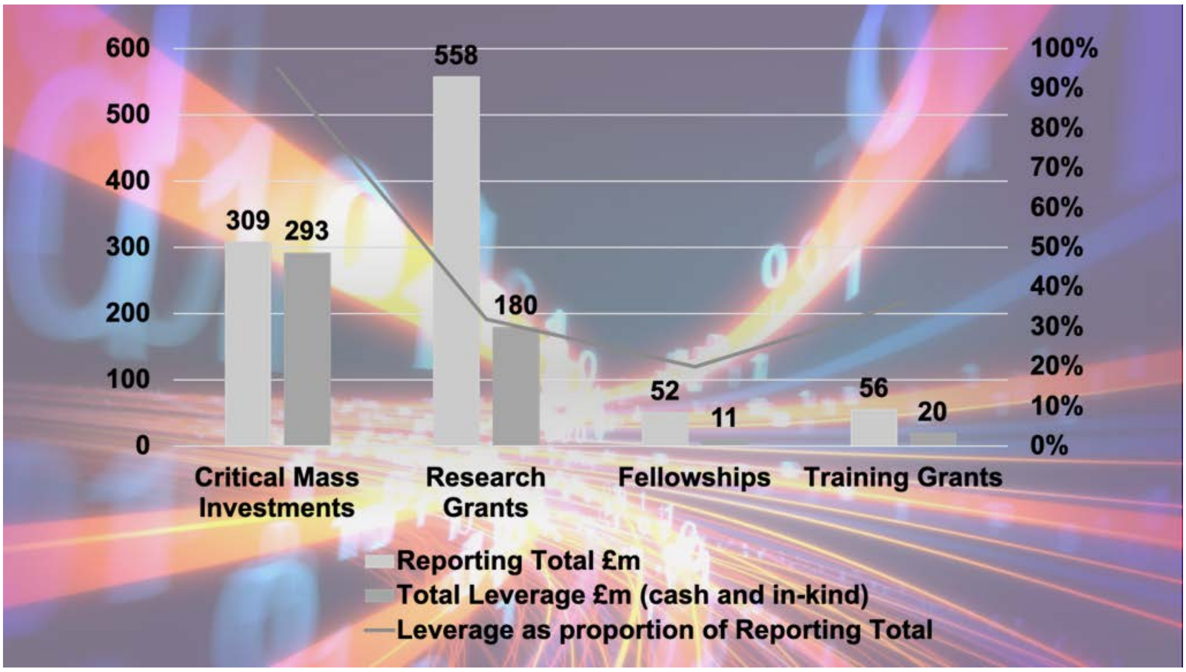
[5] As part of the data cleansing process, it was agreed that projects related to Graphene and projects delivered by EPSRC on behalf of others but with no direct EPSRC funding should be excluded from the analysis

Figure 3.2 External R&D Investment Secured by the MtF Programme by Grant Type

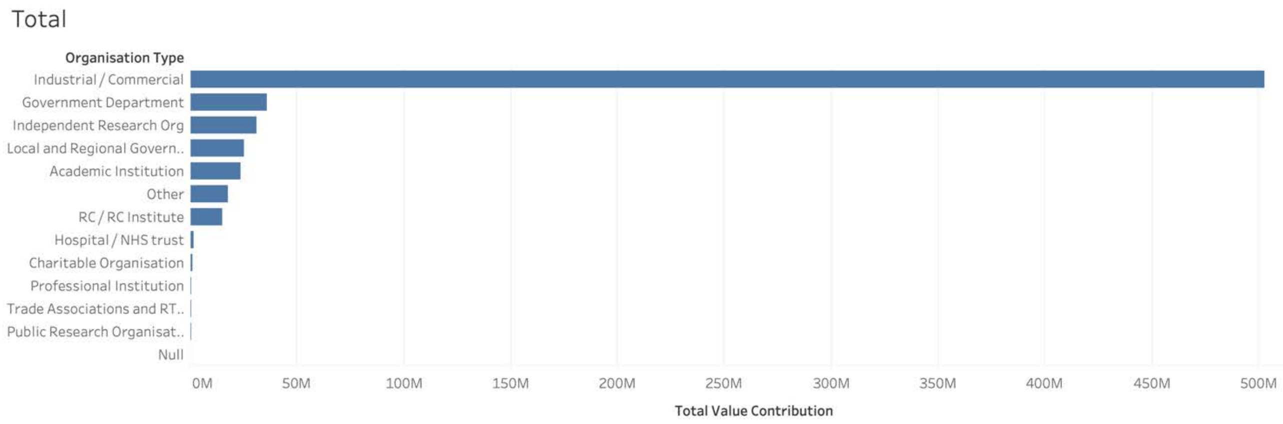


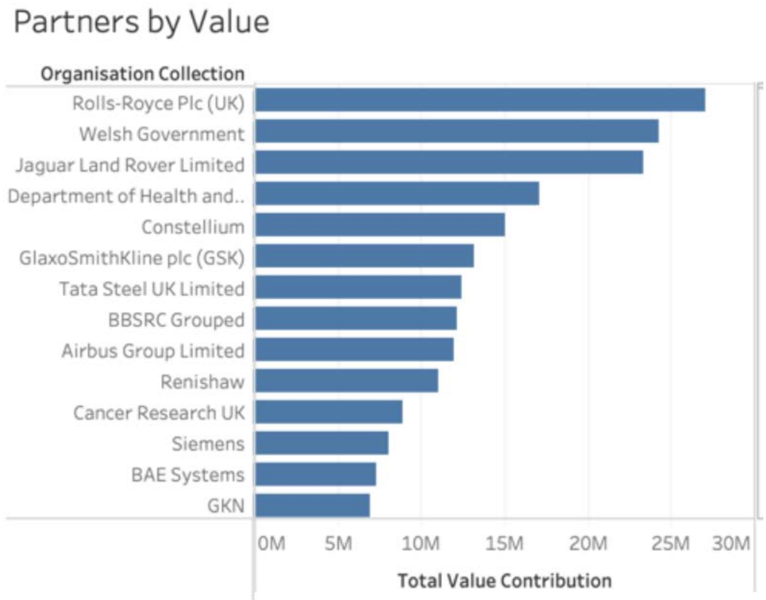
Source: Brookdale Analysis of EPSRC Grants Database

Figure 3.3 shows how external R&D investment in MtF breaks down by funding source. It can be seen that the largest external funders of MtF R&D are UK businesses. Major contributors include Rolls Royce, Jaguar Land Rover, Constellium, Airbus, GKN and Renishaw to name a few.

There are also significant contributions from public sector partners such as Innovate UK which demonstrates the pull-through of basic early-stage research funded through MtF into the innovation support framework for more applied research provided by the Catapult Network and others. Similarly, the pull-through of basic MtF research into real economic development is evidenced by the contributions from regional government and economic development bodies. For example, the Welsh Government contribution to the South Wales semi-conductor cluster is the largest financial contribution recorded.

Figure 3.3 External R&D Investment Secured by MtF Programme by Funding Source





Source: Brookdale Analysis of EPSRC Grants Database

3.3 New Start-Ups / Spin-Outs

A feature of the MtF Programme is the number of spin-out companies that have been established. In total 78 active spin-out companies are recorded on ResearchFish. Several of the spin-outs feature in Section 5 which provides insights and examples of the way in which the MtF Programme has led to real-life impacts.

Brookdale Consulting analysis of company accounts data for the 78 active spin-out companies reported finds that they have:

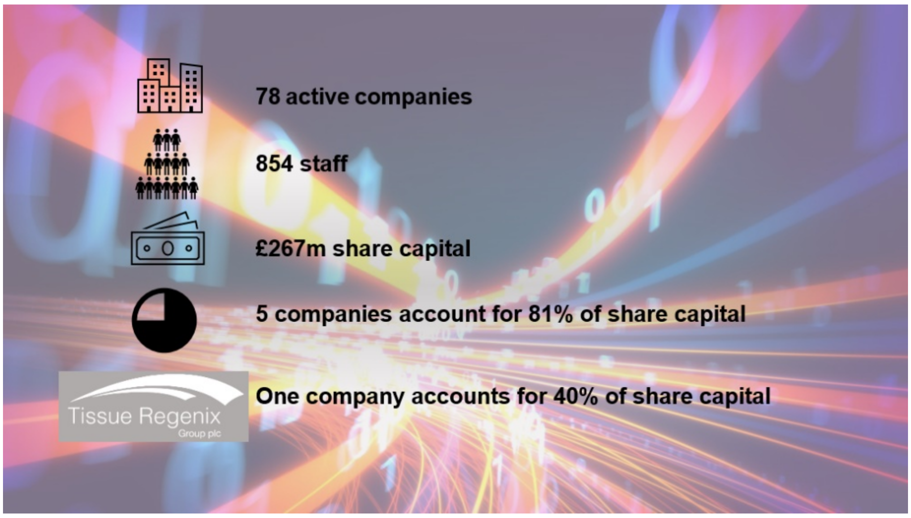
- c850 staff
- £267m of share capital
- £90m net worth[6]

[6] It should be noted that the analysis also highlights 17 companies with negative net worth of -£7.6m in total

As is typical of early-stage businesses, a small number have grown much more quickly than the rest. Five spin-outs account for 81% of share capital, with one company (Tissue Regenix) accounting for a 40% share on its own.

This provides only a partial picture as many of the companies are pre-commercial and spending significantly on research and development (so in many cases burning cash).

Figure 3.4 Analysis of MtF Spin Outs from Companies House Data

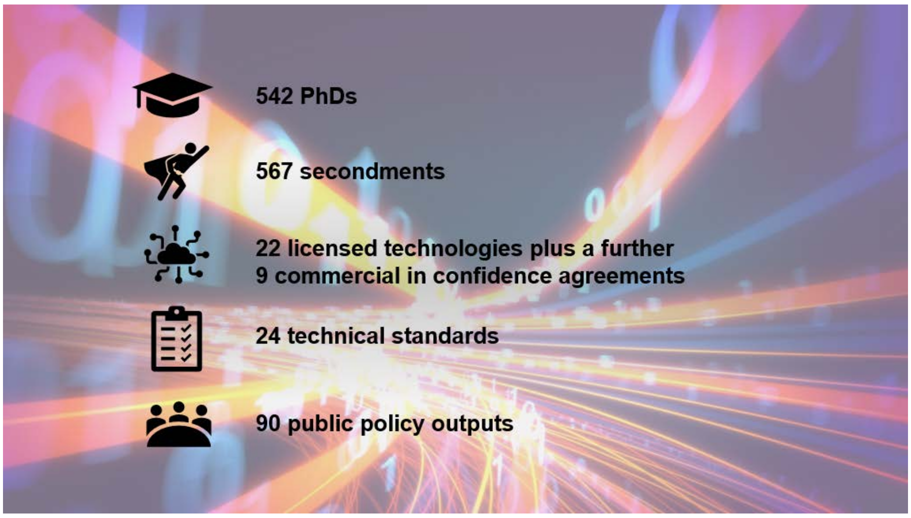


Source: Brookdale Analysis of EPSRC Grants Database

3.4 Skills, Training and other Outputs

The MtF programme includes significant investment in training through PhDs in the Centres for Doctoral Training (CDTs) as well as through Fellowships and Training Grants. In addition, the Programme has supported over 567 secondments, 22 licensed technologies with a further 9 commercial in confidence agreements, 24 new technical standards, and over 90 public policy contributions.

Figure 3.5 Skills, Training and Other Outputs



Source: Brookdale Analysis of EPSRC Grants Database

3.5 Public and Policy Impacts

Typical public policy impacts include:

- Informing public policy and strategy
- Informing and inputting to new Standards
- Cost savings to the public sector

Figure 3.8 shows that across the Programme there were 90 different policy impacts reported, the highest average being amongst the CMIs whose long term nature and critical mass means they can invest in policy advice.

Figure 3.6 Public Policy Impacts Recorded by the Programme

Type of MtF Investment	Total Number of Investments	Investments Reporting Policy Impact (% of total)	Average Number of Policy Impacts Reported
CMIs	41	21 (51%)	5.3
Research Grants	867	63 (7%)	2.0
Fellowships	54	6 (11%)	1.0
Training Grants	16	0 (0%)	0
TOTAL	978	90 (9%)	2.7

Source: Brookdale Analysis of EPSRC Grants Database

4. Return on Investment in the MtF Programme

This section sets out the return on investment (ROI) from MtF, based on the data collected from the impact case studies and the economic model constructed for the study.

The costs and benefits consider both actual and potential impacts. The period of analysis is from 2005 onwards, with a 50-year appraisal period giving the most complete results (to 2054) as may MtF research projects take a long time to lead to impacts. In addition, very few case studies were chosen from the early part of the MtF programme (2005-2010) due to a likely lack of data given the passage of time.

The analysis focuses on returns to the UK economy only, so wider global impacts are not included. The analysis also includes only impacts that are attributable directly to EPSRC, despite most projects having multiple partners and funders. Attribution of impacts to EPSRC is based on consultations with academics and industry. The impacts are considered additional to the UK economy as they relate to activity which would likely not have happened elsewhere or as quickly or at a similar scale without EPSRC investment.

The analysis includes the following types of costs:

- EPSRC direct MtF – the direct grant associated with the research project converted from nominal to real terms
- Other EPSRC MtF grants, for example previous research that links directly to the current case study project
- Other R&D grants received from public bodies e.g. Innovate UK, EU
- Business R&D investment – both cash and in-kind as part of delivering the research project, plus commercialisation spending by businesses beyond the project grant period to bring products and services to market.

The analysis includes the following types of benefit expressed in real terms:

- Increased sales for UK economy eg. where there is evidence of a business bringing a new product or service to market which does not just displace other domestic output – but reduces the need to import and/or the opportunities to export at a national level
- Cost efficiencies and hence productivity increases for the UK economy
- Carbon impacts
- Health and wellbeing impacts.[7]

In most cases the benefits are subject to a fifteen-year period of persistence with a five year build-up, five-year maximum impact and five year tail-off. Attribution of benefits to EPSRC funding is based on two methods – what the PI suggested and what the share of funding would suggest.

Some of the case studies undertaken produced significant impacts and others did not generate any monetised impacts. There is considerable variation across the case studies. This is what we would expect given the random stratified approach used to select the case studies. In some cases, the consultees could point to significant future potential impacts, but these were not included in the cost-benefit analysis if they were considered to be too

[7] Though no actual health or wellbeing impacts were quantified in the case studies

speculative. Working with academic and industry consultees, Brookdale Consulting made a conservative judgement about which potential future impacts should be included.

Appendix 3 presents more information on how costs and benefits were calculated along with the basis for assumptions.

Table 4.1 shows the present value (PV) of grant funding and direct leverage associated with the case studies in real terms[8]. The MtF grant accounts for 9% of the MtF Programme total funding awarded. This includes £55.8m for the CDTs in nominal terms. Excluding the CDTs, the MtF grant is £31.9m in nominal terms.

Table 4.1 Case Study Grant Funding and Leverage in Real Terms

Funding - Gross	Total	Average
EPSRC - direct MtF	£75,027,421	54%
EPSRC - direct MtF plus other MtF	£91,721,970	66%
Total Grant Funding	£101,390,402	72%
Direct Leverage	£38,756,738	28%
Total Funding	£140,147,140	100%

The overall ROI is shown in Table 4.2 which shows the present value (PV) of gross benefits being £8.9bn over 50 years. This translates to every £1 spent on MtF returning £63 at the UK level over a 50-year appraisal period. £41 of this can be attributed to EPSRC.

Table 4.2 Overall ROI for the case studies on different appraisal periods

Appraisal Period	Total PV of Benefits less Costs
50yr – 2005-54	£8,853,980,067
ROI based on total grant and leverage	62.8-63.2 – midpoint 63
Attributable to EPSRC %	65%
Attributable to EPSRC £mid-point of attribution	£5,764,145,423
ROI based on attribution to EPSRC	41.0

The benefits are heavily influenced by four case studies that record reduced carbon emissions of £5.9bn at the UK level associated with successful development of technologies such as fuel savings for more efficient aircraft engines, reduced lighting and display emissions, large-scale PV solar and more efficient data storage. If these carbon savings are excluded from the cost-benefit analysis, the 50 yr PV of benefits is £3.0bn.

The case studies show a mix of actual impacts and potential impacts. Actuals are those which have already happened or are very likely to happen. Potential impacts are more speculative and may include estimates from Brookdale Consulting of what could happen if further development takes place. The most speculative impacts are not included in the analysis. As mentioned earlier Brookdale Consulting made a conservative judgement about which potential future impacts should be included in consultation with the PI and industry contact(s). Table 4.3 shows the relative mix of actual and potential impacts in the monetised benefits reported over different appraisal periods. Actual impacts range from £15m to £1.6bn over a 50-year period. Potential impacts are much larger but there is more uncertainty about whether

[8] EPSRC normally presents grant information in nominal values which is the actual prices that existed at the time. For the modelling, figures are adjusted for inflation into real terms

they will occur. Over 50 years they rise to £5bn which includes substantial impacts from carbon reduction. For the case studies with a mix of actual and potential impacts, the range is from £12m over 10 years to £2.2bn over 50 years.

Table 4.3 Mix of Actual and Potential Impacts over different appraisal periods

Appraisal Period	Total Impacts	Actual Impacts	Potential Impacts	Mix of Actual/Potential Impacts
10 Years 2005-14	£27,354,160	£15,224,941	£0	£12,129,219
15 Years 2005-20	£298,438,810	£264,745,946	£1,050,229	£32,642,635
30 Years 2005-34	£6,953,665,114	£1,614,667,894	£3,627,506,111	£1,711,491,109
59 Years 2005-54	£8,853,980,067	£1,631,138,692	£5,010,094,947	£2,212,746,427
	% of total impacts at 50 years	18%	57%	25%

In conclusion, these are substantial impacts based on rigorous assessment of research outcomes working both with the academics and industry consultees. They support a finding that EPSRC's MtF Programme is a significant contributor to growing the UK economy.

5. Insights on MtF Impacts

5.1 Introduction

As explained in Section 2, market failure means there is a role for Government in de-risking basic, early-stage research. There is no emphasis on picking 'winners' at this stage. EPSRC's MtF approach is to support a balanced portfolio of research funded on the merit of its scientific excellence and novelty. This is complemented by the CMI programme where scientific quality is still the paramount consideration, but there is also a focus on technologies and market sectors of particular interest to UK manufacturing industry and the Government.

The previous section presented the ROI findings on the MtF programme. This section provides insights and examples of the way in which MtF is translating into real-life impacts.

5.2 New Market Opportunities for UK Manufacturing

New market opportunities for the purpose of this study are those that do not displace other domestic output, but instead reduce the need to import from outside the UK and/or increase the opportunities to export (due to growing comparative advantage and competitiveness).

The MtF Programme pre-dates the 2021 UK Innovation Strategy but nevertheless, it is possible to see how EPSRC investment in early-stage manufacturing research during the period 2005-2020 is feeding through into some of the high value technology areas that the Government has prioritised for the next decade.[9] These include:

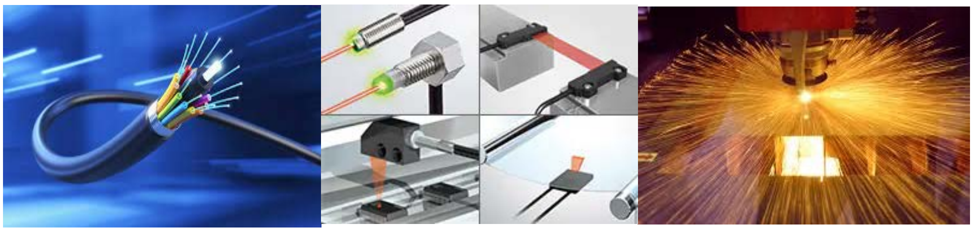
- Advanced Materials and Manufacturing
- AI, Digital and Advanced Computing
- Bioinformatics and Genomics
- Engineering Biology
- Electronics, Photonics and Quantum
- Energy and Environment Technologies
- Robotics and Smart Machines.

This section provides examples of the practical impacts of MtF projects, in areas such as:

- Photonics
- Biotechnology
- Energy & Environment
- SME development
- Talent & Skills Development.

[9] UK Innovation Strategy 2021, BEIS

Photonics – *'the science of light waves'*



Nothing has changed modern communications more than the development of **optical fibre.** Made from either glass or plastic, optical fibres are roughly the diameter of a human hair and can transmit data much more quickly than through a metallic conductor such as copper. Optical fibres also have the ability to channel remarkably high levels of power, making them useful for tasks such as laser cutting.

In the last decade the UK photonics sector has experienced phenomenal growth of 335% to reach £14.5bn output, £6.5bn GVA and 77,000 jobs[10]. To put this in context, UK manufacturing output as a whole increased by 30% over the same period[11.] There are now 1,200+ businesses operating in the sector covering 14 different distinct markets.

The knowledge base which underpins the sector can be traced back, in part, to the 1970s when EPSRC backed initial highly speculative basic research at the University of Southampton. Long-term investment from EPSRC since then, including through the MtF Programme, has led to a pipeline of new discoveries, many of which have been commercialised. Hollowcore optical fibre is one of the most recent, offering significant performance advantages over conventional fibre optic cable in high performance datacom and telecom applications. Lumensity is a spin-out company from the Optoelectronics Research Centre at the University of Southampton, which was established to commercialise discoveries in hollow core optical fibres.

Lumenisity – a spin-out company from the University of Southampton established in 2017 to commercialise breakthroughs in the development of hollowcore optical fibre

LUMENISITY
Connect. Light. Faster.

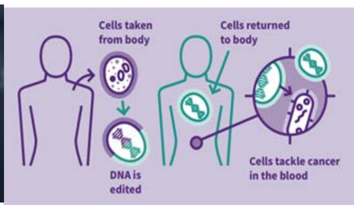
Lumenisity's hollowcore fibre based optical cable, CoreSmart® allows data to travel 50% faster than in traditional solid core fibre, which results in a 30% reduction in latency (delay) between nodes, data centres or exchanges. Key application areas are financial trading where low latency cross connects between data centres and exchanges is transformational in an environment where every nanosecond matters. critical to complement and enhance the optimised wireless network. The technology also makes it possible to increase the efficiency of data centres. For example, with CoreSmart technology, the separation between data centres can be increased from 60km to 90km while maintaining the critical round trip latency time, in a region twice as large as is currently possible using conventional cable.

Long term EPSRC research funding to the Optoelectronics Research Centre at the University of Southampton, including through MtF, has been critical to solving the fundamental challenges of producing cables with low latency - giving researchers the space and freedom to work on new ideas

[10] Photonics Leadership Group, July 2021
[11] ONS manufacturing output 2009 to 2019

Lumenisity is committed to manufacturing in the UK. Its headquarters are in Romsey, close to the University of Southampton, which continues to be a key partner. The company employed 50+ staff in 2021 and has ambitious plans for further growth.

Cell and Gene Therapies – ‘*a new generation of personalised medicine’*

Cell and gene therapies (CGT) are a transformative new category of medicines whose full potential is only just emerging. In Europe, only a small number of CGTs have been authorised at present, but there are nearly 300 in development that could be approved in the next few years. Examples of CGTs approved for use in the UK include CAR T-cell therapies for acute lymphoblastic leukaemia in children and for large B-cell lymphoma in adults. CAR T-therapies involve extracting and re-programming a patient’s own immune cells (T-cells) to make them better at detecting and killing cancerous and other abnormal cells.

A new generation of CGTs, called Oligonucleotides, are also showing promise. They work by introducing a piece of mRNA into a patient’s body, which alters how a faulty gene is expressed, compensating for the fault. In the UK, Waylivra has been approved for the treatment of Familial Chylomicronaemia Syndrome, a rare genetic condition. In the USA, AMONDYS 45 has been approved for patients with Duchenne Muscular Dystrophy. Oligonucleotide therapeutics are now advancing to a point where there is potential for their use in not only treating rare genetic diseases, but also chronic diseases such as cancer that affect much larger patient populations.

However, one of the challenges with Oligonucleotide medicines is that they are very difficult to manufacture at scale. For rare diseases, a few kgs of material may be all that is required, but to treat chronic diseases, much larger quantities are needed. With many prospective oligonucleotide-based medicines already in development and clinical trials, industry was challenged to find solutions to the problems holding-back larger scale manufacturing.

In 2015 MtF funded curiosity-driven research at Imperial College London looking at the synthesis of polymers in liquid phase. Usually, biopolymers such as oligonucleotides are prepared by solid-state synthesis, which has very poor scaling capabilities. The Imperial research produced polymers of unprecedented precision and length using this new process, opening the way to making oligonucleotides at a drastically reduced cost. Exactmer is a company spun out of Imperial College to commercialise this new ‘Nanostar Sieving’ technology.

Exactmer - revolutionising the manufacturing process for oligonucleotide medicines to enable wider use in treating chronic diseases such as cancer

Exactmer was established in 2018 as a spin-out from Imperial College London. It aimed to commercialise a new technology for synthesising polymers, which in turn would open the door to much cheaper production of oligonucleotide medicines. The early-stage research underpinning this technology was funded by EPSRC and was critical in securing the patents on which the business is based.

Exactmer has a production facility in Dagenham, East London. This is set to grow further as a result of a collaborative venture involving Exactmer and partners AstraZeneca, Novartis, and the Medicines Manufacturing Innovation Centre. The aim is to make the UK the first country to manufacture oligonucleotides at scale. Inclisiran, an innovative small interfering RNA medicine from Novartis, approved for the treatment of atherosclerotic cardiovascular disease, will be one of the first medicines to be produced at scale due to this collaboration. AstraZeneca also has a rich pipeline of oligonucleotide candidates to be put into production.

The partners are aiming to use their combined expertise across scale-up, analytics and process development, to transform the production of oligonucleotides driving down their unit costs. Initial activities will take place at Exactmer's facilities in Dagenham, with the large scale later phases taking place at the Medicines Manufacturing Innovation Centre in Renfrewshire, Scotland. A global market opportunity awaits.

Energy and Environment – *harnessing innovation to drive-down the cost of energy and its carbon footprint*

a) LED Lighting

By 2035, all the UK's electricity will need to come from low carbon sources (subject to security of supply), whilst also meeting a 40-60% increase in demand.[12] This means there will need to be far more efficient use of energy, through new technologies, better energy management, and direct investment in energy efficiency measures.

Traditional lighting technologies have little leeway for improvements in efficiency, but solid-state lighting (SSL) technology, particularly light-emitting diode **(LED)-based technology**, still has significant room for growth in achieving its full potential. Although most products today use phosphor conversion (PC) to produce white light from a blue LED, having a good green source could lead to colour-mixed white sources that would avoid the losses associated with the PC approach and be significantly more energy and cost efficient. But better green LEDs are needed to make the colour-mixing approach competitive.

LED-based lighting still has potential to become even more efficient

KUBOS SEMICONDUCTORS

plessey microLEDs

In 2016 EPSRC funded a research fellowship to investigate how to grow and control Gallium Nitride (GaN) device layers on large diameter Silicon substrates (up to 200mm). GaN devices have the potential to significantly improve the energy efficiency of a range of electrical and electronic products, in turn contributing to reduced carbon emissions.

This research project aimed to improve the efficiency of green LEDs. A combination of red, green and blue (RGB) LEDs would mimic natural daylight and address the downsides of the blue light emitted from current electronic displays. RGB LED light bulbs and displays could also be up to 60% more efficient than existing technologies, reducing energy demands and costs. The cubic-GaN technology developed through the project produces a major improvement in light output, particularly

[12] Net Zero Strategy: Build Back Greener, HM Government, October 2021

in the under-developed region of the visible spectrum (green and amber colours), when compared with the current commercially available LEDs. The technology has not yet moved beyond early-stage specialist products, but a spin-out company, Kubos Semiconductors Ltd, has been established to focus on the commercialisation of the technology. Whilst currently pre-commercial, the company is talking to potential customers about licensing its technology. The Carbon Trust has estimated that widespread adoption of Kubos technology has the potential to save nearly 700mt CO_2e in the period 2024-2029, compared to the use of existing LED technologies.

UK companies such as Plessey could also benefit from this proprietary technology. LED manufacturing is predominately based in the USA and China. Plessey, a partner in this EPSRC MtF research project, is the main UK LED manufacturer of scale. It has a major deal to develop microLED displays using GaN as a scale-up route to 12 inch wafers, well beyond the current 8 inch maximum. This will both improve quality and reduce costs. Plessey estimates that successful implementation of the technology could speed up product development by 20% and bring forward the next generation of its products to 2026. The company is however keeping its options open, with other alternative technologies also in development, to ensure ultimate delivery of the contract.

b) Solar Photovoltaics

The decarbonisation of energy requires more clean electricity sources and Solar Photovoltaic (PV) has an important role to play. PV has already seen significant expansion over the last decade. Between 2010 and 2020, global PV capacity increased by almost 20x while costs fell by 85%[13]. Notwithstanding this growth, it is estimated that the current rate of PV deployment (c140GW pa[13]) will need to quadruple again by 2030 to meet the net zero goal[14].

In simple terms, a solar PV cell works by using light energy (photons) to displace electrons from an absorber material in a 'sandwich' of other materials which then creates a flow of electricity through a circuit. The difference between cell types is mainly the materials used in the 'sandwich'. Crystalline silicon (c-Si) dominates the PV market due to its low cost and mature supply chain and uses an absorber arrangement mounted on relatively thick and heavy glass panels. Thin-film PV alternatives that are lightweight and physically flexible have been commercialised for specific applications. The principal technologies are CIGS (Copper, Indium, Gallium, & Selenium) and CdTe (Cadmium/Tellurium). The demand outlook for thin-film PV applications is substantial, but the existing technologies have limited growth potential because they rely on raw materials that are rare (Indium, Gallium) or potentially toxic (Cadmium). This is one of the research challenges that EPSRC's MtF Programme has been working on.

Harnessing innovation in photovoltaics (PV) for greener buildings

In 2014 EPSRC funded early-stage basic research to look at whether it was possible to develop a sustainable and scalable alternative to existing thin-film PV technologies. The objective of the *PVTEAM* project, led by the University of Bristol in collaboration with 10 other universities and businesses, was to develop a new technology known as CZTS (Copper, Zinc, Tin & Selenium). Its advantages include the use of earth-abundant, low toxicity materials, good low-light performance, durability, and compatibility with a wide range of substrate backing materials. Working

[13] Fraunhofer ISE: Photovoltaics Report (2021).
[14] International Energy Agency (IEA): A roadmap for the global energy sector (2021)

with industry partners such as Tata Steel, Pilkington and Johnson Matthey the research delivered promising initial findings which are now being developed further in a collaboration with the Centre for Process Innovation (part of the High Value Manufacturing Catapult).

Thin-film PV is unlikely to compete with established crystalline silicon technology in the utility-scale market. Instead, the potential for CZTS will be in more specialist markets such as retrofitting fragile or complex rooftops. It is estimated that 40% of all commercial rooftops are too fragile to support conventional silicon retrofit solar panels. Thin-film PV cells dispense with the need for glass encapsulation and are c80% lighter. Based on recent adoption rates Brookdale Consulting estimates this could be a c$17bn global market by 2030.

At present, most PV manufacturing takes place in Asia but recent supply chain disruption means the UK is well placed to capitalise on industry looking closer to home for new manufacturing locations. EPSRC's investment in how thin film PVs can be made with less use of rare-earth raw materials, could reap considerable benefits for the UK in an era where global supply chains are under pressure.

5.3 SMEs – Closing the Productivity Gap between Small and Large Companies in the Manufacturing Sector

To reap the benefits of innovation, new knowledge must be widely adopted. Despite its excellent research base, the UK is only 30th in the world for knowledge diffusion and has a significant "long tail" of low-productivity firms. Evidence suggests that companies in London and the South East tend to be quicker to adopt and disseminate new technologies - places with a typically larger proportion of bigger companies than elsewhere.[15]

In the manufacturing sector, where production tends to be more capital-intensive and larger companies can exploit increasing returns to scale, large companies show almost consistently higher levels of productivity than smaller ones. In the UK, micro manufacturing firms have about 60% of the productivity level of large firms. Differences in productivity between large companies and SMEs are relatively smaller in the service sector. SMEs can even outperform larger companies, due to niche knowledge, high-brand or high intellectual property content.[16]

EPSRC's MtF programme has invested in reaching out, and engaging with, SMEs. This is something that R&D and innovation programmes find difficult, because it takes resources and experience to build relationships with complex academic institutions and small companies do not have this. A good example of how EPSRC's MtF Programme has assisted SMEs, is the research it funded, initially at Cranfield University, and then at Aston University on product service systems. 'Servitisation' is a business strategy where manufacturers enhance and differentiate their product, by integrating high-value services into the overall offer. In this way customer value changes from simply the product itself, to the use of the company's services relating to the product. This helps to increase margins because a bespoke product service package is more valuable to the customer than the product alone. It also changes the relationship with customers, making the core business of the two parties more intertwined, which raises the bar for new competitors and supports margins into the longer term.

[15] Levelling Up White Paper
[16] OECD (2017), "Productivity gaps across enterprises", in Entrepreneurship at a Glance 2017, OECD Publishing, Paris

An early form of servitisation emerged when Rolls Royce pioneered its "Power by the Hour" aircraft engine service concept. However, a decade ago few other manufacturers had followed Rolls Royce. One of the barriers was believed to be the complexity of such a major business transformation exercise, for all but the largest companies such as Rolls Royce.

Unlocking Productivity Growth in West Midlands SMEs

A decade ago, EPSRC's MtF Programme funded the first exploratory research on the use of servitisation business models in manufacturing. This began at Cranfield University's School of Management. The lead researcher then moved to Aston University and the research continued with one of the key focus areas being the use of computer games and digital learning to demystify the concept of servitisation, and to make it more relatable to SMEs in the manufacturing sector.

The research was ahead of its time in seeing the potential of gaming for bringing alive business training for SME manufacturers. It was EPSRC which made this possible by de-risking the initial investment of time in carrying out the research and developing the digital content from it.

In collaboration with local economic development bodies, Aston University secured funding to put its research into practice and started to deliver training to local SME manufacturers in the West Midlands on introducing product service systems into their businesses. their for West Midlands SME manufacturers since 2012. Close to 350 SME manufacturers in the West Midlands have participated in the training programme, and companies that implemented changes subsequently achieved significant increases in productivity, equating to a £78 million GVA uplift.

5.4 Impact on Talent & Skills Development

a) Centres for Doctoral Training

Skills development is an integral part of the MtF programme. Without it, there is no skilled workforce to transfer new technologies and advances into industry. MtF has chosen to invest in training through Centres for Doctoral Training (CDTs). As at the 31 March 2020,16 CDTs had been established training c450 PhD students.

Each CDT is typically funded for 4-5 annual cohorts of c10 students. A proportion of CDT costs (c20-40%) are funded from sources outside EPSRC, usually industry collaborators engaged with the research area. The numbers starting PhDs in CDTs are higher than the numbers completing. Anecdotally this is prescribed to these students being highly employable and receiving offers from industry partners before completing their PhD research.[17] If allowance is made for this too, the number of PhD students supported through the MtF Programme from 2005-2020 rises to c550.

The majority of the CDTs funded through the MtF Programme mirror the technology areas supported by the MtF CMI research hubs. For example, over the period 2005-2020 the University of Strathclyde ran both a CMI and CDT in the area of Continuous Manufacturing and Crystallisation. This 'doubling-up' helps EPSRC to get the most from its investments, because both are drawing on the same core academic resource.

[17] Review of EPSRC-Funded Doctoral Education, EPSRC, 7 October 2021

One of the larger CDTs funded through the MtF Programme is the Centre for Doctoral Training in Sustainable Chemical Technologies at the University of Bath. It has c50 current students and has already graduated 7 previous cohorts (>100 PhD students overall). The CDT was set up to build on related EPSRC research investments (MtF and others). For example, EPSRC has made a significant R&D investment investigating terpene-based manufacturing as a substitute for hydrocarbons. Terpenes are naturally occurring chemical compounds which can be synthesised (more easily than other compounds) for use in petrochemical processing facilities. Potentially they could replace traditional hydrocarbons such as oil in plastics, cleaning products and all manner of other everyday products. But the technological challenges are significant, and this continues to be an on-going research area.

Despite the relatively early stage of the research, there is now an emerging industrial biotechnology sector which is looking to commercialise promising early-stage research in universities. It needs talented people who have the right subject knowledge and skills to realise the commercial potential of research, and the CDT in Sustainable Chemical Technologies at the University of Bath is responding to this need.

Kelpi – Recruiting talent to take the plastic out of packaging

Kelpi is a material innovation company based in Bath that seeks to replace single-use plastics with premium performance bioplastics, harnessing the novel properties of seaweed. Currently, around 8% of the world's oil is used to make plastic, and plastics and other petrochemical products are expected to account for more than a third of global oil demand growth by 2030. Kelpi is one of a new wave of biotech businesses pushing at the cutting edge of scientific research to bring new bio-based packaging to market. Its relationship with the University of Bath and the CDT for Sustainable Chemical Technologies enables it to draw on a rich talent pool to accelerate the testing of its biopolymer composite materials.

b) Skills Development through CMI Research Hubs and Projects

EPSRC also encourages its CMIs to provide their own bespoke training to industry partners. They can use the 'platform grant' element of their funding to do this. For example, at the UCL Targeted Healthcare Hub, this funding has been used for developing training modules for the Bioprocess Industries (MBI) CPD programme. Recently, two new MBI modules have been created in *Antibody Targeted Therapies* and *Cell and Gene Therapy Bioprocessing*.

6. Added Value from Critical Mass Investments (CMIs)

CMIs are multi-disciplinary research hubs that receive secure, long-term funding (typically 5-7 years) from the MtF Programme. Approximately a third of the MtF budget was channelled through CMIs from 2005-2020.

The CMI approach, with its hub and spoke structure, brings together best-in-class researchers from across the UK to work on strategic technology areas. This approach enables access to leading academics across disciplines in multiple universities, and so is fundamentally different to the way that conventional project grants operate. CMIs are also distinctive in having a wider service offer beyond R&D (particularly in relation to academic-business networking) and a recognised brand.

A number of CMIs were reviewed at an early stage in the study because EPSRC was keen to have an independent view on the added value from the CMI funding approach, whether there was added value to MtF from investing in CMIs alongside project grants, and the case for continuing to invest in CMIs in the future.

CMIs are defined as IMRCs (Innovative Manufacturing Research Centres), CfIMs (Centres for Innovative Manufacturing) and FMRHs (Future Manufacturing Research Hubs). In total 42 CMIs came within the scope of the requirement:

- 15 Innovative Manufacturing Research Centres (IMRCs) 2006-2011 c£5m over 5 years. All have now completed
- 16 Centres for Innovative Manufacturing (CfIM) 2010-19 ca £5m over 5 years. All have now completed
- 11 Future Manufacturing Research Hubs (FMRHs) which are currently in operation (2015-26). They have larger grants and a longer duration than previous CMIs, ca £10m over 7 years

Brookdale Consulting's CMI review looked at 9 CMIs as shown in Table 6.1 (1 IMRC, 4 CfIM, and 4 FMRH) accounting for 22% of CMI funding (£69m).[18]

Table 6.1 Critical Mass Investments Included in the Review

CMI Title	Technology Area
UCL Innovative Manufacturing Research Centre for Bioprocessing 2007-2012	Biologics & Biotechnology
UCL Centre for Innovative Manufacturing in Emergent Macromolecular Therapies 2011-2016	
UCL Future Manufacturing Research Hub for Targeted Healthcare 2017- 2023	
Strathclyde Centre for Innovative Manufacturing for Continuous Manufacturing and Crystallisation 2011-2016	Digitalisation, Automation, Intelligent Manufacturing Formulation
Strathclyde Future Manufacturing Research Hub for Continuous Manufacturing and Advanced Crystallisation 2017-2023	
Huddersfield Centre for Innovative Manufacturing in Advanced Metrology 2011-2017	Metrology

[18] Some being led by the same organisation over more than one CMI funding period

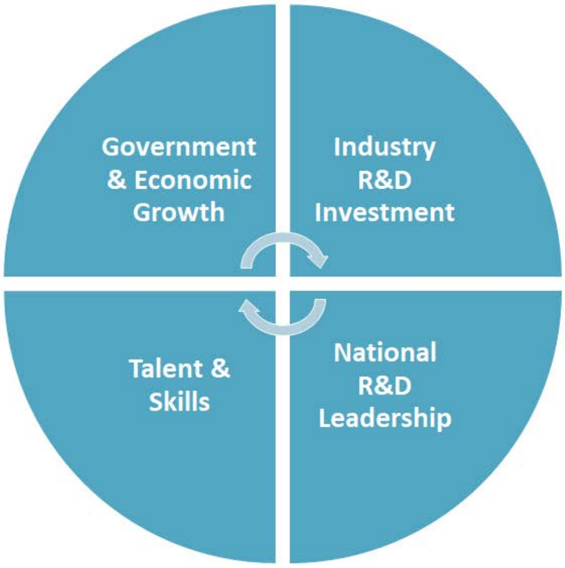
Huddersfield Future Manufacturing Research Hub for Advanced Metrology 2017- 2024	
Cardiff Future Manufacturing Research Hub for Compound Semiconductors 2016-2023	Electronics / Optoelectronics
Nottingham Centre for Innovative Manufacturing for Food 2013-2019	Other

The conclusion from Brookdale Consulting's independent assessment, is that there are significant benefits from the CMI funding approach which cannot be delivered by individual project grants alone. The full CMI assessment report can be found in Appendix 4 and the CMI case studies in Appendix 5. The rest of this section summarises the key findings from the review.

6.1 The 4 Key Added Value Benefits from the CMI Funding Approach

The four key added value benefits from the CMI funding approach are illustrated in Figure 6.1 starting with the level of business R&D investment and proceeding in a clockwise direction. Each is discussed below.

Figure 6.1 Added Value Benefits from Investment in CMIs



Industry R&D Investment

When industry engages in a low TRL pre-competitive research project, it does not know if the project will produce anything of use. Understandably, industry is reluctant to invest when the risks are so high, and hence governments bear much of the burden of funding basic research.

The scale at which CMIs operate, means there is a larger and more diverse portfolio of early-stage research projects, across which industry can spread risk. The evidence is that industry is more willing to co-invest in pre-competitive research under this model. This can be seen from the high levels of external leverage achieved by the CMIs. Every £1 invested by EPSRC, leveraged a further £1.30 from other external collaborators. This is way above the levels of external leverage for individual early-stage basic research projects.

Aside from the 'pooled risk' appeal of CMIs to industry, CMIs themselves are tasked with reaching out to businesses and receive ringfenced funding from EPSRC to do this. For example, EPSRC's most recent call for Future Manufacturing Research Hubs, advised applicants to budget not only for their planned programme of research, but also for 'platform activities' such as business outreach, networking and bespoke knowledge transfer projects to maximise the impact of the research. A number of CMIs have used this funding to employ specialist staff to engage with industry, and in particular to seek out SMEs who could benefit.

Analysis of CMI industry partners shows a healthy mix of corporates and SMEs. It appears some SMEs are part of supply chains for the corporates, and it makes sense to be involved collectively. This is something EPSRC should continue to encourage as interaction between customers and suppliers is one of the key drivers of innovation across the world. The CMI approach builds the innovative capacity of supply chain companies by giving them access to a broader range of contacts, networks and knowledge.

The Strathclyde Continuous Manufacturing and Crystallisation CMI is a good illustration of this in practice. It brokers relationships between Tier 1 companies, Tier 2 suppliers, and technology providers in the small molecule pharmaceutical manufacturing sector. The CMI facilitates technical dialogue and helps suppliers to tailor their products and services to the requirements of their larger customers, as well as getting an insight into the future direction of the market. The neutral pre-competitive research environment is also conducive to the creation of an open and trusting environment for on-going collaboration – very different to a research grant where time horizons are typically shorter.

National R&D Leadership

CMIs have the critical mass to attract strategic investors and to grow into national centres of excellence through a virtuous circular process whereby the more businesses they engage (especially strategically important companies), the more other businesses want to engage too as it becomes riskier not to be involved.

UCL's Department of Biochemical Engineering has had three recurrent CMI investments from EPSRC over the last 15 years, the latest being the Future Targeted Healthcare Manufacturing (FTHM) Hub (2017-23).

From the start, the vision has been *'to change fundamentally the ways in which bioprocesses are developed for the manufacture of complex and highly specific next-generation biopharmaceuticals.'* The scale and diversity of the CMI has attracted a number of strategic industry players to make significant investments (eg. Astra Zeneca, Pall Corporation (a global biotech company providing filtration, separations and purification products). As its profile has grown, the Hub has attracted more business partners – to the point where it is now recognised as a national collaborative research network in its specialised field of manufacturing processes for next-generation biopharmaceuticals such as cell and gene therapies. Although the market is currently small and niche, it is growing rapidly. By 2035, the UK cell and gene therapy sector is forecast to be worth ca £10bn and supporting 18,000 high quality jobs.[12]

In 2017 when the latest UCL Future Targeted Healthcare Manufacturing CMI was launched, 34 partners signed up as collaborators – ranging from large pharma corporates to smaller biotech SMEs, plus the key follow-on innovation funding bodies and the industry representative bodies. The virtuous circular process mentioned above whereby the more businesses are engaged, the more other businesses want to engage too, is illustrated by the fact that the number of collaborators continues to grow – with a further 11 added since 2017. The outcome is that EPSRC's £10.5m investment is being more than matched by the partners investing £13.7m, plus intangible benefits from interaction and knowledge exchange within the collaborative network.

Only the scale of a CMI makes this possible. The platform grant element of CMI funding provides the resources needed for outreach, partnership management and the national sector networking and engagement activities. The importance of this is not to be under-estimated – it is the wider diffusion of new knowledge and technologies that helps all businesses to recognize the value of new technological developments, to assimilate them in the context of their business, and to apply this to commercial ends.

UCL Future Targeted Healthcare CMI – Collaborative Partners
Partners at Launch
Total: 34 **Companies (26)**: Albumedix, Allergan/Pharmaron, Autolus, BIA Separations, Biologic B, Biopharm Services, DeltaDOT, Eli Lilly, Francis Biopharma, Fujifilm Diosynth Biotechnologies, GSK, Ipsen, Lonza, Medimmune/AstraZeneca, Oxford Biomedica, Pall, Perceptive Engineering, Puridify, Purolite, ReNeuron, Sartorius, Sutro Biopharma, Tillingbourne Consulting, TrakCel, West Pharmaceutical Services, Wyatt Technologies UK **Industry/Govt. Associations, Charities (6):** Association of the British Pharmaceutical Industry (ABPI), BioIndustry Association (BIA), Knowledge Transfer Network (KTN), LGC, Medicines Manufacturing Industry Partnership (MMIP), National Institute for Biological Standards and Control (NIBSC) **Translational Spokes (2):** Cell and Gene Therapy Catapult, Centre for Process Innovation/National Biologics Manufacturing Centre (CPI/NBMC)
New Partners at Mid-Term
Total: 11 **Companies (+10):** 3M, Adaptimmune, Aglaris, Applikon Biotechnologies, CellMedica, Kuopio Centre for Cell and Gene Therapy (KCT), Kymab, Orchard Therapeutics, SSC Bio, Univercells **Industry/Govt Associations, Charities (+1):** Cancer Research UK

Talent and Skills

a) Alignment of CMIs and CDTs

A burning issue for industry is finding the next generation of top talent. All CMIs employ PhD students and PDRAs on research contracts where training is provided, similar to most project grants. The added value from the CMI approach is the opportunity for PhDs/PDRAs to acquire wider knowledge and experience beyond their specific research project, due to being part of a larger programme of related research.

In addition, CMIs complement EPSRC's flagship programme for training - Centres for Doctoral Training (CDTs). CDTs provide comprehensive formal training alongside a 4-year PhD research project. They focus on priority skill areas working with employers, with an annual cohort of c10 PhD starts over a typical 5-year period (so 9-year grant period). There is often a good alignment between CMIs and CDTs since both have a focus on emerging and high-growth technology areas.

EPSRC has been able to run a number of CDTs alongside CMIs which is beneficial in a number of ways. Aligning CMIs and CDTs means everyone involved has a wider range of learning opportunities, and there are also opportunities for operational efficiencies. For example, it is reported that a CMI researcher took up the opportunity for entrepreneurial training through the CDT, and subsequently became the founder of a successful spin-out company. Case study examples of CMIs and CDTs running alongside each other are:

- EPSRC's embedded CDT from 2012-2019 at the University of Strathclyde CMI on Continuous Manufacturing and Crystallisation. The CDT's PhD students have benefited from being immersed in a wide range of projects linked to the CMI. To date 100+ PhD students have been trained and many have been recruited by industry leaders such as Astra Zeneca, Pfizer, GSK, Lilly, Novartis, Roche
- EPSRC is funding a Compound Semiconductor CDT alongside the CMI for Compound Semiconductors led by the University of Cardiff. This makes a lot of sense because the cluster cannot achieve its potential unless there is major upskilling across the locality

Consultations with industry show that where skills and training are promoted as part of the CMI offer, this is highly valued by employers. Industry says CMIs provide a perfect environment for developing the next generation of top talent because students are working with some of the best academics in the country on cutting-edge research, and Industry likes the collegiate training environment which is facilitated by the scale and diversity of research undertaken in CMIs. Employers also value the 'soft skills' that students gain from the greater opportunities to get involved in team working, collaboration and partnerships – which makes them more 'job-ready'.

b) New curriculum and taught courses

The scale of CMIs gives universities a platform to develop new curriculum and launch new teaching programmes, because there is a high level of knowledge creation and CMIs are funded to coordinate and promote new content. Examples include UCL's new MSc Manufacture & Commercialisation of Stem Cell and Gene Therapies programme (which is overseen by an Industry Group within the Future Targeted Healthcare Hub), and the new MSc in Advanced Pharmaceutical Manufacturing at the Strathclyde CMI.

c) Continuous professional development

CMIs provide a range of staff development opportunities for industry. New industry recruits are encouraged to attend meetings and network events as part of their introductory training and early professional development. The opportunities for more experienced industry employees to engage with students and to have a role in supervising a research project is also good for keeping staff interested and motivated.

Government Policy and Economic Growth

a) Rapid Scale-Up of UK Manufacturing Capacity for Covid Vaccine Roll-Out

The UK is a global leader in vaccine discovery but pre-Covid, its capacity to manufacture vaccines at scale was limited. The Department for Health and Social Care (DHSC) recognised the need for more research on vaccine manufacturing. However, it was keen to bring experts together from across universities, medical establishments, and industry to tackle the challenge. EPSRC's MtF programme had a track-record of managing these types of collaborative academic–industry research hubs for manufacturing, so it was agreed DHSC would fund two vaccine hubs adopting the MtF CMI model, and they would be managed as part of EPSRC's Future Manufacturing Research Hub Programme. In 2017, VaxHub was established under the joint leadership of Professor Sarah Gilbert at the University of Oxford Jenner Institute and Professor Martina Micheletti at UCL.

When the Covid pandemic hit the UK, the country was fortunate in being able to develop a vaccine quickly because of the expertise at the Oxford Jenner Institute. The next challenge was how the Oxford / Astra Zeneca vaccine could be rolled out quickly at a massive scale. The relationships with industry established through VaxHub are said by consultees to have been pivotal in scaling-up vaccine production so quickly. The key players who were involved in manufacturing the vaccine for the UK roll-out, knew each other through VaxHub and related networks, which meant they were able to mobilise quickly to fight the virus. Their respective capabilities that could be redeployed to fight the virus.

b) New Innovation Clusters

Knowledge-based industries draw competitive advantage from their proximity to customers, skilled workers, specialised suppliers, and industry networks. Cluster development is therefore an important driver of economic growth.

CSconnected is the collective brand for a growing cluster of advanced semiconductor related activities in South Wales. In the past, companies such as Cardiff-based IQE which manufactures advanced 'compound' semiconductors produced a specialised product for niche markets, due to its costs being much higher than for silicon. In recent years, although costs are still higher than silicon, the special properties of compound semiconductors have become more sought after in critical sectors such as 5G communications, autonomous and electric vehicles, advanced medical devices, and various other consumer electronics of the future.

In 2020, CSconnected received government funding through UKRI's Strength in Places Fund (SIPF) to capitalise on the opportunity to develop a global advantage in this key enabling technology. The consortium brings together R&D expertise in local universities and local compound semiconductor manufacturing companies including: Cardiff University (lead), Swansea University, IQE, SPTS, Nexperia (previously Newport Wafer Fab), Microchip, Microlink Devices, the Compound Semiconductor Centre, the Compound Semiconductor Applications Catapult, the Cardiff Capital Region (CCR) City Deal and Welsh Government.

The evolution of the cluster began with the establishment of the Institute for Compound Semiconductors at the University of Cardiff followed by the IQE / University of Cardiff Compound Semiconductor Centre to build on research undertaken at the ICS and to take forward new innovations and market opportunities. In 2016, the EPSRC MtF Programme made a significant investment in funding the establishment of a Compound Semiconductor CMI at the University of Cardiff, in collaboration with a range of other academic and business partners. The CMI aimed to address the challenges of large-scale manufacturing of novel compound semiconductor materials and was one of the first investments that sought to engage with the wider supply chain of businesses. It was one of the foundations for the subsequent investment attracted to the area – notably through the Compound Semiconductor Catapult and the latest Strength in Places programme, which both have funding from business as well as government.

The benefits are an additional £277m GVA and 2,400 FTE jobs, but the longer term goal continues to be positioning the cluster to capture a significant share of the expected global growth for compound semiconductors in the future.

Figure 6.2 Current Economic Impact of Activity Undertaken through the Compound Semiconductor Cluster

Source: Annual Report: Compound Semiconductor Cluster in South Wales, January 2022

7. Conclusions and Next Steps

a) There is a strong public investment return from EPSRC MtF funding

The Return on Investment (RoI) from the EPSRC MtF Programme is positive and substantial. Every £1 spent on MtF returning £63 at the UK level over a 50-year appraisal period. £41 of this can be attributed to EPSRC.

b) There is a high level of additionality from MtF funding

The creation and application of new knowledge is the lifeblood of innovation. However, business investment in R&D is predominately near to market. Only 10% of business R&D investment is in early-stage basic research. Left to their own devices, businesses do not invest adequately in basic research.

However, basic research such as that funded through the MtF Programme has underpinned some of the major economic success stories over the last couple of decades. Moreover, there is evidence that the revenues and jobs associated with these success stories continue to accrue strongly to the geographic areas where they were developed.
The MtF Programme supports this type of early-stage basic R&D which will always be under-provided by the market. Hence, the additionality of benefits is high.

c) The MtF 'portfolio' approach to R&D investment is a positive feature

In its 2021 UK Innovation Strategy, Government is concerned that there is a need, not only for more R&D investment, but a bolder approach. It advocates a more adventurous 'portfolio mindset' which means accepting some failures as the price for success "s*uch failure is not 'waste' but rather the overhead for success."*

The MtF Programme follows this mantra. The portfolio approach means EPSRC spreads its risk across different types of interventions. The emphasis is on the impact of the portfolio as a whole, not individual grants / projects. In our own case study work based on a random stratified sample, we came across projects that had generated no tangible impacts to date. However, these were more than compensated for by a small number of projects which had achieved very high levels of impact. There needs to be a willingness to take risk (across a portfolio) to find the gems. Sometimes it has been MtF's capacity and agility to fund high quality, curiosity-driven research proposals through its responsive programmes which has made the difference.

d) There are significant benefits from the CMI funding approach which cannot be delivered by individual project grants alone

The scale at which CMIs operate, mean there is a larger and more diverse portfolio of early-stage research projects, across which industry can spread investment risk. The evidence is that industry is more willing to co-invest in pre-competitive research under this model. This can be seen from the high levels of external leverage achieved by the CMIs. Every £1 invested by EPSRC, leveraged a further £1.30 from other external collaborators, which is way above what would be expected for standalone early-stage basic research projects.

There are also benefits in terms of national R&D leadership, skills and training, and strategic support for government policies.

e) It is not only the creation of new knowledge, but its diffusion into industry, that contributes to the impact of the MtF Programme

The economic benefits from R&D accrue more from the diffusion of new knowledge, spurring lots of different, incremental productivity improvements across industry, than the introduction of completely new products or services. The UK performs strongly as an innovative nation globally, ranking 4th in the 2020 Global Innovation Index. It performs very strongly at being at the forefront of new ideas and technologies. However, the 'trickle down' of innovation capability is weak with the UK 11th in the world for knowledge diffusion and 27th for knowledge absorption. Hence the often-discussed disparity between the quality of knowledge creation and its implementation in the UK.[19]

Innovation in businesses is typically a collaborative process. Businesses rarely innovate in isolation - the more usual approach is to draw in information and knowledge from outside the business by working with other companies, universities or knowledge organisations. Being part of R&D networks is therefore important for innovation, and this is recognised in the MtF approach.

For example, a proportion of MtF funding for CMI Research Centres is ring-fenced for 'platform activities' such as the establishment of technology networks with industry. Increasingly, wider knowledge diffusion is also becoming a feature of standard project grants. SMEs, in particular, do not necessarily have to be a funder of the research, to have engagement with the academic team and other business collaborators. EPSRC encourages this wider networking to build the absorptive capacity of industry – to deploy new knowledge effectively for commercial ends.

Downstream translational bodies such as the Centre for Process Innovation (part of the High Value Manufacturing Catapult) are increasingly partners on MtF projects, which is facilitating more routes to market.

There is flexibility of funding within MtF to resource activities that are not research, but which are pivotal to the use of the research such as partnership building, outreach and industry networking.

f) MtF investment in skills as part of its portfolio is a good use of resources

Skills development is an integral part of the MtF programme. Without it, there is no skilled workforce to transfer new technologies and advances into industry. It is sensible for MtF to deploy some of its portfolio to skills development, especially where this can piggy-back on MtF R&D investments.

[19] Evidence for the UK Innovation Strategy 2021

g) Future economic impact assessment of MtF

The impact of basic research can only be assessed over long time horizons, but the longer the time period, the more difficult it is to contact the right people. This is a tricky issue for which there is no easy solution but is something that could be discussed with MtF leaders. Could a small amount of funding be used for 'account management' at the end of contracts to stay in touch with industry collaborators and record the key impacts? Should the lead industry collaborators have a contractual obligation to provide impact data post-project?