Department for
Business, Energy
& Industrial Strategy

Precision Medicine Innovation in Scotland: Accelerating Productivity Growth for Scotland and the UK

Science and Innovation Audit Report
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Contents

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The University of Glasgow has been privileged to lead this important Science & Innovation Audit for Scotland, on behalf of the UK Department of Business, Energy and Industrial Strategy.

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Technopolis

Thermo Fisher Scientific Ltd

University of Aberdeen

University of British Columbia, Canada

University of Dundee

University of Edinburgh

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"The adoption of precision medicine has the potential to be transformative for the people in Scotland, through improved diagnostics and patient treatment. That is why precision medicine has been a priority for the Scottish Government for more than five years, and I am pleased that this Science and Innovation Audit (SIA) recognises the many strengths and capabilities Scotland has in this field.

The Scottish life sciences industry is hugely significant for Scotland and, through the further development and adoption of precision medicine, is well placed to be an international leader in precision medicine technologies, products and services that can be exported around the world. This is supported by the world-class Imaging Centre of Excellence at the Queen Elizabeth University Hospital (QEUH) campus in Glasgow which is pioneering the use of precision medicine to develop new treatments for patients facing serious conditions such as strokes, brain tumours, multiple sclerosis and dementia. The Centre is also attracting academics and businesses to relocate from elsewhere in Europe to be based here, as part of this world-leading beacon of science and innovation. As recognised by the consortium behind this SIA, the campus has the potential to become an important hub for an emerging precision medicine cluster for Scotland.

Whilst the SIA consortium has been led by the University of Glasgow, the process has very much been characterised by a genuine 'Team Scotland' approach, with support, commitment and real insight from industry, academia and the NHS across Scotland. This is another positive example of collaborative working in Scotland which reinforces our commitment to world class research and innovation, supporting advances in health care, improved patient outcomes and sustainable economic growth."

Nicola Sturgeon MSP, First Minister of Scotland

In today's society, individuals are living longer, resulting in an ageing population which is also affected by multi-morbidities. New innovative treatments, e.g. cancer therapies, are available but are expensive to produce and are not effective for all, and the rising costs of medicines is becoming increasingly unaffordable to healthcare systems across the world. Precision Medicine – which enables clinicians to match medical treatments to the individual characteristics of each patient – will be transformative in the way that healthcare is delivered in future.

Precision medicine is important to patients because it offers the promise of better outcomes, less side effects and reduced costs. But it also offers opportunities for a wide range of stakeholders. It is of interest not only to scientists and medical professionals, but provides opportunities for industry, academia, health charities, the NHS and governments to collaborate to tackle the significant healthcare challenges that we face.

This important Science & Innovation Audit evidences the wealth of expertise and capabilities that Scotland has, underpinning its leadership in precision medicine. Scotland's well-established Ecosystem for Precision Medicine, centred around the Scottish Government's investment in the Stratified Medicine Scotland Innovation Centre and the Queen Elizabeth University Hospital, the combination of world-class clinical research, high quality electronic health data, patient samples, a single healthcare provider (NHS Scotland), and large cohorts of patients with chronic disease differentiates Scotland from many other countries.

This Audit also outlines the actions and 'game-changing opportunities' which will allow Scotland to realise the full potential of precision medicine, with estimated cumulative health savings which could amount to £70 billion over fifty years as well as economic gains through the creation of a knowledge based economy. Precision medicine promises to deliver both patient and economic benefit for Scotland, and Scotland should now do all it can to realise that promise.

Dr Victor Dzau, President of US National Academy of Medicine

Executive summary

Introduction

1. In autumn 2015, the UK Government announced regional Science and Innovation Audits (SIAs) to catalyse a new approach to regional economic development. SIAs enable local consortia to focus on analysing regional strengths and identify mechanisms to realise their potential. In Scotland, a consortium was formed in 2017 to focus on our strengths in Precision Medicine (PM). This report presents the results which includes a broad-ranging analysis of Scotland's capabilities, the challenges and the substantial opportunities for future economic growth.

2. This SIA report has been developed by an impressive consortium comprising public and private sector partners from across Scotland, as well as a number of leading international actors involved in PM globally. As described by the First Minister of Scotland in her foreword, the SIA process has very much been characterised by a genuine 'Team Scotland' approach, with support, commitment and real insight from industry (both large and small), academia, NHS Scotland, Scottish Enterprise, Scottish Government and the health charities sector operating across the country.

3. The SIA Steering Group includes a wider range of national and international experts from industry, academia, NHS and Government. These include: Professor Dame Anna Dominiczak, Vice-Principal and Head of College of Medical, Veterinary & Life Sciences at the University of Glasgow (Chair); Dr Victor Dzau, President of the US National Academy of Medicine; Peter Silvester, Senior Vice President of Thermo Fisher Scientific; Dr Menelas Pangalos, Executive Vice President of AstraZeneca; Dr Ken Sutherland, President of Canon Medical Research Europe Ltd; Dr David Sibbald, Chair of the Stratified Medicine Scotland Innovation Centre; and John Brown, Chair of NHS Greater Glasgow & Clyde Health Board and NHS Tayside Health Board. A full list of the SIA Steering Group members is included in Annex A.

4. Over recent months, partners have enthusiastically joined together to progress this SIA, ensuring that it provides a robust, balanced and granular assessment of Scotland's PM strengths and emerging prospects for growth. The evidence suggests that the further development and adoption of PM will potentially be transformative for the Scottish and UK life science clusters, developing expertise and know-how that can be exported around the world through new technologies, products, services and behaviours. Indeed, one of the key drivers for the audit has been a recognition across consortium members that Scotland is extremely well positioned to unlock the exciting and substantial productivity growth opportunities associated with PM.

5. The growth and development of Scotland – and indeed the wider UK's - PM ecosystem and associated digital and life science clusters, is only one of the economic benefits. Implementation of PM will help our NHS to generate significant savings at a time when it is struggling to meet increasing demand from an ageing population. Analysis conducted by health economists at the University of Glasgow reveals that PM generated innovations could help deliver billions of pounds of healthcare cost savings. Furthermore, more effective targeted treatments and better prevention of disease will create a healthier and more productive UK workforce.

6. The SIA has ensured we are fully cognisant of the nature and scale of the challenges in translating our research and clinical excellence into a globally significant PM business cluster in Scotland. A review of the evidence collated through this SIA work confirms that most of the key elements of our ecosystem are already in place – and we are well on our way to creating a healthier and wealthier Scotland.

What is Precision Medicine?

7. According to the WISH Precision Medicine Forum, Precision Medicine is defined as:

> *"the tailoring of medical treatment to the individual characteristics of each patient… to classify individuals into subpopulations that differ in their susceptibility to a particular disease or their response to a specific treatment… allowing preventative or therapeutic interventions to be concentrated on those who will benefit, sparing expense and side effects for those who will not".*[1]

8. PM offers business, clinical and social opportunities for a range of stakeholders. It is not only of interest to scientists and medical professionals, but provides a clear space for industry, academia, health charities, the NHS and governments to collaborate to tackle the significant healthcare challenges that we face. There are a number of key market and technology drivers of change impacting on the PM opportunity, including an ageing population, increasing costs of healthcare and the emergence of new technologies (which are converging rapidly) allowing us to develop better, more targeted and tailored healthcare solutions for both economic and patient benefit.

The SIA area

9. This SIA covers the whole of Scotland. The opportunities to grow the PM cluster in Scotland will build on existing clinical, research and commercial expertise in the four major cities (Aberdeen, Dundee, Edinburgh and Glasgow). Scotland is already widely recognised as one of the key life science clusters in Europe[2], and as demonstrated in a Wave 1 SIA, the Edinburgh city region is a global centre of excellence for computer science and informatics. Through this SIA, we have started to explore how best to leverage the expertise set out in the Edinburgh city region SIA on Data Driven Innovation and develop new collaborative action areas designed to unlock new synergies and associated growth opportunities for the benefit of Scotland and the UK's life science industry as a whole.

10. The core approach that the consortium has adopted in undertaking this SIA has been to demonstrate the scale and nature of the PM opportunity to the whole of Scotland. Whilst Edinburgh and Glasgow boast a wide range of clinical medicine expertise, Dundee has strengths in drug discovery and Aberdeen has expertise in bio-pharmaceuticals. The role of NHS Scotland is also critical in scaling up the PM cluster - both as a key innovation partner and customer - and its remit covers the whole of the country. Indeed, as Scotland's fully integrated healthcare provider, NHS Scotland works closely with industry, academia and the health research charities sector. It provides co-ordinated access to clinical investigators and patients through a single point of contact for industry, accessible clinical research support infrastructures, and streamlined and timely clinical trial approvals.

Our vision

11. The high calibre SIA consortium of public and private partners from across Scotland and international experts are committed to helping Scotland become a global centre of excellence for the implementation of PM over the next 10 years. In order to achieve this vision, the SIA focuses on four main opportunity areas:

    - The £1bn Queen Elizabeth University Hospital (QEUH) campus in Glasgow is acting as a focal

[1] World Innovation Summit for Health (WISH) (2016) Precision Medicine, A Global Action Plan for Impact – Report of the WISH Precision Medicine Forum

[2] See for example: Science Business/Sanofi (2015), 'The leading life sciences clusters in Europe'

point for Scotland's wider ecosystem for PM, delivering substantial clinical and economic benefits to Scotland and the UK

- Driving increased awareness and adoption of PM, as well as the strengthening of our innovation ecosystem, will accelerate productivity growth and improved patient outcomes
- Enhancing Scotland's leadership role in the advancement of PM will help to speed up the adoption of PM, providing an internationally significant UK exemplar, attracting Foreign Direct Investment (FDI) and delivering competitive advantage for the UK
- Scotland's PM strengths have the potential to add significant economic value by complementing and synergising with other major UK innovation initiatives; including those in adjacent sectors most notably drug discovery. Specifically we will build on existing close relationships with the UK based European Lead Factory and the Medicines Drug Discovery Catapult. PM will lead to much better understanding of molecular mechanisms of diseases and therefore is prime source of new druggable targets.

Key strengths

12. In recent years, Scotland has built strong foundations, which support the development and diffusion of PM focused approaches to healthcare. Major investments have been made at the new £1bn QEUH campus in Glasgow, including the Stratified Medicine Scotland Innovation Centre (SMS-IC), the Clinical Innovation Zone and the Imaging Centre of Excellence (ICE). This is the first clinical-academic industry campus worldwide designed around the clinical implementation of PM and it is one of the jewels in the crown of Scotland's burgeoning ecosystem for PM. In 2016, the UK's first 7-Tesla (7T) MRI scanner in an acute clinical setting was installed at ICE. Only 75 7T scanners exist worldwide and the Glasgow scanner is one of the first with the capability for use in clinical practice.

13. We have a well-established Scotland-wide Ecosystem for Precision Medicine, centred around the SMS-IC, which is funded by the Scottish Government/Chief Scientist Office (CSO) and industry. The combination of world class clinical research, high quality patient data, patient samples, a single healthcare provider (NHS Scotland), and large cohorts of patients with chronic disease, differentiates Scotland from other life science clusters. Scotland is already widely recognised as a key location for hosting clinical trials andhas strong relationships with the global pharmaceutical industry.

ReproCELL Europe is headquartered at the West of Scotland Science Park in Glasgow. It is a contract research services company that works with 19 out of the 20 major global pharmaceutical companies. ReproCELL invested in Scotland in 2015 when it acquired Biopta, a spinout from Glasgow Caledonian University. A new company ReproCELL Europe was then created in 2016, merging Biopta and another acquisition, Reinnervate. ReproCELL Europe currently has 23 employees, with 19 in Glasgow and 4 in County Durham. Its annual turnover is around £1.5m and 90% of sales are exports.

Working with NHS, academic and industry partners at the SMS-IC has helped ReproCELL to improve the selection of patient stratification criteria based on a combination of genomics and associated functional data from studies in human tissue samples. The project was a key factor in ReproCELL's decision to buy Biopta and has also been successful in showcasing the opportunities of industry, academia and the NHS (the triple helix model) working together in the area of Precision Medicine.

14. Scotland's investment in PM has been recognised internationally. In a report for the World Innovation Summit for Health (WISH), Dr Victor Dzau (President of US National Academy of Medicine) highlighted Scotland as an exemplar in terms of cross sector collaboration and the important roles being played by SMS-IC, the Scottish Genomes Partnership, Generation Scotland, and Glasgow Polyomics[3].

15. The strength of the PM ecosystem was also recognised by AstraZeneca, when SMS-IC was invited to join its Global Genomics Initiative. In addition, the Universities of Edinburgh and Glasgow have partnered to establish the Scottish Genomes Partnership (SGP). Professor Andrew Biankin, at the University of Glasgow, has led the formation of the International Cancer Genome Consortium (ICGC) Accelerating Research Genomic Oncology (ARGO) project, which is analysing biospecimens from over 100,000 cancer patients worldwide with standardised methods and high quality clinical data.

16. Scotland's key strengths in PM are summarised in Table 1.

Thermo Fisher SCIENTIFIC

Thermo Fisher Scientific Inc. is a global leader in serving science, with a total revenue of more than $20bn. It supplies instruments, equipment and software, as well as services and consumables to help conduct research, solve complex analytical challenges, improve patient diagnostics, deliver medicines to market and increase laboratory productivity. Around 850 of Thermo Fisher's 70,000 global employees are based in Scotland: 700 at Inchinnan near Glasgow, 100 in Perth, and 50 who are field based. Thermo Fisher generates approximately $1bn revenue from Scottish customers.

In 2015, a new £14m facility was opened to use Thermo Fisher's proprietary technology to manufacture dry media powder, which is then used to manufacture a range of drugs. One of only two such plants in the world, products from Inchinnan are used by customers across the Europe, Middle East and African (EMEA) markets. These customers then develop drugs that can be used to treat targeted groups of patients. The company was also a founding partner in the SMS-IC.

[3] Dzau et al (2016), Precision Medicine, A Global Action Plan for Impact -Report of the WISH Precision Medicine Forum 2016

Table 1: Scotland's key strengths in Precision Medicine – an overview

Scotland's unique strengths and key assets		Globally significant PM research base	Expanding PM business base
• **Queen Elizabeth University Hospital (QEUH)** – the new £1bn hospital campus opened in 2015 and is the largest acute hospital in the UK. It is home to major specialist services such as renal medicine, transplantation and vascular surgery, with state-of-the-art critical care, theatre and diagnostic services • **Imaging Centre of Excellence (ICE)** - located in the QEUH campus, the centre hosts an ultra high-field 7T MRI scanner, a 3T MRI scanner and a 320 multi-slice CT scanner and houses clinical academic and industry personnel dedicated to the development and deployment of next generation imaging • **Stratified Medicine Scotland Innovation Centre (SMS-IC)** – based within the Clinical Innovation Zone at QEUH, SMS-IC was set up in 2013 as a partnership between four Scottish NHS Health Boards, four Scottish Universities and two industrial partners in informatics - Aridhia Ltd - and in genomics with ThermoFisher Scientific Ltd	• **Quality of Scotland's electronic health records** – among the world's best and include a Community Health Index (CHI) number, which was introduced over 30 years ago and uniquely identifies a person on the index. Data on Scotland's entire population is captured routinely at all points of contact with the health service, meaning patient demographics and clinical information can be readily accessed for clinical research and trials • Scotland has the ability to bring together real patient data, historic data and patient samples, as well as unique patient databases such as SHARE and Generation Scotland • **Single healthcare provider** – NHS Scotland is made up of only 14 regional health boards and patient records and regulation is consistent across Scotland	• **Scotland's universities produce world-class research and perform well across various international rankings** – five of Scotland's universities are in the world's top 200 in the categories of clinical, pre-clinical and health, life sciences and computer science[4] • The quality of research from the four SMS-IC partner universities in PM-related subjects is higher than in other key university groupings in the UK[5] • **Key figureheads driving Precision Medicine in Scotland** – Professor Dame Anna Dominiczak, Vice-Principal and Regius Chair of Medicine and Therapeutics at the University of Glasgow, and Professor Andrew Morris of the University of Edinburgh and the Farr Institute are at the forefront of developing the PM Ecosystem in Scotland • **SMS-IC projects showcasing Scotland's expertise** – demonstrating the applicability of PM in a range of chronic diseases, and including large multinational consortium projects	• **Growing life sciences cluster** – Scotland is one of the largest life science clusters in Europe. It employs over 37,000 people across 700 organisations, and contributes around £2bn in annual Gross Value Added (GVA) for the Scottish economy. There has been significant growth in the sector with GVA increasing 45% between 2010 and 2015, and employment growing by 16%[6 7] • **Regarded as one the best locations for the development and clinical trials of treatments and therapies** – high number of trials taking place compared to other countries with eight out of the top 10 global CRO's located in Scotland • **Increasing number of businesses involved in PM** – including Canon Medical Systems, Aridhia, Fios Genomics, Pharmatics, Sistemic, Destina Genomics, Biopta (ReproCELL), BioClavis, ThermoFisher Scientific and Arrayjet • Overall, it is estimated by Scottish Enterprise that there are currently **around 230 companies undertaking PM related activity in Scotland**[8]

Scotland's unique strengths and key assets		Globally significant PM research base	Expanding PM business base
• **MRC/ EPSRC Molecular Pathology Nodes** – two of the six UK nodes are based in Glasgow (the UK's largest) and Edinburgh. The nodes provide infrastructure and expertise to deliver PM in a wide range of disease areas • **NHS/ University Clinical Research Facilities** and accredited **Clinical Trials Units** – coordinated facilities in Aberdeen, Dundee, Edinburgh and Glasgow bringing together university and NHS Scotland research expertise • **NHS Research Scotland** – encourages researchers to bring studies to Scotland, and invests in nationwide clinical research infrastructure • **NHS Scotland Biorepositories and Safe Havens** – a network of four regional biorepositories for tissue samples and health data 'safe havens' located in Aberdeen, Dundee, Edinburgh and Glasgow.	• **Continuing prevalence of chronic disease in Scotland** – these diseases include heart disease, stroke, cancer, diabetes, chronic inflammatory and autoimmune diseases such as multiple sclerosis. In addition, Scotland has a very stable population, which also helps with longitudinal health monitoring • **Significant Scottish Government support for PM** – major investments in SMS-IC, facilities at the QEUH campus, and funding for the Scottish Genome Partnership • **Scottish Genomes Partnership (SGP)** – investment from CSO, MRC and the Universities of Edinburgh and Glasgow to establish sequencing capabilities.	• In 2016, **SMS-IC joined AstraZeneca's Global Genomics Initiative**. Other partners include the University of Cambridge, the Wellcome Trust Sanger Institute, Genomics England, Human Longevity Inc. in the USA, Columbia University in Canada and Finland's Institute for Molecular Medicine • SMS-IC partners are looking to enhance Scotland's expertise in bioinformatics, next generation sequencing, data assimilation, biomarker identification and diagnostics development • **Complementary expertise in health economics** – University of Glasgow's Health Economics and Health Technology Assessment team (HEHTA) is at the forefront of developing robust economic models on the effectiveness of PM, and the University of Aberdeen Health Economics Research Unit won the Queen's Anniversary Prize for sustained research excellence.	• **Strengthening links between life science companies and Scotland's emerging data and informatics sector** – strong strategic focus on health informatics in Edinburgh and Glasgow, making links with Edinburgh City Region SIA • **Supportive business environment for start-ups and growth companies** – support for firms provided by Scotland's enterprise agencies (Scottish Enterprise, Scottish Development International, Highlands and Islands Enterprise, Skills Development Scotland, Scottish Funding Council) and through private sector investors (e.g. Epidarex Capital) • Broad range of business accommodation tailored to life science and technology rich companies – with key concentrations of sites in the Edinburgh and Glasgow areas (Clinical Innovation Zone, BioCity, BioQuarter)

Source: Precision Medicine in Scotland SIA Consortium

[4] Times Higher Education World University Rankings

[5] Based on SQW analysis of SciVal citation impact scores 2014-17 – SMS-IC universities were compared with N8 Research Partnership, Russell Group and Golden Triangle

[6] Sciences in Scotland (2017), Life Sciences Strategy for Scotland 2025 Vision - Accelerating Growth, Driving Innovation

[7] The Office for Life Sciences also produces data on the life sciences sector across the UK. The latest data in the 'Strength and Opportunity 2017' report estimates there are just over 15,000 jobs in Scotland in the biopharma and medtech sub-sectors. The SIA consortium agreed that the wider Scottish Government definition of the life sciences cluster was more appropriate to use for the purposes of this Audit

[8] Analysis undertaken by Scottish Enterprise

Growth opportunities

17. There are several market and technology drivers of change impacting on PM including an ageing population, increasing healthcare costs and the emergence of new disruptive technologies. Changes to regulation, approvals processes, new business models in the pharmaceuticals sector, and growing demand for non-invasive and personalised treatments are also important contextual developments for PM.

18. The global PM market value was estimated at almost $43bn in 2016 and this figure is projected to rise to around $134bn by 2025, so it is a prize worth pursuing for both the Scottish and wider UK economies[9]. However, there are significant global challenges in implementing PM in terms of data privacy, the integration of health datasets, regulation, and evidencing impact. Despite these hurdles, the SIA evidence suggests that Scotland has the complementary expertise in clinical research, computer science and informatics needed to create substantial economic opportunities from exploiting PM.

19. More specifically, there are three main areas of economic opportunities from investing in PM in Scotland:

    - It will create new business opportunities in a range of sectors including life sciences, data analytics and informatics, and over 200 Scottish firms are already involved in this area.

    - Implementing PM will help our NHS to generate significant savings at a time when it is struggling to meet increasing demand. Initial analysis by health economists at the University of Glasgow demonstrated how PM generated innovations could help deliver billions of pounds of health savings across Scotland.

    - More effective treatments and better prevention of disease will create a healthier and more productive UK workforce.

Gap analysis

20. The development of this SIA has involved extensive consultation with 45 public and private sector organisations from across Scotland. These in-depth discussions have been used to clarify the existing PM related strengths of Scotland and helped partners to identify where more can be done. The main gaps and solutions are as follows:

    - **Limited integration of, and exploitation of potential synergies across, Scotland's expertise in clinical medicine and data science, both in terms of research and commercial activities. This is a major missed opportunity for the UK**

        > **Develop a more strategic partnership between clinical medicine and data science capabilities**, including machine learning and artificial intelligence (AI) and the opportunities enabled by new 5G data networks – building on the work of SMS-IC and Datalab, and other joint research, PM offers a major opportunity for closer collaboration between the Universities of Edinburgh and Glasgow, along with NHS Scotland, industry and the major health research charities

    - **Low levels of entrepreneurship in Scotland, compared to other parts of the UK, and a relatively limited number of start-ups to date targeting the PM opportunity**

        > **Embed a more pervasive culture of enterprise and attract more Venture Capital (VC)**

[9] Frost & Sullivan (2017), Global Precision Medicine Growth: Opportunities, Forecast to 2025. Strategies and Tactics for Accelerating Growth in a Transforming Market

Funds to support the commercialisation effort – we need to promote the PM opportunities for new tech start-ups, celebrate the successes that we have in Scotland, and ensure that growth finance is available (on attractive terms) for investable propositions

- **Inconsistent messaging across Scotland about the scale and nature of the business growth opportunities linked to PM** for start-ups, existing SMEs, and potential inward investors. This has resulted in a lack of clarity and general awareness amongst the business and investor communities

  > **Create PM champions within NHS Scotland, academia and the Scottish Government**, to work together and with the enterprise agencies and industry to drive demand/investment and raise the profile and awareness of PM related opportunities. A clearer demand statement from NHS Scotland and the Scottish Government would accelerate the development, adoption and mainstreaming of PM in Scotland

  > Complementing the previous action area, **better PM promotion to the SME base and potential inward investors** – the partners involved in developing this SIA are committed to working with different sectors and investors to articulate the scale and nature of Scotland's offer and the exciting market opportunities associated with PM

- **Insufficient promotion of Scotland's existing key PM assets and centres of excellence** – there needs to be greater clarity on the PM offer and the major investments in new facilities over recent years. A more coherent, powerful and compelling narrative is needed around the PM ecosystem in Scotland and its key differentiators

  > Encourage **stronger collaboration between key PM assets and centres of excellence** (e.g. the Clinical Innovation Zone at QEUH, BioCity and the Edinburgh BioQuarter etc.), with support from Scottish Enterprise, ensuring a fully integrated offer combining both hard and soft enabling infrastructures

- **Lack of clarity on the skill-sets required to grow and develop the PM cluster in Scotland**

  > Invest more in targeted PM and bioinformatics and AI for Health skills development programmes – the integration of different skill-sets will be key to developing and maximising Scotland's PM opportunity

Key ambitions and investment proposals

21. Building on the evidence and feedback from SIA Steering Group members and framed by the potential high-level benefits outlined above, we have identified the following key action areas for Scotland to maximise its existing and emerging strengths in PM:

- **Integrate complementary regional strengths in data science and PM** – Scotland now has a potentially transformational opportunity to combine the regional strengths in data science and PM, particularly in Edinburgh and Glasgow, to accelerate the implementation of PM and achieve long term economic impacts for Scotland through NHS savings, a healthier and more productive workforce, and growing Scotland's PM focused business base

- **Develop the QEUH as a 'living lab' to realise the potential of PM and drive economic growth** – the new hospital campus provides an exciting and timely opportunity to pilot the adoption of PM within the UK's largest health board. This will enable the scalable Real World implementation of PM, demonstration of savings to the NHS and patient benefit by the use of health economics, and accelerating the growth and development of the flagship PM cluster in Scotland, creating high value jobs in Govan, an area of historic high unemployment and disadvantage

- **Create next generation clinical decision support tools or 'clinical cockpits'** – these tools will be developed by making use of Scotland's enviable access to large databases of relevant patient data (with governance through Scotland's Safe Havens) to allow the relevant models of population based precision pathways of care to be built. They will also involve clinicians to guide the design and development of these next generation clinical cockpits, and will utilise advances in AI. These tools will be applicable elsewhere in the UK and by other global care providers

- **Develop SMS-IC as a gateway to 'Scotland's Ecosystem for PM'** – broadening out the initial work undertaken by the SMS-IC, to encompass other tools for PM such as omics, imaging and digital pathology, work with the NHS on the regulatory aspects and implementation of PM, strengthen the application of health economics and build stronger links with global pharmaceutical and diagnostics firms

BioClavis is a personalised diagnostics spin-out of US based BioSpyder Technologies. In early 2018, BioClavis set up at the Queen Elizabeth University Hospital (QEUH) campus in Glasgow supported by a £3.4m R&D grant from Scottish Enterprise. The parent company BioSpyder was set up in 2011 and developed a novel product for targeted sequencing called TempO-Seq™, a transcriptomic/ genomic platform technology. It has five employees in Glasgow.

BioSpyder considered a range of locations around Europe (in the UK, Ireland, Germany, Switzerland, Netherlands) but soon realised the QEUH in Glasgow was the best location for setting up BioClavis. The first key attractor was the scale and quality of clinical data and samples that they would be able to access. QEUH has one of the largest pathology laboratories in the UK and Europe, and a large biorepository, which is networked to others across Scotland. The company also saw the networking infrastructure as a real asset of Glasgow, specifically the integration of industry, academics and clinicians at the Clinical Innovation Zone.

Networking and collaborating

22. The development of this SIA has been shaped by an open, inclusive and wide-ranging programme of stakeholder engagement and consultation. This has included consultations with 45 stakeholders, in-depth case study research to showcase examples of PM excellence and knowledge exchange on the ground, regular meetings with the SIA Delivery Team, as well as continuous 'check and challenge' provided by the high-level SIA Steering Group.

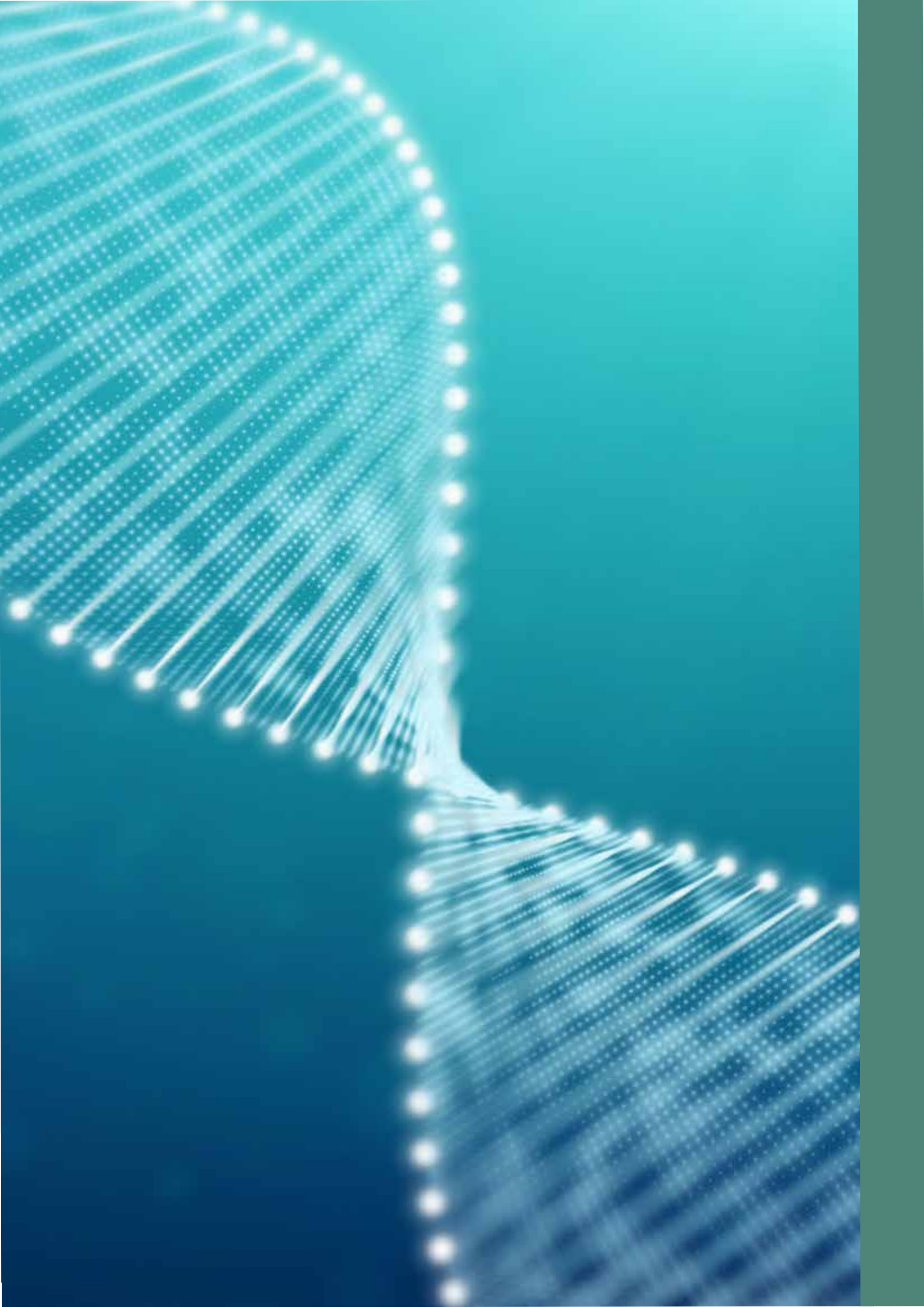
23. We are at the start of an exciting process to scope, define and implement the key growth opportunities for Scotland in the context of a rapidly evolving and highly competitive global PM landscape. Informed by these SIA findings - and indeed the two previous Scotland SIAs, which focused on enabling technologies and data driven innovation - consortium partners are now much better equipped to focus their effort and investment on those niche areas where Scotland is either currently leading the world or has the potential to do so over the next 10 years.

24. The process of developing this SIA has increased the profile and understanding of Scotland's areas of comparative advantage for both internal (Scottish) stakeholders and wider UK and international partners. There is now a clearer understanding of the PM opportunity within the Scottish Government and its agencies. The SIA foreword provided by Scotland's First Minister reflects this strong policy support, and plans are being developed for Scotland to host an international 'Summit in Precision Medicine', to showcase Scotland's highly differentiated and internationally significant PM focused capabilities.

25. Importantly, our consortium is confident and bold enough to know that competitor areas elsewhere in the UK and beyond are also moving fast in relation to PM innovation and adoption. Therefore, we are already using the SIA process and audit report to help us demonstrate to others where and how Scotland can contribute to this exciting global agenda.

26. Indeed, we have a long and proud history of collaborating with the best and we will continue to do this where there are clear complementarities and strong alignment with our strategic objectives. For instance, constructive discussions with the Northern Powerhouse have already taken place and these are giving rise to new partnerships, collaborative ideas and areas of joint working. The partners involved in SMS-IC have also been using the SIA process to highlight Scotland's opportunity and explore new collaborations with partners in Finland and British Columbia in Canada.

27. Encouragingly, the SIA process has energised partners, strengthening their commitment to realise our vision and provided an opportunity for them to foster new relationships across the ecosystem. It has enabled us to shine a spotlight on Scotland's impressive and internationally recognised PM related capabilities. Informed by robust evidence, we have identified a number of targeted new investment propositions designed to complement our existing activities and take us towards our long term goal of translating Scotland's well-established scientific excellence into innovation-led inclusive growth. Many of the pre-requisites for success are in place, but this SIA report has revealed some important gaps which we are determined to fill so we can grow a large and dynamic cluster of exporting frontier companies.



1. Setting the Scene

Introduction

1.1 This Science and Innovation Audit (SIA) report has been developed by an impressive consortium comprising public and private sector partners from across Scotland, as well as a number of leading international actors involved in Precision Medicine (PM) globally. Whilst the consortium has been led by the University of Glasgow, the SIA process has very much been characterised by a genuine "Team Scotland" approach, with support, commitment and real insight from industry (both large and small), academia, NHS Scotland, Scottish Enterprise, Scottish Government and the health charities sector operating across the country.

1.2 The SIA Steering Group includes a wider range of national and international experts from industry, academia, NHS and Government. These include: Professor Dame Anna Dominiczak, Vice-Principal and Head of College of Medical, Veterinary & Life Sciences at the University of Glasgow (Chair); Dr Victor Dzau, President of the US National Academy of Medicine; Peter Silvester, Senior Vice President of Thermo Fisher Scientific; Dr Menelas Pangalos, Executive Vice President of AstraZeneca; Dr Ken Sutherland, President of Canon Medical Research Europe Ltd; Dr David Sibbald, Chair of the Stratified Medicine Scotland Innovation Centre; and John Brown, Chair of NHS Greater Glasgow & Clyde Health Board and NHS Tayside Health Board. A full list of the SIA Steering Group members is included in Annex A.

1.3 Over recent months, partners have enthusiastically joined together to progress this SIA, ensuring that it provides a robust, balanced and granular assessment of Scotland's PM strengths and emerging prospects for growth. The evidence suggests that the further development and adoption of PM will potentially be transformative for the Scottish and UK life science clusters, developing expertise and know-how that can be exported around the world through new technologies, products, services and behaviours. Indeed, one of the key drivers for the audit has been a recognition across consortium members that Scotland is extremely well positioned to unlock the exciting and substantial productivity growth opportunities associated with PM.

1.4 The growth and development of Scotland – and indeed the wider UK's - PM ecosystem and associated digital and life science clusters, is only one of the economic benefits. Implementation of PM will help our NHS to generate significant savings at a time when it is struggling to meet increasing demand from an ageing population. Analysis conducted by the University of Glasgow's Health Economics and Health Technology Assessment (HEHTA) team reveals that PM generated innovations could help deliver billions of pounds of healthcare cost savings. Furthermore, more effective targeted treatments and better prevention of disease will create a healthier and more productive UK workforce.

1.5 The SIA has ensured we are fully cognisant of the nature and scale of the challenges in translating our research and clinical excellence into a globally significant PM business cluster in Scotland. A review of the evidence collated through this SIA work confirms that most of the key elements of our ecosystem are already in place – and we are well on our way to creating a healthier and wealthier Scotland.

Overview of the SIA process. . .

1.6 The development of this SIA has been shaped by an open, inclusive and wide-ranging programme

of stakeholder engagement and consultation. This has included consultations with 45 stakeholders, in-depth case study research to showcase examples of PM excellence and knowledge exchange on the ground, regular meetings with the SIA Delivery Team (members are listed in Annex B), as well as continuous 'check and challenge' provided by the high-level SIA Steering Group. We have also undertaken an e-survey which provided feedback from around 80 stakeholders across Scotland with an interest in PM.

1.7 We are at the start of an exciting process to scope, define and implement the key growth opportunities for Scotland in the context of a rapidly evolving and highly competitive global PM landscape. Informed by these SIA findings - and indeed the two previous Scotland SIAs, which focused on enabling technologies and data driven innovation - consortium partners are now much better equipped to focus their effort and investment on those niche areas where Scotland is either currently leading the world or has the potential to do so over the next 10 years.

1.8 Importantly, our consortium is confident and bold enough to know that competitor areas elsewhere in the UK and beyond are also moving fast in relation to PM innovation and adoption. Therefore, we will use this audit report to help us demonstrate to others where and how Scotland can contribute to this exciting global agenda. Indeed, we have a long and proud history of collaborating with the best and we will continue to do this where there are clear complementarities and strong alignment with our strategic objectives. For instance, constructive discussions with the Northern Powerhouse have already taken place and these are giving rise to new partnerships, collaborative ideas and areas of joint working.

1.9 As described later in this report, Scotland has a number of unique strengths and areas of competitive advantage in relation to PM. These must be leveraged fully if the UK is to maximise the productivity gains, NHS savings, improved health outcomes and wider socio-economic benefits that the mainstreaming of PM technologies, techniques and behaviours, and the development of a globally significant PM cluster in Scotland will deliver. Therefore, towards the end of this SIA report in Section 7, we present a prioritised shortlist of new investment proposals designed to help us achieve against our long-term productivity growth agenda.

1.10 We thank partners for their continued support throughout this SIA process and we welcome the opportunity of discussing our transformative investment action ideas with Government, health charities and private sector investors.

. . . and our SIA geography

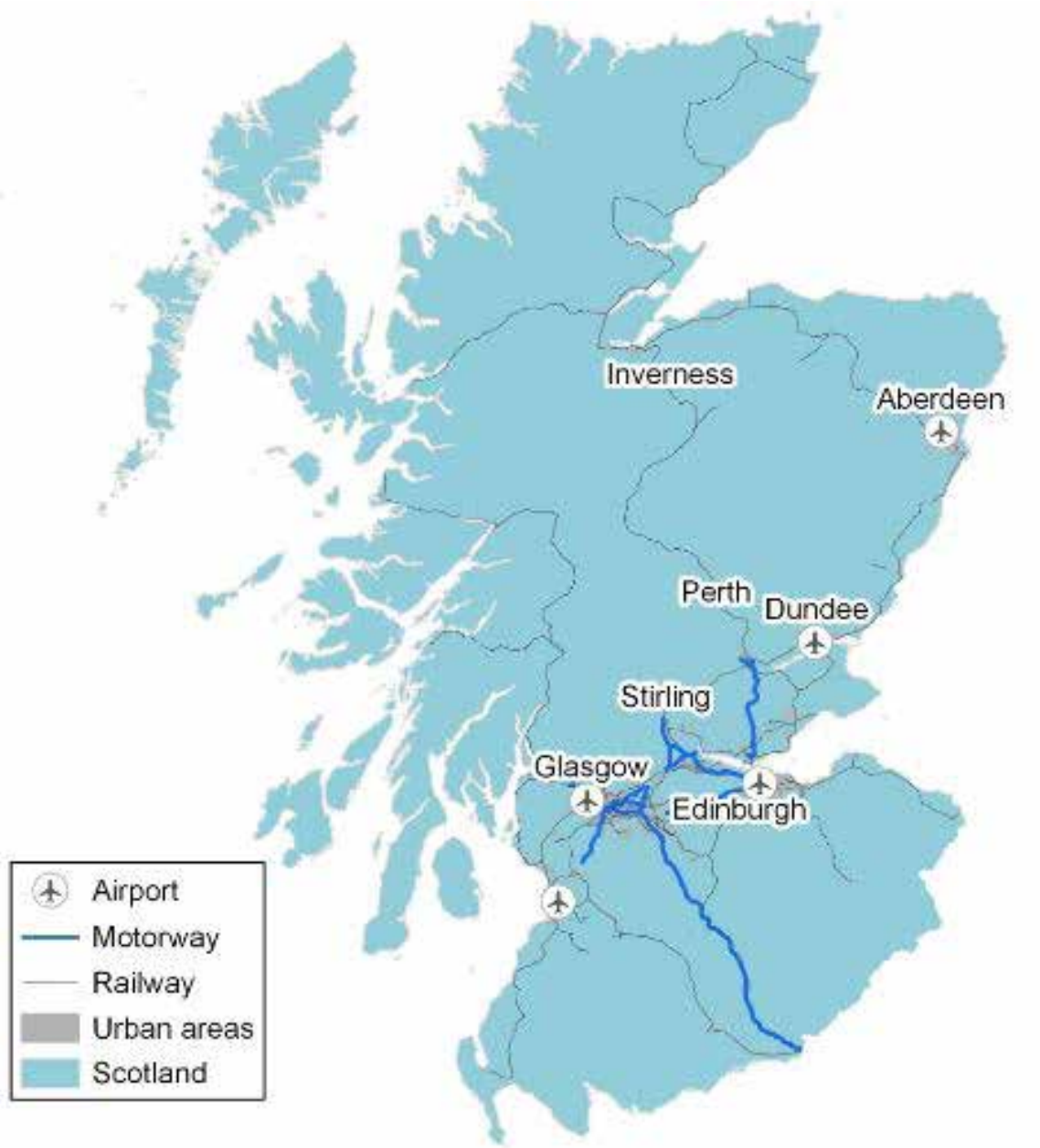
1.11 This PM SIA covers the whole of Scotland. The opportunities to grow the PM cluster in Scotland will build on existing clinical, research and commercial expertise in the four major cities (Aberdeen, Dundee, Edinburgh and Glasgow). Scotland is already widely recognised as one of the key life science clusters in Europe[10], and as demonstrated in a Wave 1 SIA, the Edinburgh city region is a global centre of excellence for computer science and informatics[11]. Through this SIA process, we have been exploring how best to leverage the expertise set out in the Edinburgh City Region SIA on Data Driven Innovation and develop new collaborative action areas designed to unlock new synergies and associated growth opportunities for the benefit of Scotland and the UK's life science industry as a whole.

[10] See for example: Science Business/Sanofi (2015), 'The leading life sciences clusters in Europe

[11] For example, according to Times Higher Education World University Rankings 2018, the University of Edinburgh is ranked 14th in the world for computer science

1.12 It is expected that the new £1bn Queen Elizabeth University Hospital (QEUH) campus in Glasgow will act as a key hub for this emerging PM cluster, maximising the world-class clinical research and facilities that have been established there over recent years. The new 14 floor building is the largest acute hospital campus in Europe and home to major specialist services such as renal medicine, transplantation and vascular surgery, with state-of-the-art critical care, theatre and diagnostic services. Major innovation facilities specifically developed for PM are co-located on site at the campus, including Stratified Medicine Scotland Innovation Centre (SMS-IC), the Imaging Centre of Excellence (ICE), Teaching and Learning Centre, Clinical Innovation Zone for industry, Clinical Research Facilities for clinical trials and the Glasgow MRC / EPSRC Molecular Pathology Node. This is the first clinical-academic-industry campus worldwide designed around the clinical implementation of PM and it is one of the jewels in the crown of Scotland's burgeoning ecosystem for PM.

Figure 1-1: SIA geography - Scotland



Source: Produced by SQW 2018. Licence 100030994. Contains OS data © Crown copyright [and database right] [2018]

1.13 The core approach that the consortium has adopted in undertaking this SIA has been to demonstrate the scale and nature of the PM opportunity to the whole of Scotland. Whilst Edinburgh and Glasgow boast a wide range of clinical medicine expertise, Dundee has strengths in drug discovery and Aberdeen has expertise in bio-pharmaceuticals. The role of NHS Scotland is also critical in scaling-up the PM cluster - both as a key innovation partner and customer - and its remit covers the whole of the country. Indeed, as Scotland's fully integrated healthcare provider, NHS Scotland works closely with industry, academia and the health research charities sector. It provides co-ordinated access to clinical investigators and patients through a single point of contact for industry, accessible clinical research support infrastructures, and streamlined and timely clinical trial approvals. As evidenced throughout this report, Scotland has some unique assets and differentiators in terms of its life sciences offer, which position it at the vanguard of the UK's PM agenda.

1.14 Scotland has a population 5.4m people and an enviable global reputation for world-class university research, a highly skilled workforce, well established sector specialisms in energy, financial services, food and drink, engineering, creative industries and life sciences. The country is also a leading tourism destination with visitors attracted by first class attractions, events and festivals and the diverse mix of rural and urban experiences. The country is globally connected through its five major airports, rail connections to the rest of the UK and port connections. Greater Glasgow is the largest city with just under one million residents. Most of Scotland's population live within the Central Belt area of Scotland between Edinburgh and Glasgow (see Figure 1-1).

Context

What is Precision Medicine?

1.15 PM is a relatively new term which is now more commonly used instead of previous labels such as 'personalised medicine' or 'stratified medicine'. Although, 'personalised medicine' is still sometimes used, it suggests a process of developing treatments unique to each individual, and is perceived as misleading by the US National Research Council and other leading bodies. Therefore, the term 'precision medicine' is generally preferred[12]. PM is at times mistakenly confused with genomics. However, genomics is only one of a number of tools which can be used to stratify disease, and which increasingly includes other 'omics (e.g. metabolomics) and imaging[13].

1.16 According to the WISH Precision Medicine Forum, PM is defined as:

"the tailoring of medical treatment to the individual characteristics of each patient… to classify individuals into subpopulations that differ in their susceptibility to a particular disease or their response to a specific treatment… allowing preventative or therapeutic interventions to be concentrated on those who will benefit, sparing expense and side effects for those who will not"[14].

1.17 PM offers business, health and social opportunities for a range of stakeholders. It is not only of interest to scientists and medical professionals, but provides a clear space for industry, the NHS, academia, health charities, and governments to collaborate to tackle the significant healthcare challenges that we face. There are a number of key market and technology drivers of change impacting on the PM opportunity, including an ageing population, increasing costs of healthcare and the emergence of new technologies (which are converging rapidly) allowing us to develop better, more targeted and tailored healthcare solutions for both economic and patient benefit.

[12] US National Library of Medicine - https://ghr.nlm.nih.gov/primer/precisionmedicine/precisionvspersonalized

[13] The Scottish Science Advisory Council (SSAC) is currently reviewing clinical genomics in Scotland and the findings are expected to be published later in summer 2018

[14] World Innovation Summit for Health (WISH) (2016) Precision Medicine, A Global Action Plan for Impact – Report of the WISH Precision Medicine Forum

Building on Scotland's research excellence and impressive innovation landscape

1.18 Scotland is recognised globally for its proud history of innovation. Over the past century, Scottish science has introduced major innovations to the world including MRI and ultrasound scanning, penicillin, the Glasgow Coma Scale, Dolly the Sheep and a variety of other medical, pharmaceutical and highly disruptive technological breakthroughs. Most recently in 2016, the UK's first 7-Tesla MRI scanner in an acute clinical setting was installed at the University of Glasgow's ICE facility at the QEUH. The 7T scanner is one of only 75 worldwide and one of the first with the capability for use in clinical practice. Scotland also benefits greatly from its university research excellence. It now has 19 universities and four of the UK's six ancient universities are based in Scotland (Aberdeen, Edinburgh, Glasgow and St Andrews). Many of our top universities are world leading and we have clear research strengths in areas such as clinical medicine and computer science.

1.19 Scotland's Economic Strategy sets out the Scottish Government's commitment to boosting investment and innovation, supporting inclusive growth and increasing internationalisation. There is also a well-established innovation support ecosystem across the country including NHS Research Scotland, coordinated NHS Health Boards, universities, the enterprise agencies (SE, HIE, SDI)[15], Skills Development Scotland, Scottish Funding Council, Further Education colleges, Business Gateway, local councils, trade bodies and Chambers of Commerce.

1.20 The development of the PM cluster within Scotland is recognised and supported within the Scottish Government's Programme for Government[16], in which it is described as being 'vitally important to Scotland's future health'. The Programme includes a commitment to build on existing strengths and support the commercialisation of quality research in PM. The Scottish Government and partner agencies have a 'Scotland CAN DO' Framework[17], which seeks to develop Scotland as a world leading entrepreneurial and innovative nation.

1.21 In 2012, a network of eight Innovation Centres was set up to facilitate collaboration between universities and businesses in emerging technology areas. Four of these centres have key roles to play in supporting our PM efforts: the SMS-IC; the Centre for Sensors and Imaging Systems; DataLab; and the Digital Health and Care Institute. Scotland is also well engaged with Innovate UK's Catapult network, particularly in terms of High Value Manufacturing, Offshore Renewable Energy and Satellite Applications.

1.22 The £20m SMS-IC has been operating for five years, and was co-funded by the Scottish Funding Council and industry, with significant additional resources provided by the University of Glasgow and Scottish Government/CSO. SMS-IC is located at the QEUH Clinical Innovation Zone and operates as a public-private consortium. This includes: NHS Scotland; the Universities of Aberdeen, Dundee, Edinburgh and Glasgow; ThermoFisher; and Aridhia. The SMS-IC Board is chaired by Dr David Sibbald, and includes representation from SMEs, Scottish Enterprise, the Scottish Funding Council and CSO, together with all SIA consortium partners.

1.23 Scotland has been identified by Innovate UK as a Centre of Excellence in Precision Medicine. We are now working with the Knowledge Transfer Network (KTN) and Innovate UK to develop a network of PM Centres of Excellence across the UK, including hosting the first PM centre-led meeting in Glasgow in April this year. The development of PM in Scotland is also very well-aligned with the

[15] Scottish Enterprise, Highlands and Islands Enterprise, Scottish Development International
[16] Scottish Government (2017) Nation with Ambition. A Programme for Government 2017-18
[17] http://www.cando.scot/

aims and objectives of the new UK Industrial Strategy[18], the Industrial Strategy Challenge Fund and Life Sciences Sector Deal[19]. The UK Government has highlighted PM as a policy priority and has embedded related policies across several sectors. The Industrial Strategy promotes a 'data driven economy' backed by a £210m investment in a 'Data to early diagnostics and precision medicine' programme to improve the quality and application of health data for diagnosis and the development of precision treatments. As a consortium, we are committed fully to playing our part in helping to deliver the UK's Industrial Strategy.

Our vision

1.24 The high calibre SIA consortium of public and private partners from across Scotland and international experts are committed to helping Scotland become a global centre of excellence for the implementation of PM over the next 10 years. In order to achieve this vision, the SIA focuses on four main opportunity areas:

- The £1bn Queen Elizabeth University Hospital (QEUH) campus in Glasgow is acting as a focal point for Scotland's wider ecosystem for PM, delivering substantial clinical and economic benefits to Scotland and the UK
- Driving increased awareness and adoption of PM, as well as the strengthening of our innovation ecosystem, will accelerate productivity growth and improved patient outcomes
- Enhancing Scotland's leadership role in the advancement of PM will help to speed up the adoption of PM, providing an internationally significant UK exemplar, attracting FDI and delivering competitive advantage for the UK
- Scotland's PM strengths have the potential to add significant economic value by complementing and synergising with other major UK innovation initiatives; including those in adjacent sectors most notably drug discovery. Specifically we will build on existing close relationships with the UK based European Lead Factory and the Medicines Drug Discovery Catapult. Precision Medicine will lead to much better understanding of molecular mechanisms of diseases and therefore is a prime source of new druggable targets.

1.25 The evidence highlighted in this SIA report has clarified and validated these opportunities, and has helped inform a prioritised shortlist of new investment proposals for SIA partners to take forward so we can deliver against our long-term productivity growth and prosperous communities agendas. As Scotland takes the lead in the implementation of PM, new businesses and jobs will be created to design, develop and integrate new technologies, products and services. Scotland will also attract international interest and investment as we help to address global challenges in healthcare delivery.

[18] HM Government (2017) Industrial Strategy: Building a Britain fit for the Future
[19] HM Government (2017) Industrial Strategy: Life Sciences Sector Deal

2. Science, research and innovation excellence

Key messages

- Scotland has 19 universities delivering world-class teaching and research across a diverse range of subjects. In 2016/17, there were c.170k undergraduate and 60k post graduates at our universities, 10% of all UK students. We have c.50k international students and a higher proportion than the UK as a whole.
- Five of our universities are in the world's top 200, with the University of Edinburgh ranked joint 27th and the University of Glasgow ranked 80th. Scotland has more universities ranked in the global top 200 per head of population than any other country apart from Luxembourg.
- The quality of Scotland's university research was recognised in the REF 2014; the Universities of Edinburgh and Glasgow are both in the UK top 15 for research power and six Scottish universities were ranked in the UK top 50.
- Over the past five years, Scotland has secured c.13% of all UK funding through BBSRC and MRC, outperforming many other parts of the UK. This is also backed up by our universities' ability to secure commercial and contract research income.
- NHS Scotland has a strong research infrastructure including six clinical research facilities and four R&D hubs of biorepositories and safe havens based in Scotland's four main cities.
- Scotland's economy represents c.8% of the UK economy, both in terms of workforce and GVA. In 2016, Scotland had just under 2.5m employees and created around £134bn in GVA. The life sciences sector employs over 37,000 people across 700 organisations, and contributes nearly £2bn in annual GVA for the Scottish economy.
- Scotland performs very strongly in terms of inward investment and has consistently been the second most attractive part of the UK (after London) for FDI projects over the last 10 years. Growth in business expenditure on R&D (BERD) has increased by 133% to £1bn over the last decade, outstripping UK growth of 57%.
- 44% of our working age population is qualified to NVQ level 4 or above, which is higher than the UK average of 38% and second only to London in the UK.
- Scotland has a well-established and successful innovation ecosystem, with many assets that are directly relevant to PM.
- However, there remain some challenges around:
    - > limited success in Scotland's ability to commercialise and leverage this research excellence
    - > Scotland has lower productivity than the UK as a whole (as measured by GVA per job)
    - > lower levels of business innovation (as measured by business expenditure on R&D) and fewer exporting firms in Scotland compared to elsewhere in the UK.

Overview of Scotland's scientific research offer

We have a world-class university sector. . .

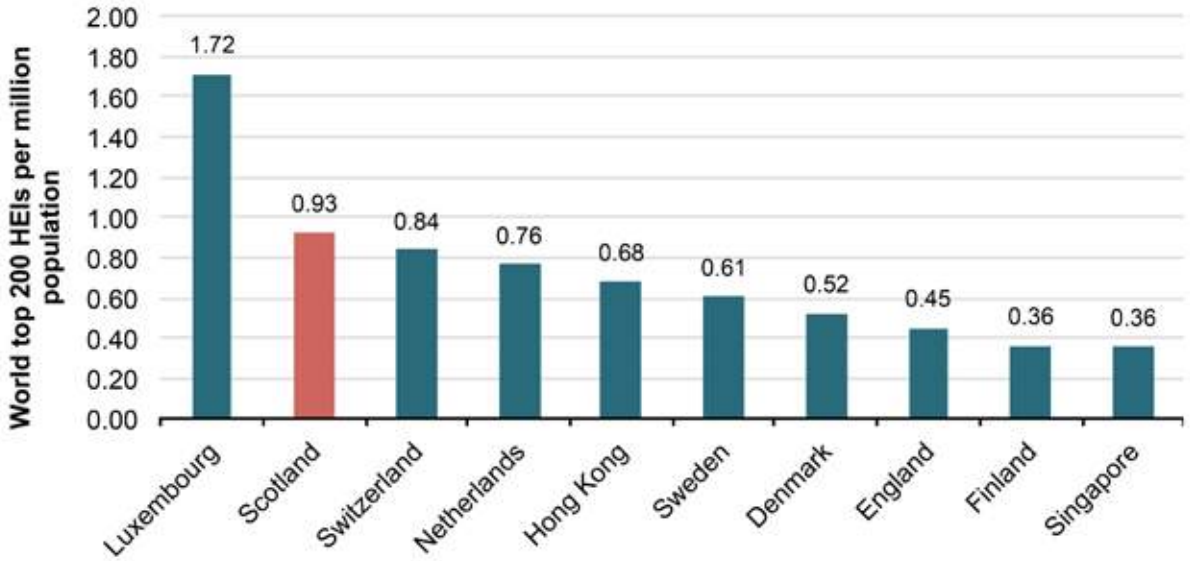
2.1 In 2016/17, there were 226,000 students enrolled at Scotland's 19 universities, of which 14 are campus-based Higher Education Institutions (HEIs). We have a diverse range of universities offering over 4,500 courses in more than 150 subject groupings at undergraduate and postgraduate levels[20].

2.2 Every Scottish university undertakes some research judged to be 'world-leading' (the highest rating classification awarded by the UK's Research Excellence Framework)[21]. Across all units of assessment in the latest REF (2014), the Universities of Edinburgh and Glasgow are both in the UK top 15 for research power. Six Scottish universities were ranked in the top 50 in the UK for the quality of their research. The universities have five medical schools (Aberdeen, Dundee, Edinburgh, Glasgow and St Andrews), three dental schools and two veterinary medicine schools.

2.3 In total, twelve of our universities have more than 10,000 students enrolled and overall we have 10% of all UK HE students. Scotland is an attractive choice for international students and nearly a quarter (23%) of our students are non-UK domiciled, compared to the UK average of 19%. This equates to over 50,000 international students in 2016/17[22]. Almost all universities deliver HE programmes outside Scotland and some have overseas campuses, e.g. the University of Glasgow in Singapore, and Heriot-Watt University in Dubai and Malaysia.

2.4 Scotland's universities are renowned internationally for the quality of their research. According to the Times Higher Education World University Rankings, five of our universities are in the world's top 200, with the University of Edinburgh ranked joint 27th and the University of Glasgow ranked 80th. The others are the universities of St Andrews, Aberdeen and Dundee (ranked 143rd, 185th and 187th respectively)[23]. All five are in the UK's top 30. On a per head basis, Scotland has more universities ranked in the global top 200 than any other country apart from Luxembourg (Figure 2-1). A more detailed analysis of Scotland's HEI rankings in subject areas relevant to PM is provided later in this SIA report.

Figure 2-1: World top 200 HEIs per million population



Source: SQW analysis of Times Higher Education World University Rankings 2018, World Bank population statistics for 2016 and UK population estimates for 2016

[20] Higher Education Statistics Agency (HESA) data 2016/17 - https://www.hesa.ac.uk/data-and-analysis
[21] Research Excellence Framework 2014 - https://www.ref.ac.uk/2014/
[22] HESA 2016/17 data - https://www.hesa.ac.uk/data-and-analysis
[23] Times Higher Education World University Rankings 2018 - https://www.timeshighereducation.com/world-university-rankings/2018/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats

. . . that outperforms the UK in securing research funding and income. . .

2.5 Over the last five years (2013-18), Scotland has secured around £450m or 13% of all UK funding through the Biotechnology and Biological Sciences Research Council and Medical Research Council (those most relevant to the area of PM)[24]. Compared to the c.8% of the UK's population and c.11% of universities that Scotland accounts for, this shows that our institutions 'punch above their weight' in attracting research income.

2.6 In addition, four Scottish universities (Dundee, Edinburgh, Glasgow and St Andrews) are in the top 30 for attracting Wellcome Trust grants, having received £316m from this funder over the last 5 years[25].

2.7 Higher Education Business and Community Interation (HEBCI) data reveal that our universities earned a total of £150m of collaborative research income involving public funding, and a further £111m in contract research income in 2015/16 (12% and 9% of the respective UK totals)[26]. The University of Edinburgh generated the 7th largest amount of collaborative research income in the UK, whilst the University of Glasgow had the 10th highest contract research income figure.

2.8 Finally, HEBCI data reveal that in 2015/16, there were 179 active spin-offs with some level of Scottish university ownership. At the institutional level, five of Scotland's universities were in the UK top 20 for active spin-offs with some university ownership: Aberdeen, Edinburgh, Glasgow, St Andrews and Strathclyde. In terms of active graduate start-ups, Edinburgh Napier is the most successful Scottish university, and is in the UK top 20, with almost 200 graduate start-ups trading in 2015/16.

. . . plus NHS Scotland has unique research capabilities

2.9 There is also a strong commitment to high quality research within NHS Scotland and clinicians are encouraged to work closely with academics, industry and researchers from the health charities. The Scottish Government's Health and Social Care Strategy[27] focuses on increasing the level of high quality health research undertaken in Scotland, and recognises the 'importance of PM as a means of transforming the way the NHS diagnoses disease and provides care'. It also sets out a clear objective to reassess the balance of funds between longer-term commitments and new priorities and initiatives such as informatics.

2.10 NHS Research Scotland (NRS) is funded by the Scottish Government's CSO and invests around £40m per annum in Scotland's health boards to meet the costs associated with the NHS hosting and participating in clinical research. The funding supports six specialist research facilities providing dedicated clinical research space and expertise in conducting clinical trials. In addition, the NRS supports four R&D hubs of biorepositories and safe havens based in Scotland's four main cities. The biorepositories are used to store and manage tissue samples and the safe havens provide secure access to Scotland's health data and patient records. NRS infrastructure also maintains the SHARE database of individuals willing to take part in clinical studies.

2.11 The Scottish National Blood Transfusion Service (SNBTS) is part of NHS Scotland and undertakes a portfolio of research and development projects. It recently set up a Cellular Therapy Development Centre at the Centre for Regenerative Medicine (University of Edinburgh) which is supporting the development of a number of different cellular therapies.

[24] Gateway to Research/UKRI data - http://gtr.ukri.org/
[25] Wellcome Trust data - https://wellcome.ac.uk/funding/managing-grant/grant-funding-data-2016-2017
[26] HESA 2016/17 data - https://www.hesa.ac.uk/data-and-analysis
[27] Scottish Government/ Chief Scientist Office (2015), Delivering Innovation through Research: Scottish Government Health and Social Care Research Strategy

2.12 Scotland also has strengths in terms of the number of clinical academics, who are university employees that spend around half their time as practising doctors. The latest figures produced by the Medical Schools Council show that in 2017, Scotland had the second highest number of clinical academics in the UK with 380 posts (London had 960 posts).

We're an open and diverse economy with a highly skilled workforce. . .

2.13 Over the last five years, Scotland's economic output increased by 18% to £134bn in 2016. This represents around 8% of the GB economy[28]. Scotland performs very strongly in terms of inward investment and has consistently been the second most attractive part of the UK (after London) for FDI projects over the last 10 years[29]. In 2016, there were 122 FDI projects and over the last decade Scotland has attracted 771 projects. In 2016, there was £75.6bn in sales of goods and services outside Scotland, of which £29.8bn were international exports[30]. Although Scotland has increased the value of exports[31] and there has been a marginal increase in the number of exporters over the last five years, been increasing the number of exporting firms, we still have fewer exporters compared to other parts of the UK[32].

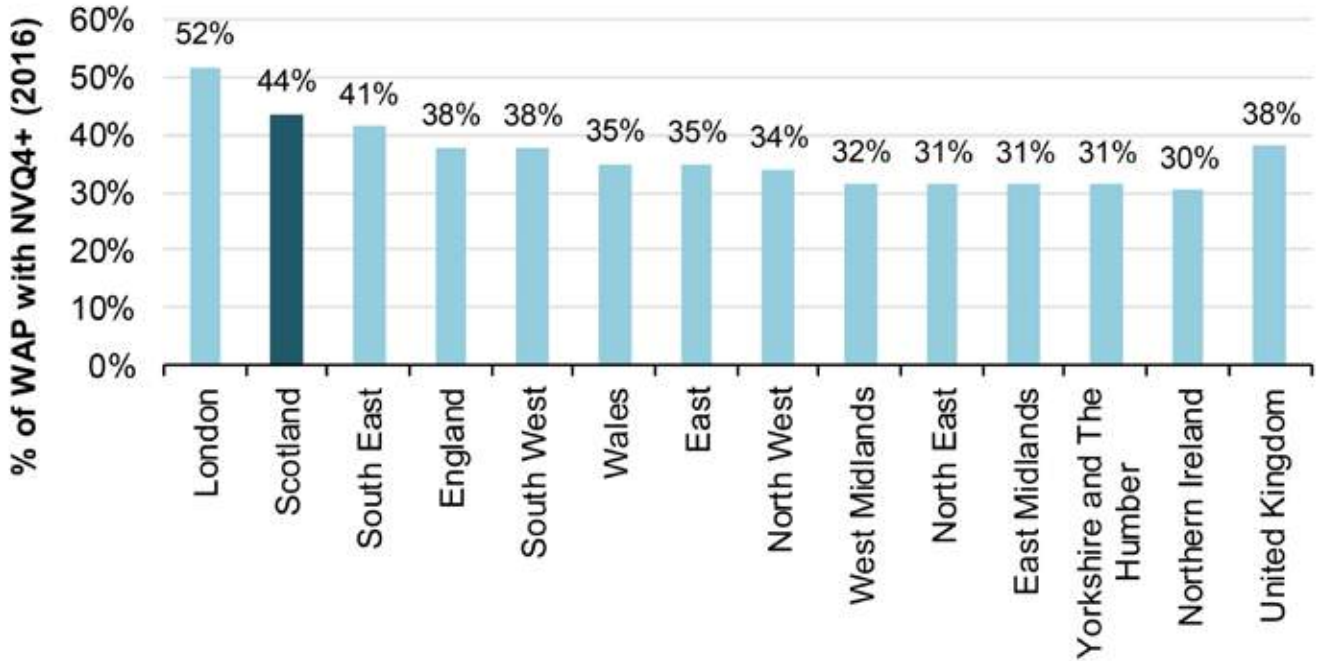
2.14 In terms of current (2016) GVA output, the largest sectors in Scotland are property (£16.7bn), manufacturing (£14.3bn) and wholesale and retail (£13.9bn)[33]. The highest levels of GVA growth since 2011 have been seen in tourism related industries (46% uplift), property (27%) and the ICT sectors. Scotland has a workforce of just under 2.5m, again eight per cent of the GB total[34]. The largest sectors are health (406,000 employees), wholesale and retail (357,000), and education (188,000). Compared to GB as a whole, Scotland has higher levels of employees in mining and utilities, agriculture and fishing, public admin, health, and construction.

2.15 Over recent years, improving productivity has been a key challenge in Scotland and the UK more generally. There are encouraging signs, with GVA per filled job increasing by 30% in Scotland over the last decade, compared to growth of 23% observed across the UK as a whole[35]. However, GVA output per filled job in Scotland (£52,000) is still slightly lower than the UK average of £53,000. The scaling up of our PM cluster will help create more highly skilled and well paid jobs in Scotland. The average GVA per job in Scotland's life sciences sector is estimated to be around £77,000, significantly higher than across the wider economy[36].

2.16 Around 77% of Scotland's working age population is economically active, which is broadly in line with the UK average. The South East of England has the highest rate at 81%. In terms of employment and unemployment, Scotland is also close to the UK averages, with 73% in work and 5% currently unemployed (and looking for work)[37]. One notable strength of Scotland's workforce is around skills with nearly half (44%) of the working age population qualified to NVQ level 4 or above (Figure 2-2). This is higher than the UK average of 38% and second to only London across the different parts of the UK[38].

[28] ONS Regional GVA Income Approach data - GB used here instead of the UK to align with workforce data from BRES which does not include Northern Ireland
[29] EY (2017), EY's Attractiveness Survey: Scotland
[30] Scottish Government (2018) Export Statistics Scotland - http://www.gov.scot/Topics/Statistics/Browse/Economy/Exports/ESSPublication
[31] According to Export Statistics Scotland, the value of international exports has increased from £27.1 bn in 2011 to £29.8 bn in 2016
[32] Based on Annual Business Survey from 2011 to 2016 - https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/datasets/annualbusinesssurveyimportersandexportersregionalbreakdown
[33] ONS Regional GVA Income Approach data
[34] ONS Business Register and Employment Survey (BRES)
[35] ONS Regional GVA Income Approach data
[36] Scottish Government – Growth Sector Database
[37] All 2016 based data from the Annual Population Survey
[38] ONS Annual Population Survey

Figure 2-2: Proportion of workforce qualified to NVQ4 or above



Source: SQW analysis of Annual Population Survey

2.17 There are wide variations in economic performance across Scotland, driven in large part by population density, the location of key industries, and wider socio-economic conditions. The largest council areas in terms of population, GVA output and employment are Edinburgh and Glasgow. GVA per job is highest in Aberdeenshire and Aberdeen City, driven in large part by oil and gas related GVA output. Edinburgh's performance is also strong due to the presence of a large financial and business services sector.

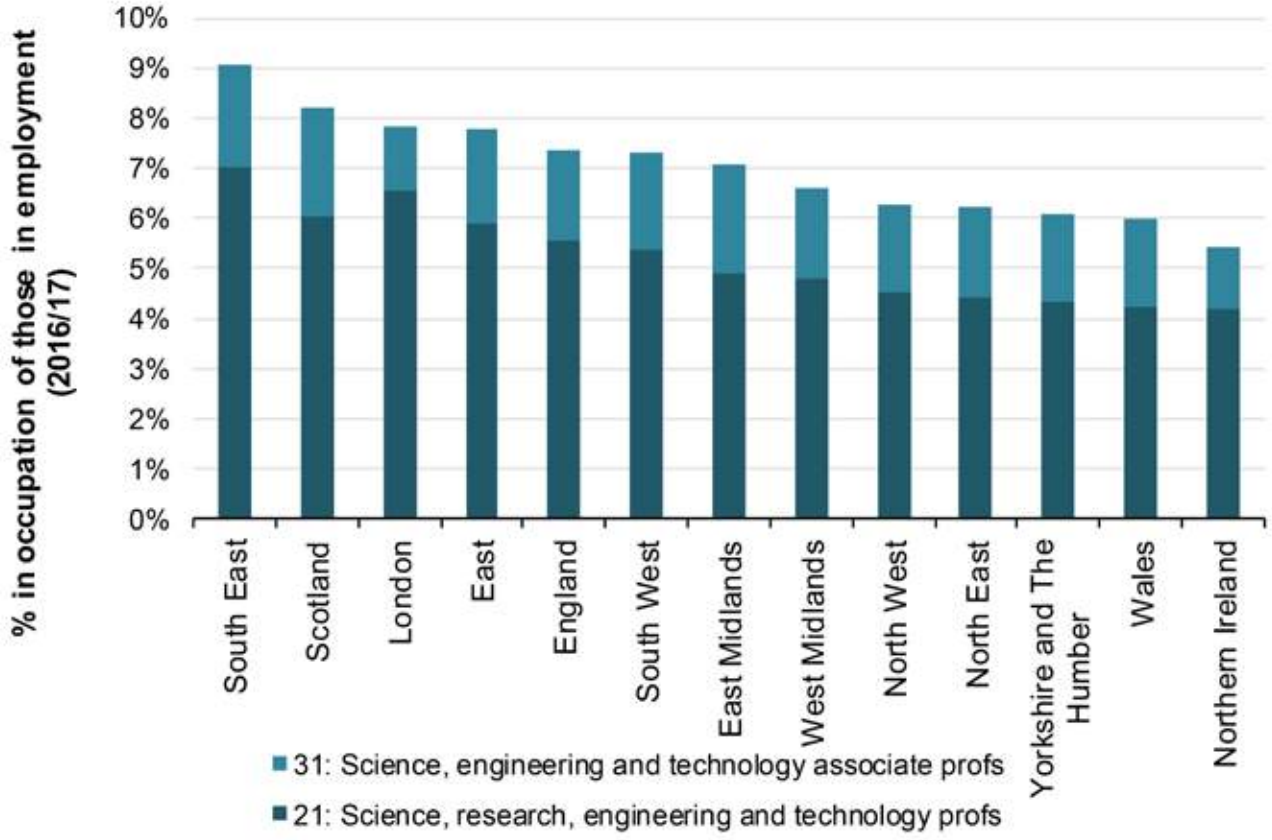
2.18 It is recognised that although Scotland produces world-class research, there has been more limited success in commercialising and leveraging this research excellence. Historically, there has been a lower business birth rate in Scotland compared to other parts of the UK. In 2016, there were 22,270 new firms created in Scotland, which represents 64 new firms per 10,000 working age population compared to a figure of 100 for the UK[39].

. . . which supports significant levels of science and technology employment

2.19 There were around 154,000 science and technology jobs in Scotland last year[40]. This represents eight per cent of all jobs in Scotland and is the second highest level of employment across all parts of the UK (Figure 2-3).

[39] ONS Business Demography data
[40] ONS Annual Population Survey

Figure 2-3: Science and technology professions in different parts of the UK



Source: SQW analysis of Annual Population Survey

Key growth sectors and business innovation

2.20 The Scottish Government has identified six 'growth sectors', which cover the country's key sectoral strengths. These are life sciences, food and drink, financial and business services, energy, sustainable tourism, and creative industries[41]. The GVA output of these six sectors account for a third of Scotland's total GVA of £134bn, but this calculation is based on quite narrow SIC-based definitions. As we will go to discuss in Section 4, the life sciences sector employs over 37,000 people across 700 organisations, and contributes nearly £2bn in annual GVA for the Scottish economy[42]. Scotland's universities and colleges play an important role in supplying the skills pipeline for these key sectors.

2.21 Scotland also has strong skills and expertise in emerging technologies and data science and these were the focus of two previous SIAs: Enabling and Emerging Technologies in Scotland's Central Belt; and Data Driven Innovation in Edinburgh and the South East Scotland City Region. The development of digital technologies, which were central to these SIAs, is also at the core of our PM proposition.

[41] http://www.gov.scot/Topics/Statistics/Browse/Business/Publications/GrowthSectors
[42] http://www.gov.scot/Topics/Statistics/Browse/Business/Publications/GrowthSectors/LifeSciencesSourcebook

2.22 The amount that businesses spend on R&D (BERD) is one of the main indicators of the level of innovation within an economy. Scotland has traditionally had lower levels of BERD than other parts of the UK, but there has been significant progress made over the last 10 years[43]. During this period, Scotland's BERD increased from £460m in 2006 to £1.07bn in 2016 (growth of 133% compared to a UK increase of 57%). Scotland's figure equates to just under £200 per head of population, which is some way down on the UK average of £340. The latest results from the UK Innovation Survey[44] also show a lower proportion of 'innovation active' enterprises in Scotland - 50% compared to 53% of UK enterprises.

2.23 Innovate UK (now part of UK Research and Innovation) provides various types of grants through the Catapults, Catalysts and Industrial Strategy Challenge Fund to support businesses and research organisations to drive innovation. Over the last five years, Scotland has secured just over 1,300 projects (around 8%) totalling £163m (5% of the total grant value)[45]. This is broadly in line with what would be expected, given Scotland's GVA is 8% of the UK total and it accounts for c.6% of the UK's business base. Scotland performs better in terms of Health and Life Science grants from Innovate UK. Over the past five years, we have secured 11% of all grants and 6% of the total value. For these grants, Scotland is ranked 4th across the UK, behind London, the South East and East of England.

Overview of Scotland's innovation ecosystem

2.24 Scotland has a well-established innovation support ecosystem including key actors such as NHS Research Scotland, individual NHS Health Boards, universities, the enterprise agencies (SE, HIE, SDI), Skills Development Scotland, Scottish Funding Council, further education colleges, Business Gateway, local councils, trade bodies and Chambers of Commerce. There is a range of business finance products available from providers including the Scottish Investment Bank (debt and equity finance), local authority loan funds, and a strong network of angel investors. In the last four years, there has been significant investment from UK and Scottish Government in Scotland's city region deals. The four deals approved so far[46] all include major investments in innovation centres and wider innovation infrastructure.

2.25 Scotland also has a network of eight Innovation Centres, which were set up to support collaboration between universities and businesses in emerging technology areas. Four of these centres have key roles to play in supporting our PM efforts: The Stratified Medicine Scotland Innovation Centre (SMS-IC); the Centre for Sensors and Imaging Systems; DataLab; and the Digital Health and Care Institute. Scotland is also well engaged with Innovate UK's Catapult network, particularly in terms of High Value Manufacturing, Offshore Renewable Energy and Satellite Applications. Glasgow is a recognised Innovate UK Centre of Excellence in PM.

[43] ONS Research and Development in UK Businesses, 2016
[44] Scottish Government (2016), UK Innovation Survey 2015 - Results for Scotland
[45] Innovate UK/ UKRI data
[46] Glasgow City Region, Inverness & Highland City Region, Aberdeen City Region, Edinburgh & SE Scotland City Region

Glasgow City Region – innovation ecosystem

The Glasgow City Region is the powerhouse of the Scottish economy, with a third of the country's population, jobs, businesses and GVA output. The region has a proud history of science, innovation and enterprise with strong private public partnership working through the Glasgow Economic Leadership, the Glasgow City of Science & Innovation partnership, and other industry bodies. Recent successes include hosting the 2014 Commonwealth Games and, in the same year, securing a £1bn Glasgow City Region Deal, at the time, the largest city deal in the UK. Glasgow was also named EU Entrepreneurial Region 2016 and was a finalist for the European iCapital Awards 2016. The City Region Deal includes a £1bn Infrastructure Fund as well as key investments in innovation assets: £16 million funding for the Imaging Centre of Excellence at the QEUH, £4m for new facilities for BioCity in North Lanarkshire, and £4m for the Tontine facility, a new Centre for Business Incubation and Development in Glasgow's Merchant City.

The city's key sectors are: education; engineering, design and manufacturing; health and life sciences; creative industries; low carbon and renewables; food and drink; tourism and events. Skills are at the heart of Glasgow and West of Scotland's growing economy, and higher education provides the skills for the city's key sectors. Glasgow has the largest academic community in the UK outside London and conducts world leading research in the fields of life sciences, engineering, science and technology. It has five higher education institutions, including four universities, and three further education colleges, and provides a pipeline of well-qualified graduates.

Examples of Glasgow's innovation assets include the Stratified Medicine Scotland Innovation Centre at QEUH, the first Fraunhofer research centre in the UK, the University of Strathclyde's Technology and Innovation Centre, and the International Technology and Renewable Energy Zone. Further innovation investment is planned across the city to develop three Innovation Districts, including the Glasgow University Innovation District, covering the City's West End and Waterfront. The project being led by the University of Glasgow, Glasgow City Council and Scottish Enterprise, will extend from the University's Clinical Innovation Zone at the QEUH to the University's new West End campus and include a new bridge to physically link these areas across the river Clyde. The Innovation District provides collaborative space for industry partners, start-ups and spin-outs to work alongside Glasgow's world-class academics. Overall £1bn is being invested in what is one of the biggest educational infrastructure projects in Scotland's history.

Glasgow is recognised as one of the world's leading conventions cities and business tourism is worth over £1bn to the city's economy. Medical and Life sciences sector conferences attracted a record number of delegates to the city in 2016/17 and it was the best performing sector in terms of the number of conferences confirmed for future years.

Focusing on the city region's life sciences sector, the Glasgow area is home to a range of life sciences companies including GlaxoSmithKline, Life Technologies, Vascutek and contract research organisations, such as BioOutsource and SB Drug Discovery. The city region has almost 50% of all of Scotland's medtech companies and 36% of all life science companies[47]. The Glasgow area includes more than 233 companies operating in the life sciences, employing upwards of 10,300 people. The aim is to grow the sector, building on the investments at the QEUH campus and BioCity Scotland and become a hub for the development and implementation of PM.

[47] Invest Glasgow - http://investglasgow.com/life-sciences/

3. Scotland's Ecosystem for Precision Medicine

Key messages

- Scotland's Ecosystem for PM is highlighted as an exemplar of collaboration in Dr Dzau's (President of The Institute of Medicine at National Academy of Sciences) global report on PM.
- Scotland has a very strong network of universities, research institutes, NHS facilities, enterprise and skills agencies and industry bodies all focused on developing, commercialising and implementing our world-class research in PM.
- NHS Scotland is a single entity, operating through a small number of large health boards. This provides many advantages for Scotland, including ease of access for industry, joined-up datasets, and a single commissioning body. NHS Scotland has been an integral partner of SMS-IC since its inception and is committed to PM.
- The main concentration of PM assets are in Edinburgh and Glasgow. Significant investment has been made in Scotland by the main health charities such as The Wellcome Trust, CRUK and British Heart Foundation.
- There a number of key strengths in Scotland's Ecosystem for PM, which differentiates its offer from other UK regions and countries:
  - > The quality of Scotland's e-health records and Community Health Index (CHI) number
  - > Our integrated healthcare model, which involves a single healthcare provider NHS Scotland
  - > The continuing prevalence of chronic disease in Scotland
  - > Significant support for PM provided by the Scottish Government and its agencies.
- These key strengths of Scotland's Ecosystem for PM are generally well understood by those organisations already involved in PM, but we need to promote these more effectively to adjoining sectors and potential inward investors.
- Although Scotland already has a strong Ecosystem for PM, there are some challenges that need to be addressed. These include: insufficient integration of Scotland's expertise in clinical medicine and data science; low levels of entrepreneurship in Scotland and a relatively limited number of start-ups targeting the PM opportunity; inconsistent messaging about the scale and nature of the business opportunity in PM in Scotland; insufficient promotion of Scotland's existing key PM assets and centres of excellence; and lack of clarity on the skill-sets required to develop the PM cluster in Scotland.

Introducing Scotland's Ecosystem for PM

3.1 The quality of the scientific research conducted in Scotland and the strong ecosystem supporting the development and mainstreaming of PM more broadly, is already widely recognised internationally. In a report for the World Innovation Summit for Health (WISH), Dr Victor Dzau (President of US National Academy of Medicine) highlighted Scotland as an exemplar in terms of cross sector collaboration and the important roles being played by SMS-IC, the SGP, Generation Scotland, and Glasgow Polyomics[48]. The creation of the Scottish Ecosystem for PM was announced by the First Minister, Nicola Sturgeon in 2016 backed by additional Scottish Government funding, including funding to establish the SGP. The strength of the PM ecosystem was also recognised by AstraZeneca, when SMS-IC was invited to join its Global Genomics Initiative. In addition, Professor Andrew Biankin, at the University of Glasgow, has led on the formation the International Cancer Genome Consortium (ICGC) Accelerating Research Genomic Oncology (ARGO) project, which is analysing biospecimens from at least 100,000 cancer patients worldwide with standardised methods and high quality clinical data.

3.2 In June 2018, the Glasgow City Region was announced as the location for the new Medicines Manufacturing Innovation Centre[49]. The £56m centre will be located in Renfrewshire and led by the Centre for Process Innovation (CPI), in partnership with the University of Strathclyde, the Medicines Manufacturing Industry Partnership (MMIP), and founding industry partners, AstraZeneca and GSK. The new centre will be positioned next to the £65m National Manufacturing Institute for Scotland (NMIS) at the heart of an Advanced Manufacturing Innovation District.

3.3 Scotland has a strong network of universities, research institutes, NHS facilities, enterprise and skills agencies and trade organisations all focused on developing, commercialising and implementing our world-class research in PM, making use of existing industrial strengths in life sciences and digital technologies. Figure 3-1 provides an overview of the Ecosystem for PM in Scotland, highlighting the different types of organisations and assets, all based around the key strengths of NHS Scotland and a supportive environment for implementing PM.

Enabling assets and facilities

3.4 In this section we demonstrate the quality of the infrastructure and physical assets, and then go on to highlight some of the unique factors and conditions which provide major advantages of implementing PM in Scotland. Detailed descriptions of Scotland's research expertise, business and skills base are provided in subsequent sections of the SIA.

3.5 The main assets and facilities in the Scottish ecosystem for PM are summarised in Table 3-1 below. An important point here is the geographic spread of assets across Scotland, but also noting the concentration around the Glasgow area and the new £1bn QEUH campus. The significant investment in Scotland made by the main health charities such as The Wellcome Trust, Cancer Research UK and the British Heart Foundation is also evident.

[48] Dzau et al (2016), Precision Medicine, A Global Action Plan for Impact -Report of the WISH Precision Medicine Forum 2016
[49] https://www.strath.ac.uk/whystrathclyde/news/strathclydeinmedicinesmanufacturinginnovationcentre/

Figure 3-1: Scotland's Ecosystem for PM

Table 3-1: Selection of key assets within the Scotland PM ecosystem

Asset	Summary
Queen Elizabeth University Hospital (QEUH) campus	The new £1bn hospital campus opened in 2015. The 14 floor building is the largest acute hospital in the UK and home to major specialist services such as renal medicine, transplantation and vascular surgery, with state-of-the-art critical care, theatre and diagnostic services. Co-location advantages of clinical, academic and commercial groups working alongside each other fostering innovation and commercialisation are evident
Imaging Centre of Excellence (ICE), QEUH campus	ICE is located at the QEUH campus and hosts an ultra high-field 7T MRI scanner, 3T MRI scanner and a 320 multi-slice CT scanners. These can be integrated into PM clinical trials utilising a common software platform and ICT resources. It also houses clinical academic and industry personnel dedicated to the development and deployment of next generation imaging
Stratified Medicine Scotland Innovation Centre (SMS-IC), QEUH campus	Set up by the Scottish Funding Council (SFC) in 2013, with investment of £20m and received a further £4m in 2016 to develop the Scottish Precision Medicine Ecosystem and the SGP (Edinburgh and Glasgow). The SMS-IC is made up of a consortium of partners from 4 Scottish NHS Health Boards, 4 Scottish Universities and 2 industrial partners involved in informatics (Aridhia Ltd) and genomics (ThermoFisher Scientific Ltd). The SMS-IC seeks to link Scotland's domain expertise, data assets and delivery capability to accelerate the adoption of PM for a global market
Clinical Innovation Zone (CIZ), QEUH campus	This UK Science Park accredited facility, includes SMS-IC and provides 22,000 square feet of high specification units designed to foster open innovation and access to world-leading clinical academics, outstanding clinical research facilities, state of the art facilities and industry partners co-located on site. The facility is attracting companies across a spectrum of PM, imaging and diagnostics who wish to collaborate with academic and NHS researchers. Companies already located include Aridhia, BioClavis, Canon Medical, Siemens Healthineers, MR Coil Tech, Causeway Therapeutics, and Spiritus
MRC / EPSRC Glasgow Molecular Pathology Node, QEUH campus	The UK's largest MRC / EPSRC-funded Node was established in November 2015 and is focussed on increasing the UK's capacity and capability to drive novel diagnostics to market through collaboration with UoG, NHS and industry and the provision of integrated support and postgraduate level training. The Node is based in the Laboratory Medicine Building at QEUH within the UK's largest Pathology Department with almost 50 consultant pathologists, providing comprehensive Histopathology and Cytopathology services, including Paediatric and Neuropathology and processes around 100,000 histopathology requests and 20,000 non-gynaecological cytopathology requests annually. The adjacent Molecular Diagnostics Laboratory offers a regional and Scottish national service, testing over 30,000 specimens annually and is accredited by Clinical Pathology Accreditation (CPA) UK and possesses hardware and software to deliver next generation sequencing

Asset	Summary
Glasgow Clinical Research Facilities	Established in 2006 and provides state-of-the-art research space across several geographical sites including Glasgow Royal Infirmary, and the new £5m Clinical Research Facility at QEUH campus, funded from The Wellcome Trust, Wolfson Foundation and UKRPIF. The latter is one of only two CRFs in the UK to combine paediatric facilities alongside adult and adolescent. This ensures clinical research is a cornerstone of person-centred healthcare development
Glasgow Clinical Trials Unit (GCTU) and Robertson Centre for Biostatistics	GCTU was established to support all aspects of clinical trial research from concept through to analysis & reporting. The GCTU can support both academic and commercial studies. The Unit is managed by the University of Glasgow and NHS Greater Glasgow & Clyde. The University of Glasgow's Robertson Centre for Biostatistics is part of the GCTU and has an international reputation for its work in clinical trials, epidemiology and health economics
CRUK Beatson Clinical Research Facility (BCRF) and Clinical Trials Unit, Glasgow	The Beatson West of Scotland Cancer Centre (BWoSCC) is one of 13 CRUK funded centres around the UK and is the largest participating site in the Scottish Cancer Research Network. The main areas of focus are Precision Oncology; Cancer Immunology; Invasion and Metastasis; Cancer Metabolism; Radiotherapy. The Clinical Trials Unit has responsibility for the development and coordination of academic-led cancer clinical trials. Key tasks involve the funding applications, development of clinical trial protocol, preparation of regulatory and ethical documentation, collection, processing and analysis of data, and preparation of trial reports
CRUK Beatson Institute	One of Cancer Research UK's core-funded institutes, the Institute carries out a programme of world-class science directed at understanding key aspects of cancer cell behaviour, with the aim of translating these discoveries into new therapies and diagnostic/prognostic tools to help cancer patients. The Institute benefits from close interactions with the University of Glasgow, including formal links with the University's Institute of Cancer Sciences
BHF Glasgow Centre of Excellence in Vascular Science & Medicine	One of six centres around the UK and opened in 2006. The aim is to consolidate internationally recognised cardiovascular research groups and to provide a multidisciplinary research environment. The Centre is part of the University of Glasgow's Institute of Cardiovascular & Medical Sciences and includes clinical research facilities, physiology and electrophysiology laboratories, molecular laboratories with facilities for human and experimental genetics, and genomics and proteomics facilities
Arthritis Research UK Rheumatoid Arthritis Pathogenesis Centre of Excellence (RACE)	Led by the University of Glasgow, RACE brings together expertise from the universities of Glasgow, Birmingham and Newcastle and is focused on understanding what causes rheumatoid arthritis to develop, why the inflammation persists and test new and existing drugs and to find new approaches that can predict which treatment works best in individuals

Asset	Summary
Glasgow Polyomics	A University of Glasgow facility, with funding from The Wellcome Trust, delivering laboratory omics analysis and bioinformatics support to academic, commercial and health sector clients. Glasgow Polyomics provides a unique combination of expertise in metabolomics and genomics. This enables analysis of the likelihood of developing a disease (genomics) as well as how a given patient will respond to a specific drug (metabolomics)
Health Economics & Health Technology Assessment (HEHTA) Group, University of Glasgow	A multi-disciplinary academic research group at the University of Glasgow that is dedicated to delivering research that has direct impact on clinical practice, population health and health policies, both nationally and internationally. Expertise include economic evaluation alongside trials, decision analytic modelling, evidence synthesis, medical statistics and qualitative evaluations
MRC/CSO Social and Public Health Sciences Unit	Based within the University of Glasgow, the Unit's aim is to promote human health by the study of social, behavioural, economic and environmental influences on health. Unit staff and students come from a range of social and public health science disciplines
MRC-University of Glasgow Centre for Virus Research	The centre was established in 2010 and represents the UK's largest grouping of human and veterinary virologists. A defining feature of the CVR is its breadth of expertise ranging from molecular virology to *in vivo* pathogenesis, virus-cell interactions, viral immunology, viral ecology, viral oncology, clinical and veterinary virology, viral diagnostics, virus epidemiology, mathematical modelling, virus genomics & bioinformatics
Glasgow Centre for Population Health	The GCPH is a partnership between NHS Greater Glasgow and Clyde, Glasgow City Council, and the University of Glasgow, funded by the Scottish Government. The current work programme focuses on: understanding Glasgow's health; urban health; poverty, disadvantage and the economy; and asset based approaches and resilience
MRC Doctoral Training Partnership in Precision Medicine	A partnership between Universities of Edinburgh and Glasgow, which provides doctoral level, multidisciplinary PM training for exceptional students
NHS Research Scotland	Scotland operates a centralised system to support clinical research and improve quality, efficiency and co-ordination. Working on a pan-Scotland basis, NHS Research Scotland provides a responsive infrastructure to encourage researchers to bring studies to Scotland. Investments in nationwide clinical research infrastructure also support researchers, clinicians and industry, providing state of the art facilities to conduct clinical trials
NHS Scotland Biorepositories	Scotland has a network of four regional biorepositories in Aberdeen, Dundee, Edinburgh and Glasgow providing streamlined access to tissue with a single point of contact, single application process and single approval process for access to tissue samples

Asset	Summary
NHS Scotland Safe Havens	Currently, Scotland has regional 'Safe Havens' located within Aberdeen, Dundee, Edinburgh and Glasgow, and a National 'Safe Haven'. Working to agreed principles and standards these Safe Havens provide access to health data and services to enable research while protecting the confidentiality of the data. Data remains under the control of the NHS and complies with legislative and NHS policies
Edinburgh Clinical Research Facility, Western General Hospital Edinburgh	The facility provides state of the art facilities to support multidisciplinary clinical research locally, nationally and internationally. A joint venture between University of Edinburgh and NHS Lothian, Edinburgh CRF was one of only five facilities in the UK to receive Wellcome Trust Millennium funding
Queen's Medical Research Institute, Little France, Edinburgh	A world class clinical research facility next to the Edinburgh Royal Infirmary, the Queen's Medical Research Institute has four strategic Centres, addressing major disease challenges. Research is broadly focussed on normal and diseased cells and inflammation and tissue repair. In QMRI the research emphasis is towards clinical-translational science, with two-way iteration from bench-to-bedside. Centres within Institutes 'hub' inter-disciplinary research and training, and investigators collaborate widely, fostering the beneficial sharing of knowledge, ideas, skills, scientific cultures and infrastructure
MRC/EPSRC Edinburgh/ St Andrews MRC Molecular Pathology Node, Western General Hospital Edinburgh	The Node integrates state-of-the-art genomic and epigenomic methods with image analysis of complex phenotypes and bioinformatics to develop molecular diagnostics for use in mainstream medicine. The main aims of the Node are to: establish and develop a Masters by Research Programme in Molecular Pathology; develop new diagnostic tests for implementation in clinical practice; ensure that protocols and assays developed are widely applicable and rapidly translated for medical use in a clinical setting
CRUK Edinburgh Centre/ Edinburgh Experimental Cancer Medicine Centre, Western General Hospital Edinburgh	The centre brings together cancer scientists and clinicians from across the University of Edinburgh, delivering outstanding cancer research and improved patient care. With full integration of the Edinburgh Experimental Cancer Medicine Centre and the Host and Tumour Profiling Unit, the scientific and technological expertise will result in new therapies being developed for patients faster. The main areas of focus are Lifestyle, Risk and Prevention; Stem Cells; Phenomics Drug Discovery; Stratified Therapies
MRC-University of Edinburgh Institute of Genetics and Molecular Medicine, Western General Hospital Edinburgh	Formed in 2007, the IGMM is a strategic partnership of the: MRC Human Genetics Unit; Cancer Research UK Edinburgh Centre; and Centre for Genomic and Experimental Medicine (CGEM). It constitutes one of the largest aggregates of human molecular genetics and biology research capacity in the UK
Scottish Genomes Partnership (SGP)	The SGP was established in 2015/16 from a £15m investment by the Universities of Edinburgh and Glasgow and a joint £6m investment by the Scottish Government/CSO and the MRC. SGP has enabled the sequencing of over ten thousand whole genomes for a range of health related and scientific projects.

Asset	Summary
Usher Institute of Population Health Sciences and Informatics/ Edinburgh Clinical Trials Unit	The Institute is an interdisciplinary environment dedicated to improving the health of individuals and populations locally and globally through research, innovation, knowledge exchange and education. The Edinburgh Clinical Trials Unit is based within the Institute and provides an infrastructure to design, plan and deliver clinical research studies across a varied portfolio of clinical specialties and methodologies
BHF Edinburgh Centre of Research Excellence	The Centre attracts the very best researchers who complement existing strengths and provide novel approaches to working. Critical core facilities, including bioinformatics and imaging facilities are run by technical experts and are shared between research divisions that focus on a range of diseases. The Centre is based in the University of Edinburgh's Centre for Cardiovascular Science
Edinburgh Genomics	Edinburgh Genomics was formed in 2013 following the merging of The Genepool and ARK Genomics. It is a world leading genomics and bioinformatics facility delivering high volume data and cutting-edge analyses to a large community of collaborators and customers across academia, government, and industry. The Edinburgh Genomics teams have been delivering genomics data and analysis to researchers for nearly 20 years, and next-generation sequencing data since 2008, and is one of the leading genomics facilities in Europe
Farr Institute of Health Informatics Research	The Farr Institute Scotland is a collaboration between six Scottish Universities (Aberdeen, Dundee, Edinburgh, Glasgow, St Andrews and Strathclyde) and NHS National Services Scotland. The aim is to both improve the health of the Scottish population and place Scotland as a global leader in health informatics research. The Institute is committed to delivering high-quality, cutting-edge research using 'big data' to advance the health and care of patients and the public. By utilising electronic health records, researchers at The Farr Institute are looking at new ways of reducing the time and cost of clinical trials which can often contribute to the costs of new drugs and technologies. The Farr Institute is now part of Health Data Research UK. The UK's new health and biomedical data science research institute, awarded £30 million funding to six areas across the UK to address challenging healthcare issues through use of data science. The Scottish site will be run by a partnership of six Scottish Universities (Aberdeen, Dundee, Edinburgh, Glasgow, St Andrews and Strathclyde)
Tayside Clinical Research Centre (CRC)	A state of the art clinical research facility, providing space, equipment and staff to support our researchers and industry partners in delivering high quality clinical research in Tayside. It is a hub for clinical trial activity, with links to satellite units elsewhere in Tayside, Fife and Perth. Conducting studies focusing on cancer, cardiovascular disease, diabetes and neuroscience - aiming for prevention, earlier diagnosis and improved treatments for these diseases. CRC positions Dundee centrally in the Scottish clinical and research network for these conditions, including the SINAPSE network for neurosciences

Asset	Summary
Tayside Clinical Trials Unit	The Unit was established in October 2008 as a collaboration of the University of Dundee and NHS Tayside to deliver excellence in the design, conduct and governance of clinical trials. It provides support to academic and NHS staff undertaking clinical trials of investigational medicinal products (CTIMPs) and non-CTIMP randomised controlled trials
Tayside Centre for Genomic Analysis	The primary aim of the Centre is to provide genomic analysis services to the University of Dundee encompassing both academic and clinical research themes. The service is also available to external research and clinical groups, capacity permitting
Dundee Drug Discovery Unit	The Unit was set up in 2006 to translate world-class biology research in to new de-risked targets and candidate drugs. The initial focus was on Diseases of the Developing World, in which the University has an outstanding international reputation. It can accept high quality, commercially viable projects in any therapeutic area as long as the approach is novel, the project addresses unmet medical need and the pathway to the clinic is clear. It is also developing an Antibacterial Drug Discovery Accelerator, working in collaboration with senior investigators across the UK and beyond, to create a step-change in the discovery of new antimicrobial drugs
Aberdeen Institute of Medical Sciences and Clinical Research Facility	Both facilities are located at Aberdeen's Foresterhill medical campus, which includes Aberdeen Royal Infirmary. The Institute of Medical Sciences is a unique, cross-school institution that supports and coordinates research between the School of Medical Sciences and the School of Medicine and Dentistry. There are a range of facilities focusing on areas such as imaging, genomics and proteomics. The University of Aberdeen's Clinical Research Facility is housed within the recently built Health Sciences Building and has a range of imaging equipment
Generation Scotland	Generation Scotland is a resource of human biological samples and data which are available for medical research. It aims to create more effective treatments based on gene knowledge for the medical, social and economic benefit of Scotland and its people. The initiative is a unique partnership with the Scottish University Medical Schools, the NHS in Scotland and the people of Scotland
SHARE database	SHARE is a new NHS Research Scotland initiative created to establish a register of people interested in participating in health research and who agree to allow SHARE to use the coded data in NHS computer records to check whether they might be suitable for health research studies. This access can be incredibly useful when it comes to developing new treatments and cures for a wide variety of health conditions
OPTIMA: The EPSRC and MRC Centre for Doctoral Training in Optical Medical Imaging	OPTIMA is hosted by the University of Edinburgh and the University of Strathclyde. OPTIMA is a 4 year PhD training programme combining: research and PhD supervision in world-leading scientific environments; and a bespoke programme of business training in healthcare innovation and entrepreneurship.

Source: SQW review of organisation websites

Imaging Centre of Excellence

The Imaging Centre of Excellence (ICE) at the Queen Elizabeth University Hospital (QEUH) opened in 2017. It symbolises the vision and ambition of the University of Glasgow in using the new hospital campus to create the triple helix model, bringing together academia, NHS and industry. The facility includes Scotland's first 7 Tesla (7T) MRI scanner, an ultra-high resolution scanner (one of only 75 worldwide, and one of the first clinical 7T scanners in the world), a 3 Tesla MRI scanner and 320 slice CT scanner, and integrating dedicated space for industry, as part of a 22,000sq ft Clinical Innovation Zone. The total investment for the ICE facility was £32m with a range of funders including the Glasgow City Region City Deal, Medical Research Council and UK Research Partnership Investment Fund (UKRPIF). Evaluated as part of the City Region Deal, ICE is expected to generate up to 400 high value new jobs over a seven year period, along with nearly £85m for the local economy.

As well as investing in world-class facilities and imaging equipment, the University has also brought in a clinical MRI team to supplement the University's existing neuroscience expertise. The team at ICE now brings together physicists, radiologists, engineers, a range of clinical researchers, and experience of working in industry, notably Siemens Healthineers, who manufactured the new scanner and have scientists based in ICE. International experts and companies have been attracted to locate in Scotland to work at ICE for the opportunity to work with a 7T MRI scanner in a clinical setting alongside industry, something that is currently happening at only a small number of sites in the world.

The new 7T scanner has been fully operational for almost a year. There has been developmental work with healthy subjects to ensure all the necessary approvals are in place and clinical research studies in stroke are due to start in the coming weeks. The scanner is already being used for functional imaging in neuroscience research projects. The team at ICE is also collaborating with other universities in Scotland through the SINAPSE (Scottish Imaging Network: A Platform for Scientific Excellence) consortium to provide access to the 7T scanner for other research groups. One such project involves a collaboration with the University of Edinburgh, in which MR spectroscopy will be used to study brain tumours. There are massive opportunities to use the new equipment for a range of clinical research and funding applications are currently being developed. In time, the 7T scanner will also be used as a diagnostic instrument and a key tool in PM.

The creation of ICE at QEUH has generated significant global profile for Glasgow as a hub for academic, NHS and industrial collaboration. Key industry players already include Siemens and Canon Medical Research and there are plans to attract further expertise in AI and machine learning. This is actively being progressed through the SINAPSE consortium of Scottish universities. The facilities are acting as a catalyst for new clinical research, attracting research expertise from across Europe and helping to stimulate new commercial opportunities in the area of imaging and PM.

Key strengths in Scotland's Ecosystem for PM

3.6 The **quality of Scotland's electronic health records is a major strength and differentiator**. These records are among the world's best and include a Community Health Index (CHI) unique identifier, which was introduced over 30 years ago and uniquely identifies a person on the index. Data on Scotland's entire population is captured routinely at all points of contact with the health service including: maternity records; acute hospital admissions; psychiatric hospital admissions; drug prescriptions; and attendance at primary care etc. This means patient demographics and clinical information can be accessed and used in clinical research and trials.

3.7 **Scotland has the ability to bring together real patient data, historic data and patient samples, as well as unique patient databases such as SHARE and Generation Scotland**. The increasing interest from global pharma firms and their willingness to participate in collaborative research on this and other Data Commons[50] highlights the potential of Scotland's data assets in progressing PM across different disease areas. The quality of this patient data is a key differentiator for Scotland and has been identified as being an asset of international significance by several big pharma companies during this SIA process.

3.8 **Scotland has a strong track record in encouraging public engagement in health initiatives designed to maximise the use of sensitive data**. Whilst other parts of the UK have come up against challenges in the integration and consented use of data (e.g. delays in implementing the 100,000 Genomes Project), Scotland has progressed a number of important innovations, which demonstrate a willingness within the population to support and engage with far-reaching initiatives.

3.9 The **Scottish Health Research Register (SHARE)** – uses individuals' electronic health record and surplus stored blood samples to rapidly identify cohorts for health research projects. SHARE relies on volunteers registering to have their data and tissue included in the searches and has so far recruited over 200,000 NHS registered individuals. SHARE is funded by NHS Research Scotland (NRS) and is implemented with support from all Health Boards and Scottish Universities.

3.10 Another strength is our integrated healthcare model, which effectively involves a **single healthcare provider NHS Scotland**. NHS Scotland is made up of 14 regional health boards and patient records and regulation is consistent across Scotland. This enables more efficient data sharing and analysis, and is supported by facilities such as the biorepositories and safe havens in Scotland that enable data access for research while maintaining data protection. The opportunity to implement PM not just in one health board area but across the country as a whole will provide a critical mass of activity. Unlike other countries, we have very limited private healthcare and this provides Scotland with the advantage of being able to access Scotland-wide data and drive PM adoption across an entire country.

3.11 The **continuing prevalence of chronic disease and multiple morbidities in Scotland**, and in the Glasgow city region in particular, is another important factor. These diseases include heart disease, stroke, cancer, diabetes and multiple sclerosis. The relatively large numbers of local patients provides sufficient numbers for clinical studies and trials of new treatments. In addition, Scotland has a very stable population, which also helps with longitudinal health monitoring. Table 3-2 shows how Scotland has a higher rate of new cases of cancer and also higher numbers of patients registered for coronary heart disease. The statistics also show that the NHS Greater Glasgow Health Clyde area has higher prevalence of these chronic diseases than other parts of Scotland[51].

[50] Data commons co-locate data, storage and computing infrastructure, and commonly used tools for analysing and sharing data to create a resource for patients, charities, clinicians and the research community. They integrate data from diverse sources such as genetic and sequence information from patient biopsy samples, imaging, histological data and clinical data from electronic patient records

[51] See for example: Glasgow Centre for Population Health (2015), History, politics and vulnerability: explaining excess mortality in Scotland and Glasgow - http://www.scotpho.org.uk/comparative-health/excess-mortality-in-scotland-and-glasgow/

Table 3-2: Prevalence of selected chronic diseases

	Cancer cases per 100k population (2015)	Coronary Heart Disease Register per 10k population (Latest year)	Stroke or Transient Ischaemic Attacks (TIA) Register per 10k population (Latest year)
Scotland	617	410	220
England	596	315	175
Wales	609	370	207
Northern Ireland	588	378	187
UK	598	327	180

Source: SQW analysis of CRUK data (2015) and British Heart Foundation data (2015/16 for Scotland; 2016/17 for other UK)

3.12 Over the last few years there has been **significant support for PM provided by the Scottish Government** and its agencies. There have been major Scottish Government investments in SMS-IC (through the Scottish Funding Council and the CSO) and the facilities at the QEUH campus, including the new 7T MRI scanner at the ICE building (through the Glasgow City Region Deal). The Scottish Government has also provided funding for the Scottish Genome Partnership and the Scottish Ecosystem for PM, which has enabled increased activity through the SMS-IC.

3.13 There has been strong policy support from the Scottish Government through its Economic Strategy, Health and Social Care Strategy and most recently in the 2017/18 Programme for Government. In the new Digital Health and Care Strategy, the Scottish Government outlines its plans for a Scottish health and care 'national digital platform' to improve the provision of real-time data and information from health and care records.

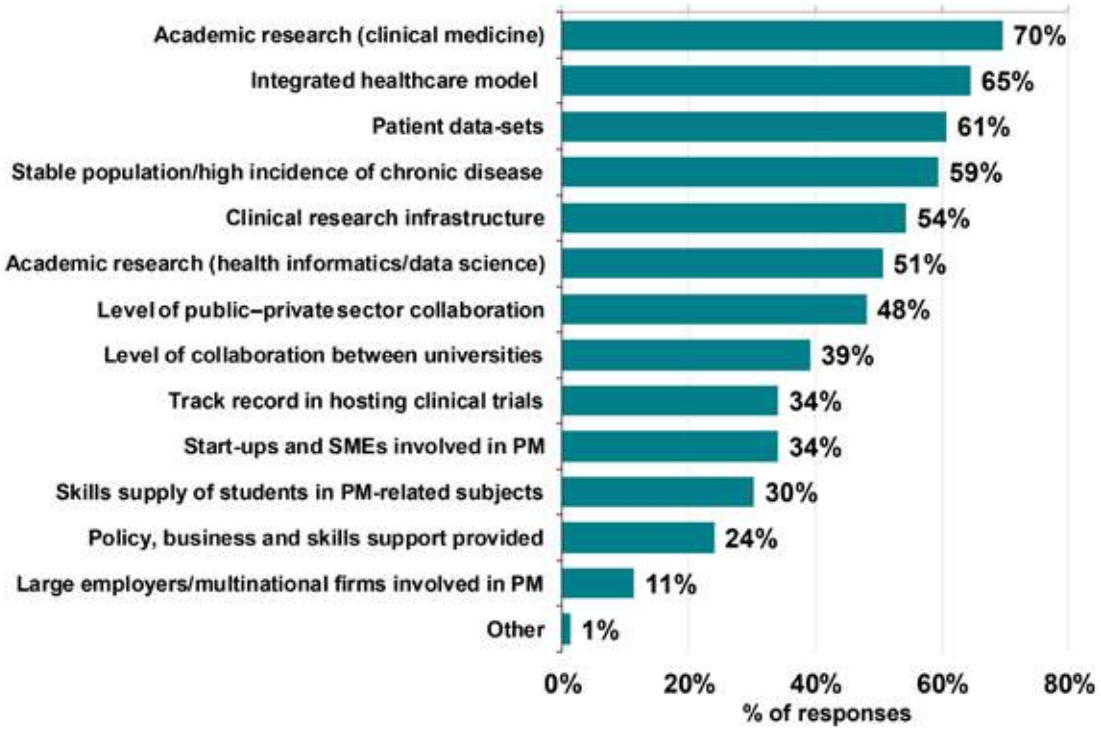
"The development of the precision medicine sector is vitally important to Scotland's future health. It will revolutionise health care, allowing specific treatments to be tailored to the individual characteristics of each patient. Scotland has outstanding strengths in this area and we will continue to build on these to assist the commercialisation of world-class research in precision medicine and genomics sequencing."[52]

3.14 As already mentioned, the Scottish Funding Council has been supporting PM-related R&D activity through its network of innovation centres including SMS-IC. Scottish Enterprise also provides a range of innovation, export and financial support to life sciences firms many of which are involved or interested in PM. In addition, Skills Development Scotland is providing skills support through the delivery of a Life Sciences Skills Investment Plan[53]. 'Personalised medicine' (another term for PM) is highlighted as one of the key market drivers for the wider life sciences sector.

3.15 The strengths described above are all reflected in feedback from our e-survey of organisations involved or interested in PM in Scotland. When asked about the key strengths that differentiate Scotland from other areas (Figure 3-2), the main areas highlighted were the quality of academic research (selected by 70% of respondees), the integrated healthcare model (65%), patient data-sets (61%), and the availability of a stable population and high incidence of chronic disease (59%).

[52] Scottish Government (2017), Nation with Ambition. A Programme for Government 2017-18
[53] Skills Development Scotland (2018), Skills Investment Plan for Scotland's life and chemical sciences

Figure 3-2: Which of the following elements of Scotland's PM Ecosystem are the key strengths that differentiate Scotland from other leading life science clusters? (Multiple choice)



Source: SQW analysis of PM SIA survey (n=79)

Gap analysis and understanding the PM opportunity in Scotland

3.16 Scotland is a major global centre of excellence for PM with a strong, collaborative network of public, academic, private and third sector organisations working together to develop and implement PM solutions. The development of this SIA has involved extensive consultation with 45 public and private sector organisations from across Scotland. These in-depth discussions have been used to clarify the existing PM related strengths of Scotland and helped partners to identify where more can be done. The main gaps and solutions are as follows:

- **Limited integration of - and exploitation of potential synergies across - Scotland's expertise in clinical medicine and data science**, both in terms of research projects and commercial activities. This is a major missed opportunity for the UK

  > **Develop a more strategic partnership between clinical medicine and data science capabilities, including machine learning and artificial intelligence(AI) and the opportunities enabled by new 5G data networks** – much has already been happening, facilitated through the work of the innovation centres such as SMS-IC and Datalab, and other joint research projects. However, PM offers a major opportunity for closer collaboration between the Universities of Glasgow and Edinburgh, along with NHS Scotland, industry and the major health research charities

- **Low levels of entrepreneurship in Scotland, compared to other parts of the UK, and a relatively limited number of start-ups to date targeting the PM opportunity**

  > Embed a more pervasive culture of enterprise and attract more VC Funds to support the commercialisation effort – we need to promote the PM opportunities for new tech start-ups, celebrate the successes that we have in Scotland, and ensure that growth finance is available (on attractive terms) for investable propositions

- **Inconsistent messaging across Scotland about the scale and nature of the business growth opportunities linked to PM** for start-ups, existing SMEs, and potential inward investors. This has resulted in a lack of clarity and general awareness amongst the business and investor communities

  > Create PM champions within NHS Scotland, academia and the Scottish Government, to work together and with the enterprise agencies and industry to drive demand investment and raise the profile and awareness of PM related opportunities. The size of Scotland and our single integrated healthcare provider are key strengths which differentiate us from other countries and regions. A clearer demand statement from NHS Scotland and the Scottish Government would accelerate the development, adoption and mainstreaming of PM in Scotland

  > Complementing the previous action area, **better PM promotion to the SME base and potential inward investors** – the partners involved in developing this SIA are committed to working with different sectors and investors to articulate the scale and nature of Scotland's offer and the exciting market opportunities associated with PM

- **Insufficient promotion of Scotland's existing key PM assets and centres of excellence** – there needs to be greater clarity on the PM offer and the major investments in new facilities over recent years. A more coherent, powerful and compelling narrative is needed around the PM ecosystem in Scotland and its key differentiators

  > **Encourage stronger collaboration between key PM assets and centres of excellence** (e.g. the Clinical Innovation Zone at QEUH, BioCity and the Edinburgh BioQuarter etc.), with support from Scottish Enterprise, ensuring a fully integrated offer combining both hard and soft enabling infrastructures. We need to make sure that there is a joined up approach to promoting the country's key assets, and maximising the complementary expertise that exists in different areas

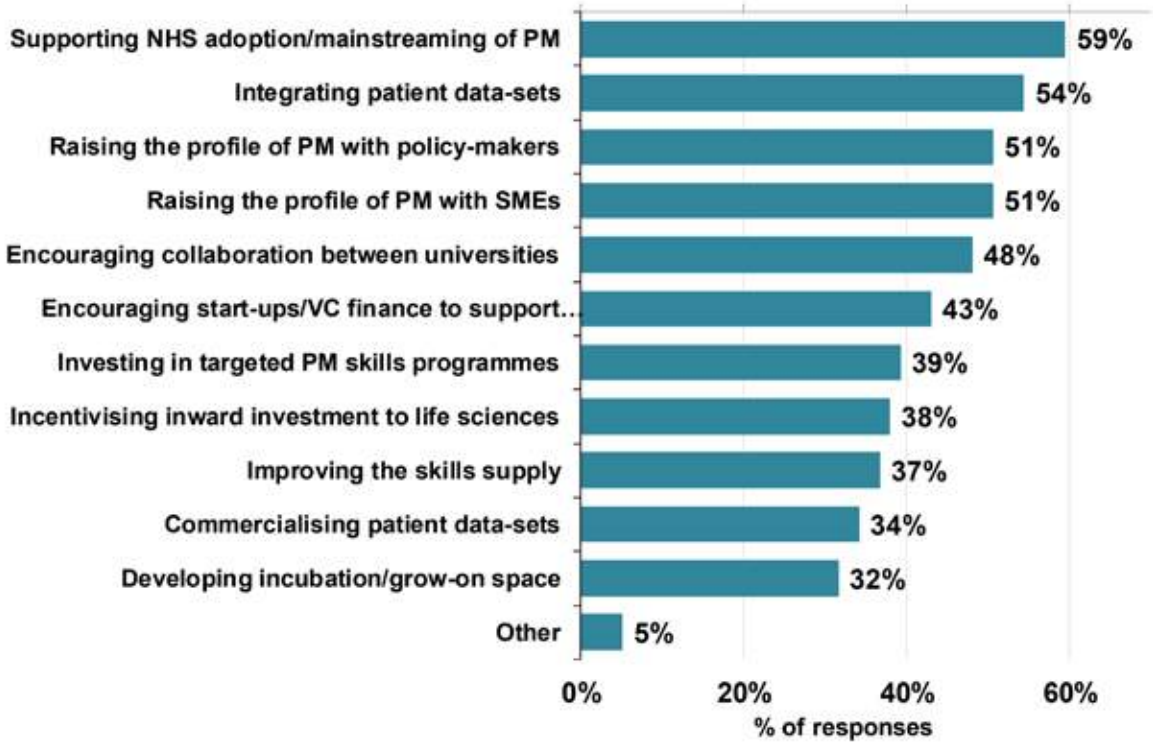
- **Lack of clarity on the skill-sets required to grow and develop the PM cluster in Scotland**

  > **Invest more in targeted PM and bioinformatics and AI for Health skills development programmes** – the integration of different skill-sets will be key to developing and maximising Scotland's PM opportunity. New training programmes are being developed across the country, but we need to do more e.g. ensuring that PM is on the Medical School curriculum. The recent Skills Investment Plan for the life sciences sector identified ongoing skills shortages in the areas of engineering, digital, regulatory and quality control, advanced manufacturing, and entrepreneurial skills[54]

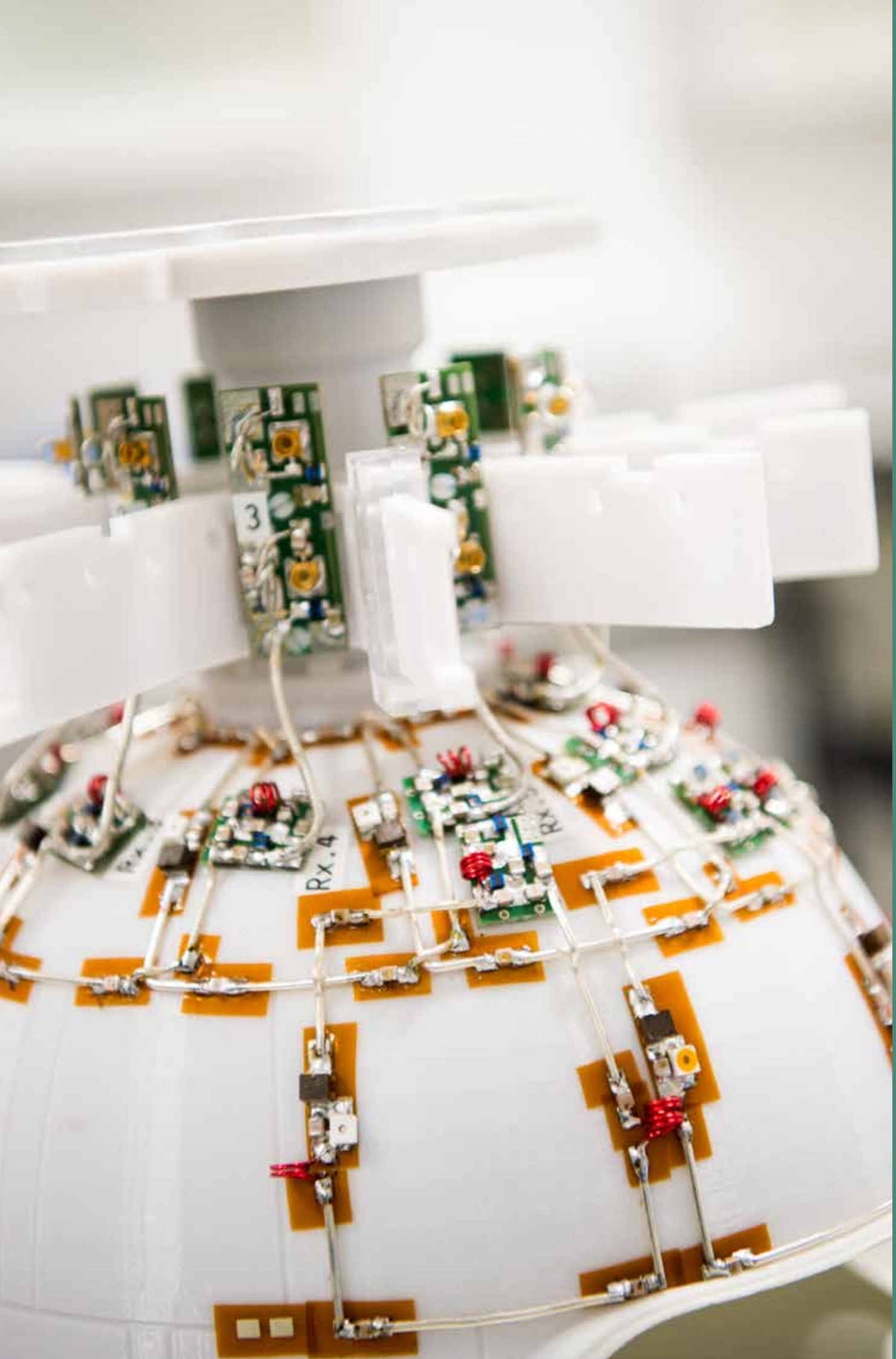
[54] Skills Development Scotland (2018), Skills Investment Plan for Scotland's life and chemical sciences

3.17 The key areas for improvement were also highlighted in the e-survey results (Figure 3-3). The main areas for action were supporting NHS adoption of PM (highlighted by 59%), integrating patient data-sets (54%), raising the profile of PM with policy-makers (51%), and raising the profile with SMEs (51%).

Figure 3-3: As we seek to grow and develop the Precision Medicine Ecosystem in Scotland, what do you think are the main priority areas for improvement? (Multiple choice – tick all that apply)



Source: SQW analysis of PM SIA survey (n=79)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RX.4

4. Scotland's life sciences business base

Key messages

- Scotland's life sciences cluster is one of the largest in Europe. It employs over 37k people across 700 organisations, and contributes around £2bn in annual GVA. We have particular strengths in medtech (250 businesses and 9k employees) and pharma services (150 businesses and another 9k jobs). Key employers include Capsugel, GSK, Johnson Matthey, Piramal Healthcare, Quotient and Thermo Fisher Scientific.
- Scotland has a growing number of businesses involved in PM. Although most of these companies are existing life science firms, there are new start-ups and in-movers involved in developing digital platforms for health data, informatics, AI and machine learning.
- The main companies that have been involved with the SMS-IC include Canon Medical Systems, Aridhia, Fios Genomics, Pharmatics, Sistemic, Destina Genomics, Biopta (ReproCELL), BioClavis, Thermo Fisher Scientific and Arrayjet. Thermo Fisher and Aridhia are founding partners of SMS-IC and have contributed more than £7m in cash and in-kind resources over the last four years. There are around 230 companies already actively involved in PM across Scotland.
- Although Scotland has an emerging PM business base, there needs be much greater clarity on the nature and scale of the PM business opportunity.
- There is an opportunity to accelerate productivity growth in Scotland by building a globally significant PM cluster. To do this, we must leverage the expertise that Scotland (and Edinburgh in particular) has in digital and informatics-based technologies.
- Scotland is recognised as one of the best locations for clinical trials of new treatments and therapies. On a per capita basis, Scotland delivers more trials than Canada, France, the US, Spain, UK, Germany, Japan and China.
- There is a strong supply of skills in subject areas relevant to PM. Last year (2016/17), there were 8k students enrolled in medicine and dentistry subjects, around 30k students doing subjects aligned to medicine, and a further 21k studying biological sciences.

Life sciences in Scotland

4.1 Scotland's life sciences cluster is one of the largest in Europe[55]. Based on analysis by the Scottish Government and Scottish Enterprise, the sector employs over 37,000 people across 700 organisations, and contributes nearly £2bn in annual GVA for the Scottish economy[56,57]. There has been significant growth in the sector with GVA increasing 45% between 2010 and 2015, and employment growing by 16%. Major capital investments have been made, which are likely to deliver further growth over the coming years. For instance, over the last three years, there has been major investments totalling £300m by leading global firms including Capsugel, GSK, Johnson Matthey, Piramal Healthcare, Quotient and ThermoFisher Scientific.

4.2 There is also a strong culture of innovation and collaboration across the sector, which is evidenced through the Life Sciences Industry Leadership Group taking ownership for the sector strategy and Skills Investment Plan. The evidence also points towards significant networking and mentoring activity across the sector.

4.3 Scotland is home to a mix of multinationals, SMEs and start-ups in the life sciences sector. According to BioCity[58], between 2012 and 2016 there were around 40 new life science start-ups in Scotland. This figure was higher than many regions in England and behind only the East of England, South East and London. Scotland has consistently been in the top three or four UK regions for the volume of start-ups over the last decade.

4.4 Financial support for life science start-ups is provided by the Scottish Investment Bank (SIB). In 2015/16, the SIB invested £7.8m into 33 life science companies and in 2016/17, there was a further investment of £11.7m in 31 companies. In addition, a £50m venture capital fund was launched by Epidarex Capital in 2014, which has so far invested in six Scottish start-ups (and 10 in the UK as a whole)[59].

4.5 The largest sub-sector in Scotland's life science cluster is Medical Technologies, with more than 250 businesses and 9,000 employees. Pharmaceutical Services is another key strength with 150 businesses and another 9,000 jobs. A high-level summary of the main sub-sectors is provided in Table 4-1 below.

[55] Life Sciences in Scotland (2017), Life Sciences Strategy for Scotland 2025 Vision - Accelerating Growth, Driving Innovation

[56] Data on the size of the Scottish life sciences sector are used in the Life Sciences Strategy for Scotland (above) but sourced from Scottish Government - http://www.gov.scot/Topics/Statistics/Browse/Business/Publications/GrowthSectors/LifeSciencesSourcebook

[57] The Office for Life Sciences also produces data on the life sciences sector across the UK. The latest data in the 'Strength and Opportunity 2017' report estimates there are just over 15,000 jobs in Scotland in the biopharma and medtech sub-sectors. The SIA consortium agreed that the wider Scottish Government definition of the life sciences cluster was more appropriate to use for the purposes of this Audit

[58] BioCity (2017), UK Life Science Start Up Report 2017 – https://biocity.co.uk/reports - over the last decade BioCity has worked with Young Company Finance to produce research on the life sciences sector informed by their extensive experience of supporting start-ups across the UK

[59] Data provided by Epidarex Capital

Table 4-1: Life sciences in Scotland – key subsectors

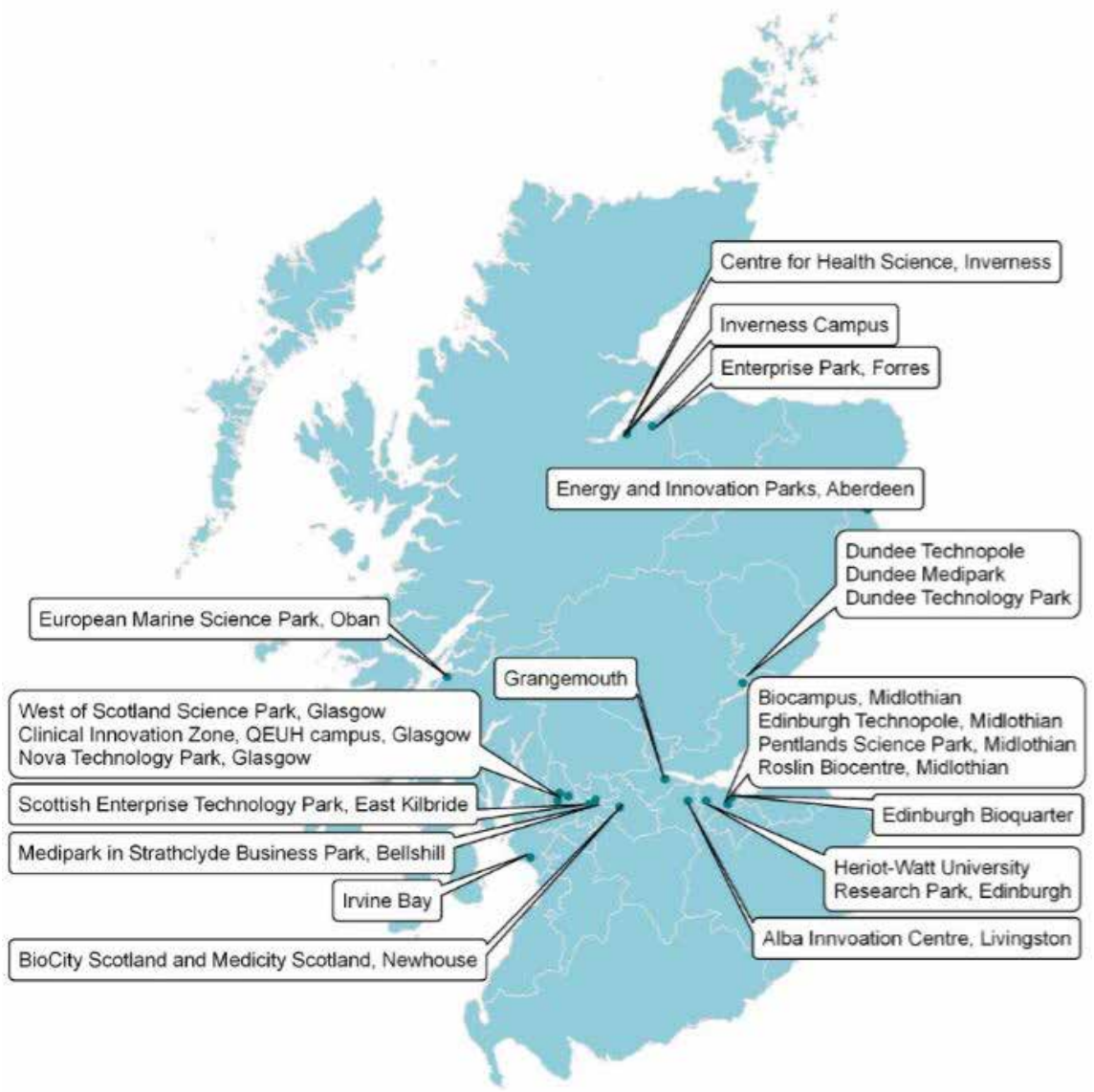
Key Subsector	Summary of key strengths and assets
Medical technologies	• More than 250 companies employing over 9,000 people • 150 supply chain companies involved in clean rooms, engineering and lab services to medical supplies, packaging and waste treatment • Easy access to clinical skills and excellence – including the NHS, Scotland's single healthcare provider and the world's biggest healthcare delivery organisation • World-renowned research – strengths in imaging, ophthalmics, orthopaedics, cardiovascular instrumentation and implants • Scotland's medtech companies such as Touch Bionics, Optos and Aircraft Medical becoming leaders in their fields boosting Scotland's international profile • State of the art Imaging technologies - 7T MRI Scanner, at the University of Glasgow's Imaging Centre of Excellence at Queen Elizabeth University Hospital in Glasgow • Key support centres are: Strathclyde Institute of Medical Devices; Institute for Medical Science and Technology (GE's first European centre of Excellence for Pre-Clinical Image-Guided Interventions and Surgery); Cuschieri Skills Centre at the University of Dundee; Biomedical Textiles Research Centre at Heriot Watt University; and Robert Gordon University • Three Innovation Centres also providing support: Digital Health & Care institute (DHI); Stratified Medicine Scotland Innovation Centre (SMS-IC); and Innovation Centre for Sensor and Imaging Systems (CENSIS)
Pharmaceutical services	• Over 150 pharma services and supply companies employing over 9,000 people • Major pharma-manufacturers such as AMRI, BASF, Lonza, GSK,SAFC • Cluster of therapeutics firms including Novabiotics, TC Biopharm, MGB Biopharm and Mironid • Comprehensive and expert preclinical research coverage with global leaders such as Charles River Laboratories, BioReliance and Eurofins • World-class facilities for clinical/pre-clinical research and drug manufacture, and clinical trials expertise • Scotland is a preferred international site for clinical trials for two of the world's top CROs, Quintiles and PPD • Collaborative working between academia, the Scottish Government and the National Health Service through NHS Research Scotland • University excellence in drug discovery and development • Scotland's strengths include patient ID from cradle to grave, strong electronic health record system, bio-banking resource • Support from Stratified Medicine Scotland Innovation Centre (SMS-IC) to create a leading global centre for specialist PM clinical trials
Digital Healthcare	• Scotland has 60 companies actively involved in digital healthcare • Comprehensive medical information, e-health patient records, and a stable population with high levels of morbidity in key disease areas • Single healthcare provider (NHS Scotland) actively engages with industry to develop digital health solutions and offers remote health and care services • Support for sub-sector provided by Digital Health & Care institute (DHI)

Key Subsector	Summary of key strengths and assets
Regenerative medicine	• Over 30 companies that provide unique solutions across the whole supply chain including cell line supplies, screening, characterisation, GMP manufacturing, QA/QC and a range of enabling technologies and supporting • Scotland is one of Europe's top locations for the development of stem cell technologies, with expertise in cell therapy clinical trials and integrated academic, clinical and commercial infrastructure • World class MHRA-accredited GMP ATMP manufacturing facilities • Single point of access to clinical and research expertise with national database of 5.3 million patient records enabling rapid clinical trial recruitment • One of Europe's largest and most highly regarded stem cell research hubs at the Scottish Centre for Regenerative Medicine at the Edinburgh BioQuarter
Animal bioscience, aquaculture and agri-tech	• Scotland has the largest cluster of animal bioscience/aquaculture researchers in Europe, with over 1,000 active researchers • The world's first cloned mammal, Dolly the sheep, was created at the Roslin Institute in Edinburgh • The Easter Bush Research Consortium is one of the world's largest animal health research groups • The UK's largest grouping of human and veterinary virologists is located at the MRC-University of Glasgow Centre for Virus Research • Key support centres include: Moredun, Roslin, and James Hutton Institutes, Scotland's Rural College, University of Glasgow School of Veterinary Medicine, University of Glasgow Institute of Biodiversity, Animal Health & Comparative Medicine, The University of Edinburgh Royal School of Veterinary Studies and the Scottish Aquaculture Innovation Centre (SAIC)
Industrial biotechnology	• Scotland has over 50 companies using industrial biotechnology including global companies such as GSK, Ingenza, Diageo, Unilever and Ineos, and smaller firms such as Cellucomp and Celtic Renewables • Main R&D centres are University of Strathclyde, Heriot Watt University, James Hutton and Roslin Institutes, and the Industrial Biotechnology Innovation Centre.

Source: Summaries based on sub-sector profiles in lifesciencesscotland.com and SDI Invest in Scotland sector profiles

4.6 Scotland has a range of business accommodation tailored to life science and technology rich companies, with key concentrations of sites in the Edinburgh and Glasgow areas. The main locations are shown in Figure 4-1.

Figure 4-1: Key locations for life science activity in Scotland

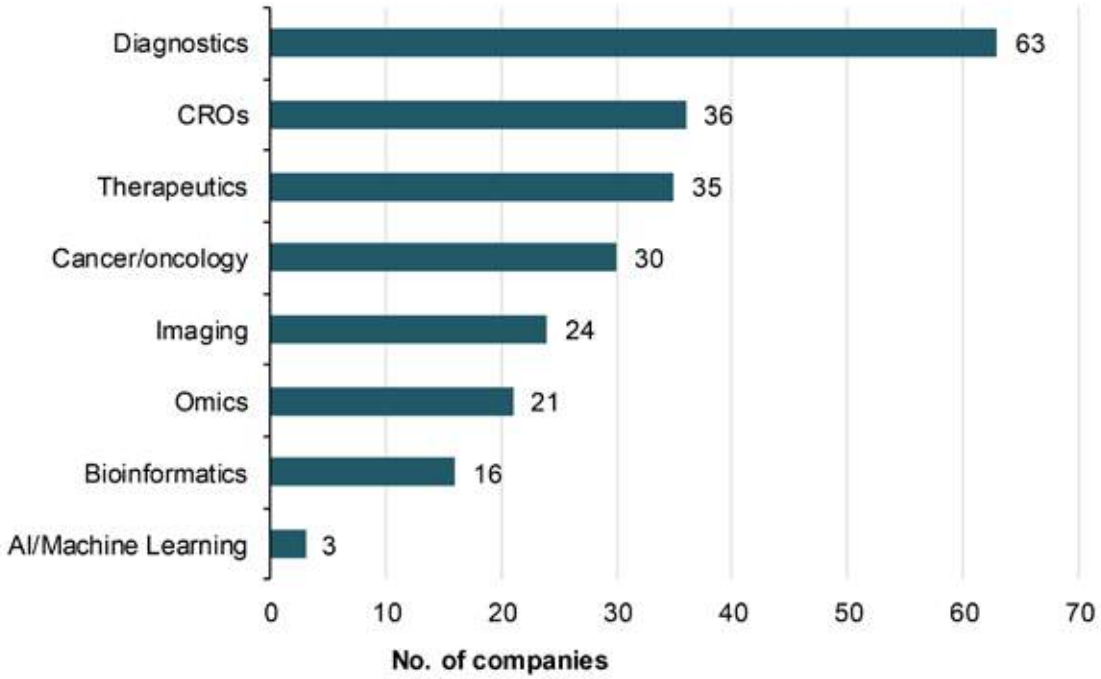


Source: Produced by SQW 2018. Licence 100030994. Contains OS data © Crown copyright [and database right] [2018] Data sourced from Life Sciences in Scotland website

An emerging and rapidly expanding PM business base

4.7 Scotland has a growing number of businesses involved in PM. Some of the main companies that have been engaged with the SMS-IC include Canon Medical Systems, Aridhia, Fios Genomics, Pharmatics, Sistemic, Destina Genomics, Biopta (ReproCELL Europe), BioClavis, ThermoFisher Scientific and Arrayjet. Overall, it is estimated by Scottish Enterprise that there are approximately 230 companies undertaking PM related activity (Figure 4-2). In terms of the largest sub-sectors, the analysis shows that there are 63 diagnostics firms, 36 Contract Research Organisations, and 35 therapeutics firms. Although Scotland has an emerging PM business base the feedback from SIA stakeholders indicated that to grow the business base there needs be much greater clarity on the nature and scale of the business opportunity.

Figure 4-2: Number of Scottish companies involved in PM, by sub-sector



Source: SQW analysis of data provided by Scottish Enterprise 2018

4.8 Examples of key companies in each of the sub-sectors is provided below.

Table 4-2: Examples of PM companies in Scotland

Subsector	Companies (location)
Diagnostics	• ReproCELL Europe (Glasgow) • ThermoFisher Scientific (Renfrew, near Glasgow, and Perth)
CROs	• Precision Oncology (Edinburgh) • PPD (Bellshill, Glasgow)
Therapeutics	• TC Biopharm (Motherwell, near Glasgow) • MedAnnex (Edinburgh)
Cancer/ oncology	• Nucana (Edinburgh) • Cumulus Oncology (Edinburgh)
Imaging	• Canon Medical (Edinburgh) • OracleBio (BioCity, Newhouse)
Omics	• BioClavis (Glasgow) • Destina Genomics (Edinburgh)
Bioinformatics	• Aridhia (Glasgow) • Fios Genomics (Edinburgh)
AI/ machine learning	• Pharmatics (Edinburgh) • Ex Scientia (Dundee)

Source: Analysis by Scottish Enterprise Company case studies

Company case studies

ReproCELL Europe

ReproCELL Europe is headquartered at the West of Scotland Science Park in Glasgow. It is a contract research services company that works with 19 out of the 20 major global pharmaceutical companies. ReproCELL invested in Scotland in 2015 when it acquired Biopta, a spinout from Glasgow Caledonian University. A new company ReproCELL Europe was then created in 2016, merging Biopta and another acquisition, Reinnervate. ReproCELL Europe currently has 23 employees, with 19 in Glasgow and 4 in County Durham. Its annual turnover is around £1.5m and 90% of sales are exports.

The company has worked closely with the Stratified Medicine Scotland Innovation Centre (SMS-IC), collaborating with the Universities of Dundee and Edinburgh, NHS Scotland and industry partners Aridhia, Fios Genomics, Sistemic and ThermoFisher Scientific (all based in Scotland). The industry-led exemplar research project has helped to improve the selection of patient stratification criteria based on a combination of genomics and associated functional data from studies in human tissue samples. The project was a key factor in ReproCELL's decision to buy Biopta and has also been successful in showcasing the opportunities of industry, academia and the NHS (the triple helix model) working together in the area of PM. The CEO of ReproCELL Europe is the PM lead in the Scottish Life Sciences Association industry body. Over the next two to three years, the company aims to grow its workforce from 23 employees to around 38 and all of this growth will be down the new opportunities in Scotland's PM cluster.

Thermo Fisher Scientific

Thermo Fisher Scientific Inc. (Thermo Fisher) is a global leader in serving science, with a total revenue of more than $20bn. It supplies instruments, equipment and software, as well as services and consumables to help conduct research, solve complex analytical challenges, improve patient diagnostics, deliver medicines to market and increase laboratory productivity. Around 850 of Thermo Fisher's 70,000 global employees are based in Scotland: 700 at Inchinnan near Glasgow, 100 in Perth, and 50 who are field based. Thermo Fisher generates approximately $1bn revenue from Scottish customers. Under Thermo Fisher's ownership, the Inchinnan plant has received considerable investment. In 2015, a new £14m facility was opened to use Thermo Fisher's proprietary technology to manufacture dry media powder which is then used to manufacture a range of drugs. One of only two such plants in the world, products from Inchinnan are used by customers across the Europe, Middle East and African (EMEA) markets. These customers then develop drugs which can be used to treat targeted groups of patients.

Thermo Fisher were also a founding partner in the Stratified Medicine Scotland Innovation Centre (SMS-IC) and hosted it at Inchinnan whilst the new premises was being built at the QEUH. ThermoFisher made a significant investment in SMS-IC. Thermo Fisher are currently developing plans for future collaborations. More broadly, PM is one of a handful of company-wide focus areas identified by Thermo Fisher. As a global company, the R&D for this will take place across the world, and Inchinnan and Scotland as a whole are both expected to remain part of Thermo Fisher's plans for supporting the implementation of PM.

MR CoilTech

MR CoilTech was set up in Germany in 2015 by Dr Shajan Gunamony who was working as a research scientist at the Max Planck Institute in Tübingen. The company was formed to commercialise a radio-frequency (RF) coil device for the new generation of ultra-high field MRI scanners. The device contains an array of antennae that pick up signals from the body, which can then be processed by the MRI scanner to generate the MR image. The RF coil enhances the image that can be produced by the scanners. MR CoilTech's founder wanted to accelerate the development of the technology and had various options in the UK and US. The company moved to Glasgow's QEUH in 2016. A key attraction of coming to Glasgow was the facilities at the QEUH, notably the Clinical Innovation Zone and Imaging Centre of Excellence with its new 7 Tesla MRI scanner. This scanner is one of only 75 worldwide and Glasgow is the only site in the UK, where it is based in a clinical setting. This provides MR CoilTech with the opportunity to develop its devices to suit the requirements of clinicians. The University of Glasgow has been very supportive of the company's ambitions and has allowed access to clinicians and the facilities at ICE, provided lab space, as well as offering the company founder a permanent academic tenure. In its first three years, the company has generated annual sales of around £200,000 and has three employees. It has developed MRI coils for research institutes in the US and Netherlands and is also working with Siemens, the manufacturer of Glasgow's new 7T MRI scanner. All of the company's sales are exports.

Spiritus Partners

Spiritus Partners is a pre-revenue start-up headquartered in Princeton, New Jersey in the United States, with a development centre in Edinburgh and a presence in Glasgow's Clinical Innovation Zone. Spiritus uses distributed ledger technology (sometimes known as blockchain) to develop service records for critical assets and infrastructure. These can be applied in the healthcare, life sciences, and energy sectors. In Spring 2017, Spiritus was awarded a £500k grant from Scottish Enterprise to create a development centre in Edinburgh. Scotland was preferred over worldwide locations such as Boston, Dublin and Belfast because of its cost-competitive and highly talented data analytics workforce, strong university system, burgeoning tech scene and strong government support. Spiritus now has six employees in Edinburgh in addition to the two co-founders. They also have taken hot-desk space in the Clinical Innovation Zone, QEUH.

With advances in technology expected to allow greater remote monitoring and self-management, including through wearable devices, Spiritus believe that their technology provides the opportunity to manage, protect and securely integrate this data with existing health records. Based on this potential, Spiritus has ambitious growth plans in Scotland, England and North America. As a relatively new company to Scotland, Spiritus has already engaged with different parts of the Precision Medicine ecosystem to discuss how its platform might be used to improve privacy, traceability and reproducibility for clinical and research purposes. It sees this supportive environment as key to its future growth plans.

BioClavis

BioClavis is a personalized diagnostics spin-out of US based BioSpyder Technologies. In early 2018, BioClavis set up at the Queen Elizabeth University Hospital (QEUH) campus in Glasgow supported by a £3.4m R&D grant from Scottish Enterprise. The parent company BioSpyder was set up in 2011 and developed a novel product for targeted sequencing called TempO-Seq™, a transcriptomic/ genomic platform technology.

BioSpyder considered a range of locations around Europe (in the UK, Ireland, Germany, Switzerland, Netherlands) but soon realised the QEUH in Glasgow was the best location for setting up BioClavis. The first key attractor was the scale and quality of clinical data and samples that they would be able to access. QEUH has one of the largest pathology laboratories in the UK and Europe, and a large biorepository which is networked to others across Scotland. The company also saw the networking infrastructure as a real asset of Glasgow, specifically the integration of industry, academics and clinicians at the Clinical Innovation Zone. The ability to interact with clinical researchers is quite different to the US, and the company has already created contacts with the main university departments in Scotland. The final main factor was the ability to attract high quality employees at a lower cost compared to other life sciences hubs.

The company already has five employees despite only being formally operating for a month. By the end of the three year R&D project the company expects to have around 40 employees. The company received a large number of high quality applications for the initial job postings and so is confident about being able to bring in the required expertise to support this growth. The company is already collaborating formally with the MRC/EPSRC Glasgow Molecular Pathology Node at QEUH. It is also working informally with SMS-IC and clinical researchers. Overall, BioClavis has been very impressed by the supportive environment for life science start-ups, and sees huge potential in developing Scotland's PM ecosystem. The company is already considering Scotland for small-scale manufacturing over the coming years, and sees similar opportunities for other start-up companies.

Extending the reach of Scotland's PM activity beyond the life sciences

4.9 One of Scotland's previous Science and Innovation Audits highlighted the opportunities of Data Driven Innovation in the Edinburgh City Region. The research highlights the economic opportunities of applying data science to support innovation and growth across a range of sectors including healthcare. It specifically highlights the informatics opportunity around the unique patient identifier and electronic health records available in Scotland. The Edinburgh City Region aims to be global destination of choice for inward investment, development capital and world leading talent in data science across a range of sectors - the University of Edinburgh has already become one of the world's leading institutions for data science.

4.10 The city has a thriving cluster of technology firms including major international companies and unicorns (privately held startup companies valued at over $1 billion) such as Skyscanner and FanDuel. In the latest Tech Nation report[60], it is estimated that there are around 38,000 digital technology jobs, and Edinburgh is seen as one of the UK's leading technology clusters. Glasgow also has nearly 34,000 digital technology jobs. Through this SIA, there is a commitment from partners to maximise the links between PM (with its focus in Glasgow) and the data science expertise that is concentrated in both Edinburgh and Glasgow. The areas of AI and machine learning are central to the integration of complex data-sets required to develop PM-led solutions.

Attracting further investment by strengthening our clinical trials capabilities

4.11 In addition to the electronic data and high incidence of chronic disease and stable population, Scotland has worked hard to streamline clinical trials approvals and patient recruitment throughout the country with centrally coordinated feasibility and governance activities. We are now recognised as one of the best locations for the development and clinical trials of treatments and therapies, with a high number of trials taking place compared to other countries. Indeed, eight out of the top 10 global CRO's are located in Scotland, and continue to attract new inward investors, for example Precision Oncology who set up offices in Edinburgh in 2017.

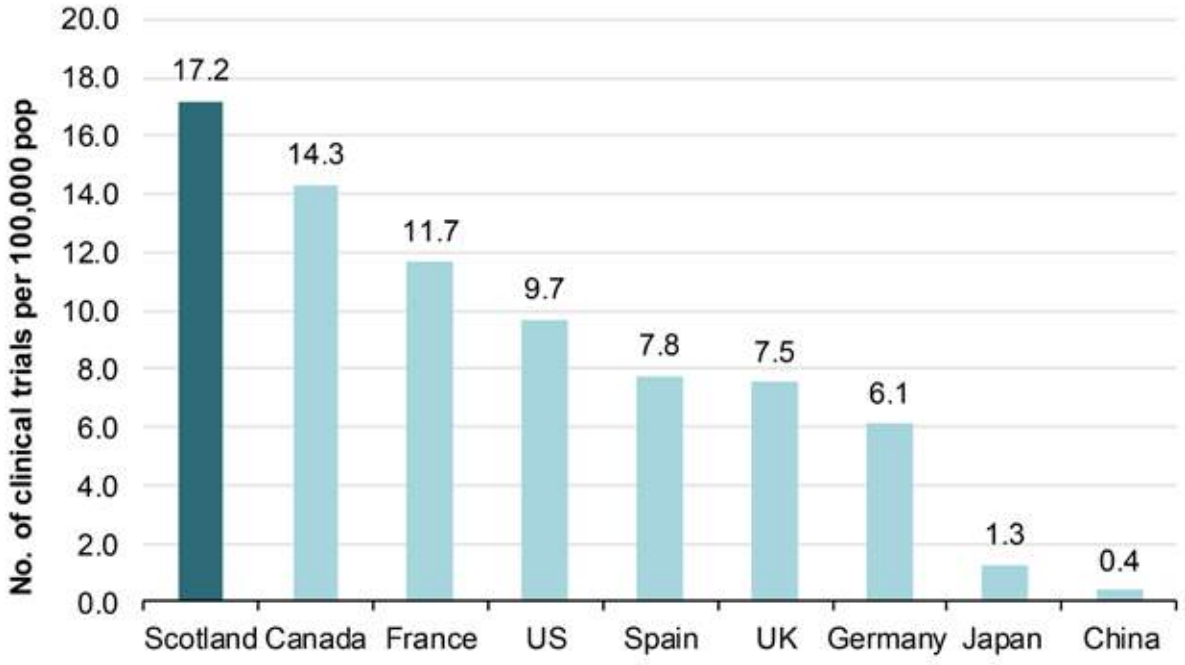
> *"We are a leader in precision medicine, developing a more data driven and personalised approach to healthcare. Stratified Medicine Scotland Innovation Centre with its co-ordinated Precision Medicine Ecosystem, has established itself as a perfect location for the development and clinical trials of novel treatments and therapies through access to its unique clinical infrastructure and patient data"* **(Dave Tudor, Vice President of Primary Supply, GSK & Chair of Life Sciences Scotland)**

4.12 Based on the data produced by clinicaltrials.gov, since 2013, there have been over 900 clinical trials in Scotland, of which nearly 400 have completed[61]. In the UK as a whole, there have been 5,000 trials, meaning that Scotland represents 19% of the UK total (but only 8% of the population). On a per capita basis, Scotland delivers more trials than Canada, France, the US, Spain, UK, Germany, Japan and China (Figure 4-3).

[60] Tech Nation 2018 - https://technation.io/insights/report-2018/

[61] The SIA consortium asked Technopolis to undertake analysis using data posted on clinicaltrials.gov posted from 01/01/2013 onwards. Only recruiting and completed trials were included in the analysis. The search was based on 31 Scottish city/town names

Figure 4-3: Number of clinical trials (completed/recruiting since 2013) per capita



Source: SQW/Technopolis analysis of data from clinicaltrials.gov

4.13 Nearly two thirds (64%) of all trials hosted in Scotland since 2013 have been funded by industry and this again is a higher proportion than other major countries. Within this figure, nearly 300 clinical trials have been funded by leading pharmaceuticals firms. As shown in Table 4-3, the largest number of trials have been sponsored by Roche, AstraZeneca and Novartis.

4.14 As the PM agenda develops over the coming years, these pharmaceutical companies will need to adapt their business model of drug testing and development. Scotland has a long-standing relationship with many of these key global players and, as a result, there is an opportunity to work more collaboratively on the stratification of new treatments, which is likely to result in more investment, jobs and GVA in Scotland for the benefit of the UK economy.

4.15 PM clinical trials will build on Scotland's existing expertise in clinical trials, but will additionally require to integrate new, innovative diagnostic tools, including genomics, metabolomics, molecular pathology and imaging, to stratify patient prior to medical treatment.

Table 4-3: Number of clinical trials funded by 'big pharma' in Scotland since 2013

Company	No. of clinical trials	Company	No. of clinical trials
Roche	43	Pfizer	16
AstraZeneca	39	AbbVie	16
Novartis	29	Amgen	16
GlaxoSmithKline	24	Merck & Co.	13
Bayer	22	Eli Lilly & Co	11
Gilead Sciences	22	Teva Pharma Industries	6
Sanofi	21	Abbott Laboratories	3
		Total	**281**

Source: Technopolis analysis of data from clinicaltrials.gov

Strong skills supply across a broad range of PM related subjects

4.16 In 2016/17 across Scotland, there were nearly 8,000 students enrolled in medicine and dentistry subjects, around 30,000 students doing subjects allied to medicine, and a further 21,000 studying biological sciences (Table 4-4)[62]. Given the importance of computer science and enabling technologies to PM, it is also helpful to consider the supply of 30,000 students in these courses.

Table 4-4: Number of students (undergrad & postgrad) in PM related subjects

	Scotland	% of UK total
Medicine and dentistry	7,645	12%
Subjects allied to medicine	29,800	10%
Biological sciences	20,940	9%
Computer science	10,775	11%
Engineering and technology	19,720	12%
All subjects	**225,315**	**10%**

Source: SQW analysis of HESA data 2016/17

"Scotland has a strong reputation for high quality translational research and is an attractive location for undertaking clinical trials due to the quality of patient data and stable population. Pfizer has a long history of collaborating with Scotland's universities and NHS. In general, Pfizer is interested to explore new opportunities around Precision Medicine, specifically Precision Drug Discovery **(Iain Kilty, Vice President, Head of Preclinical, Inflammation and Immunology Research Unit, Pfizer)**

[62] HESA 2016/17 data - https://www.hesa.ac.uk/data-and-analysis

4.17 Nearly all of the medicine and dentistry students are based at the four medical schools at the Universities of Aberdeen, Dundee, Edinburgh and Glasgow. Glasgow has the largest number with 2,500 medicine and dentistry students (Table 4-5).

Table 4-5: Number of medicine and dentistry students by university

	No. of students
The University of Glasgow	2,565
The University of Edinburgh	2,070
The University of Dundee	1,335
The University of Aberdeen	1,105
The University of St Andrews	490
Other	80
Total	**7,645**

Source: SQW analysis of HESA data 2016/17 4.22

4.18 In addition to the subject areas mentioned above, there are two training programmes specifically focused on PM. These are summarised below.

- A new industry-designed taught postgraduate Masters course in Stratified Medicine and Pharmacological Innovation was developed and over 100 students have now graduated. This programme is awarded by the Universities of Glasgow, Aberdeen and Strathclyde, in collaboration with the Universities of Dundee and Edinburgh. Students can be based at a core location in either Glasgow or Aberdeen. The multidisciplinary course covers the scientific basis of stratified medicine, the commercialisation of science, the application of research, and all students undertake an industrial placement or a project which addresses an industrial need. The course has been developed in partnership with firms involved at the SMS-IC. Around 35 students are trained on the course each year, and a large number have now taken up employment in industry.

- Most recently, a new MRC Doctoral Training Programme (DTP) in PM has been developed through a collaboration between the Universities of Edinburgh and Glasgow. The DTP provides state-of the-art training in informatics, data analytics, genetics, genomics, epidemiology, clinical populations, clinical tissue and 'liquid biopsy' interrogation and molecular pathology, and includes joint supervision by academics from the Universities of Edinburgh and Glasgow.

4.19 The SIA partners are committed to developing further skills programmes in line with the actions set out in the Skills Investment Plan (SIP) for the life sciences sector[63]. The SIP highlights for additional investment in apprenticeships, enhanced CPD provision, increasing work placements for undergraduates, and increasing industry engagement in the skills system. These are all relevant action areas for PM, and enhancing CPD within the NHS is one example of an activity which could be developed with partners in the Northern Powerhouse SIA consortium.

4.20 The SMS-IC has identified an extensive pathway of future skills requirements for PM, in areas of industry need including genomics and metabolomics, informatics, AI and machine learning, data security/management, as well as life sciences lab skills. These requirements range from industry relevant skilled technicians, via apprenticeships and College-level training, to undergraduate Life Sciences students who are 'industry aware', to highly skilled postgraduate researchers with industry

[63] Skills Development Scotland (2018), Skills Investment Plan for Scotland's life and chemical sciences

experience. In addition, there is an identified requirement for academic researchers to spend short periods in industry and vice-versa.

4.21 The opportunity (outlined in section 7) to utilise the new QEUH as a 'living lab' for PM will accelerate the need for NHS staff (both clinicians and allied health professionals) to have a solid understanding of PM, and an awareness of the beneficial role that industry plays. It will also accelerate the requirement for skilled employees across all sectors of relevance to PM.

Other enabling infrastructures – adopting a 'whole system' view

4.22 As evidenced above, Scotland's life sciences cluster is one of the largest in Europe, with a growing number of businesses involved in PM. Building on the recent transformational investments at the QEUH campus in Glasgow, the Edinburgh BioQuarter and other strategically important life science sites across Scotland, there is now an exciting and timely opportunity (in the context of the UK's Industrial Strategy) to accelerate the UK's productivity growth by building a globally significant PM cluster.

4.23 A high-level review of good practice in relation to life science cluster development activity elsewhere (conducted by SQW) has identified the following pertinent learning points for Scotland:

4.24 The comparator research summarised above demonstrates the importance of having: strong and effective leadership for the Scottish PM cluster; a clear and coherent vision for its growth and development; and a highly supportive policy framework for driving increased levels of new business formation/spin outs and attracting internationally mobile companies, health research charities and workers.

4.25 Creating an interesting, attractive working environment is also extremely important. A huge amount of thought went into the design of Biopolis in Singapore, and the result is a really vibrant place which people enjoy working in. As new sites and innovation districts with a strong emphasis on PM are brought forward across Scotland, partners will need to ensure that they create dynamic places where talented young people want to live, work and socialise.

4.26 However, perhaps the most important learning point for the SIA consortium in the context of its PM cluster development agenda is that a 'whole system' view is essential. For instance, as partners seek to leverage recent investments into the QEUH campus and build a critical mass of PM-led innovative firms, they cannot solely focus on access to clinicians, patients or specialist kit within clinical settings. A wide range of other enabling infrastructures are necessary in order to maximise the growth potential of the cluster. As well as a good supply of specialist skills (including very strong digital capabilities and broader business building competencies), businesses demand high quality flexible accommodation, which may include category two labs as well as office space (smaller units at first, but larger units/grow-on space as they mature and develop), access to different types of growth finance (on attractive terms), tailored business support (and incubation during their initial phases of development), and access to collaborative innovation networks, with strong linkages to the local science/university base.

4.27 Those places that are able to develop a strong offer across all domains of their innovation ecosystem - and to integrate these seamlessly - will be able to maximise synergies and compete most effectively on the global stage.

- Certain developments within leading life science cluster tend to act as significant focal points – for example, Biopolis in Singapore and the Cambridge Biomedical Campus (CBC) at Addenbrooke's in Cambridge.
- These help to attract publicity and represent a high profile manifestation of the cluster. However, most companies are attracted and retained by the totality of the cluster, not the size or profile of individual developments within it.
- There are some significant advantages of a big cluster, such as access to a large specialist labour market, the potential for interaction with and use of specialist facilities (including, but not restricted to, teaching hospitals, related research assets within the local university base, health research charities and other Research and Technology Organisations etc.), access to funding sources (such as dedicated life sciences investment funds) which understand the specific needs of life science businesses, and a good supply and mix of premises at different prices for different types of activity.
- The value of choice in the type and cost of specialist property is that companies can move within the cluster as they grow and change their mix of activities – for example, hardening into manufacturing after a 'soft start'.
- In comparison with Scotland's life sciences offer, leading life science clusters within the Golden Triangle (Cambridge, Oxford and London) arguably have a higher profile internationally, and are stronger in some aspects of research, including pharmaceuticals and genomics (see the next Section for details on those areas where Scottish HEIs outperform the Golden Triangle institutions).
- However, Scotland has important strengths which Cambridge, Oxford and London lack, such as access to fully digitised longitudinal patient records.
- Scotland also has a much stronger manufacturing/engineering heritage, a large and diverse catchment population (with an increased prevalence of certain disease types), which make it more suitable for some PM related investment, for example in clinical trials.
- The Golden Triangle is also far more expensive for both businesses and residents, plus the constraints on development and congestion are significantly greater.
- Cambridge has benefitted from effective promotion, marketing and leadership of the cluster as a whole, with a consistent and coherent message from different partners who recognise the importance of the 'big picture' as well as of their component organisations/facilities.
- This includes competitors, such as Granta Park and the CBC in Cambridge where both are seeking to differentiate themselves but also acknowledge the value of each other in the overall promotion of inward investment. Scotland faces similar pressures and challenges across the different city-regions and specific developments within them, although there is a strong commitment through SE, SFC, CSO and wider partners to develop a genuinely 'pan Scotland' approach to progressing the PM Ecosystem.
- Internationally, the highest profile clusters are located in the Boston area and Singapore. There are smaller clusters elsewhere in Europe (e.g. northern Switzerland, around Basle and Zurich), but generally they do not compare with the critical mass of the Golden Triangle, the North West of England and Scotland.
- The Boston cluster grew up around the strengths of Harvard University and medical school, major teaching hospitals, and some very successful bioscience companies (e.g. Genzyme). Boston and Massachusetts is an interesting comparator for Scotland because the area has a similar manufacturing heritage.
- In recent years the Massachusetts State Government has played a significant role in supporting the development of the cluster, including through attraction of inward investment and establishing the Massachusetts Life Sciences Centre (MLSC), which provides significant amounts of grant funding to life science businesses.
- Biopolis in Singapore is another example of strong public policy and funding support underpinning the development of a bioscience cluster which now has international recognition.

Source: SQW research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5. Scotland's Precision Medicine research offer

Key messages

- Scotland is at the forefront of world leading PM-related research. This is evidenced by the Scottish HEI rankings and SciVal data on research output and citation impact.
- The combined quality of research of Scotland's four main universities that come together under SMS-IC compares well to other key university groupings in PM related subjects.
- The University of Glasgow also holds the UK's only Regius Chair in Precision Medicine, and widely recognised leadership of PM by Professor Dame Anna Dominiczak.
- There are several important flagship research projects and initiatives that illustrate the breadth and depth of Scotland's PM capabilities including the SMS-IC's multiple exemplar projects, Precision-PANC (Pancreatic Cancer), IMIDBio-UK project (Rheumatoid Arthritis), Scottish Genomes Partnership (genome sequencing), SMS-IC participation in AstraZeneca's Global Genomics Initiative and the Innovate UK NASH Data Commons project.
- Scotland also has key strengths in health economics research. Analysis by the University of Glasgow Health Economics and Health Technology Assessment team suggests that over a fifty year period, a 10% reduction in the burden of five key disease types, through the implementation of PM, would generate cumulative health savings of around £70bn.

Scotland has a globally significant PM scientific research base

5.1 As demonstrated in Section 2, Scotland's universities produce world-class research and perform well across various international rankings. This global excellence is particularly apparent within those subject areas of direct relevance to PM. For instance, according to the Times Higher Education World University Rankings (2018), five of Scotland's universities are in the world's top 200 in the categories of clinical, pre-clinical and health, life sciences and computer science (Table 5-1)[64].

5.2 Focusing in on the rankings by subject, it is clear that our universities have particular specialisms in the subject areas most closely aligned with PM. For example, the University of Edinburgh ranks 17th in the world for Clinical, Pre-clinical & Health, 23rd for Life Sciences and 14th for Computer Science. The University of Glasgow ranks 53rd for Clinical, Pre-clinical & Health and 49th for Life Sciences.

[64] Times Higher Education World University Rankings 2018 - https://www.timeshighereducation.com/world-university-rankings/2018/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats

Table 5-1: Top Scottish university world rankings in PM-related subjects

University	Clinical, Pre-Clinical & Health	Life Sciences	Computer Science	Overall
University of Edinburgh	=17	=23	14	=27
University of Glasgow	53	49	101-125	=80
University of St Andrews	176-200	72	201-250	=143
University of Aberdeen	126-150	79	151-175	185
University of Dundee	=86	=55	-	187

Source: SQW analysis of Times Higher Education World University Rankings 2018

5.3 In addition to the university rankings, it is also important to note that the University of Glasgow has the UK's only Regius Chair in Precision Medicine. Professor Dame Anna Dominiczak, Vice-Principal and Regius Chair of Medicine and Therapeutics at the University of Glasgow, and Professor Andrew Morris of the University of Edinburgh and Health Data Research UK have been at the forefront of developing the PM Ecosystem in Scotland.

5.4 SciVal produces data on academic research output and quality. The data are useful as they allow benchmarking across the UK and internationally. For the SIA analysis, we have selected a range of subjects related to PM and focused on the four universities that are partners in the SMS-IC (Universities of Aberdeen, Edinburgh, Dundee and Glasgow).

Research output

5.5 Across the four main Scottish universities involved in SMS-IC, the three main subjects for research output are Clinical Medicine (nearly 13,000 publications), Biological Sciences (12,000) and Public Health (11,000). Around three quarters of Scotland's research on Clinical Medicine is produced by the Universities of Edinburgh and Glasgow (see Table 5-2 for details).

Table 5-2: Number of research publications in PM subjects (2014-17)

	UoA	UoD	UoE	UoG	SMS-IC HEIs	All Scottish HEIs
Biological Sciences	1,895	1,726	5,617	3,512	12,012	15,372
Clinical Medicine	1,931	1,852	5,841	3,958	12,683	14,361
Public Health, Health Services & Primary Care	1,834	1,482	5,065	3,387	10,920	13,826
Computer Science & Informatics	564	442	2,894	1,585	5,401	9,586

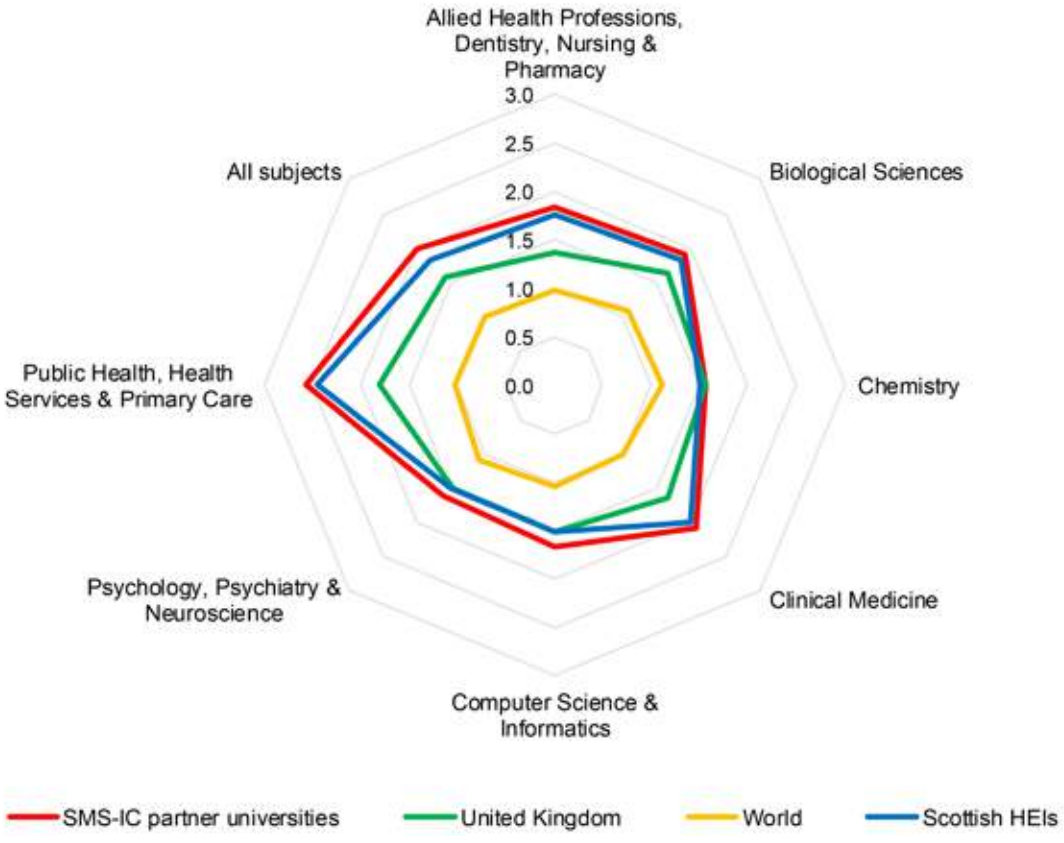
	UoA	UoD	UoE	UoG	SMS-IC HEIs	All Scottish HEIs
Psychology, Psychiatry & Neuroscience	853	559	3,115	1,571	5,782	8,580
Chemistry	968	587	2,191	1,462	5,035	8,308
Allied Health Professions, Dentistry, Nursing & Pharmacy	381	587	953	707	2,453	3,534
All research	**9,027**	**6,119**	**27,588**	**17,932**	**57,092**	**85,389**

Source: SQW analysis of SciVal data

Research quality

5.6 The quality of the research produced by Scotland's key universities in PM related subjects can be measured in terms of its Field-Weighted Citation Impact (FWCI). The score produced is a ratio of citations received relative to the expected world average for the subject field, publication type and publication year. As shown below (Figure 5-1), the quality of research from the four SMS-IC partner universities in PM subjects is higher than all of the Scottish, UK and world scores. The FWCI scores for Clinical Medicine and Public Health are particularly impressive.

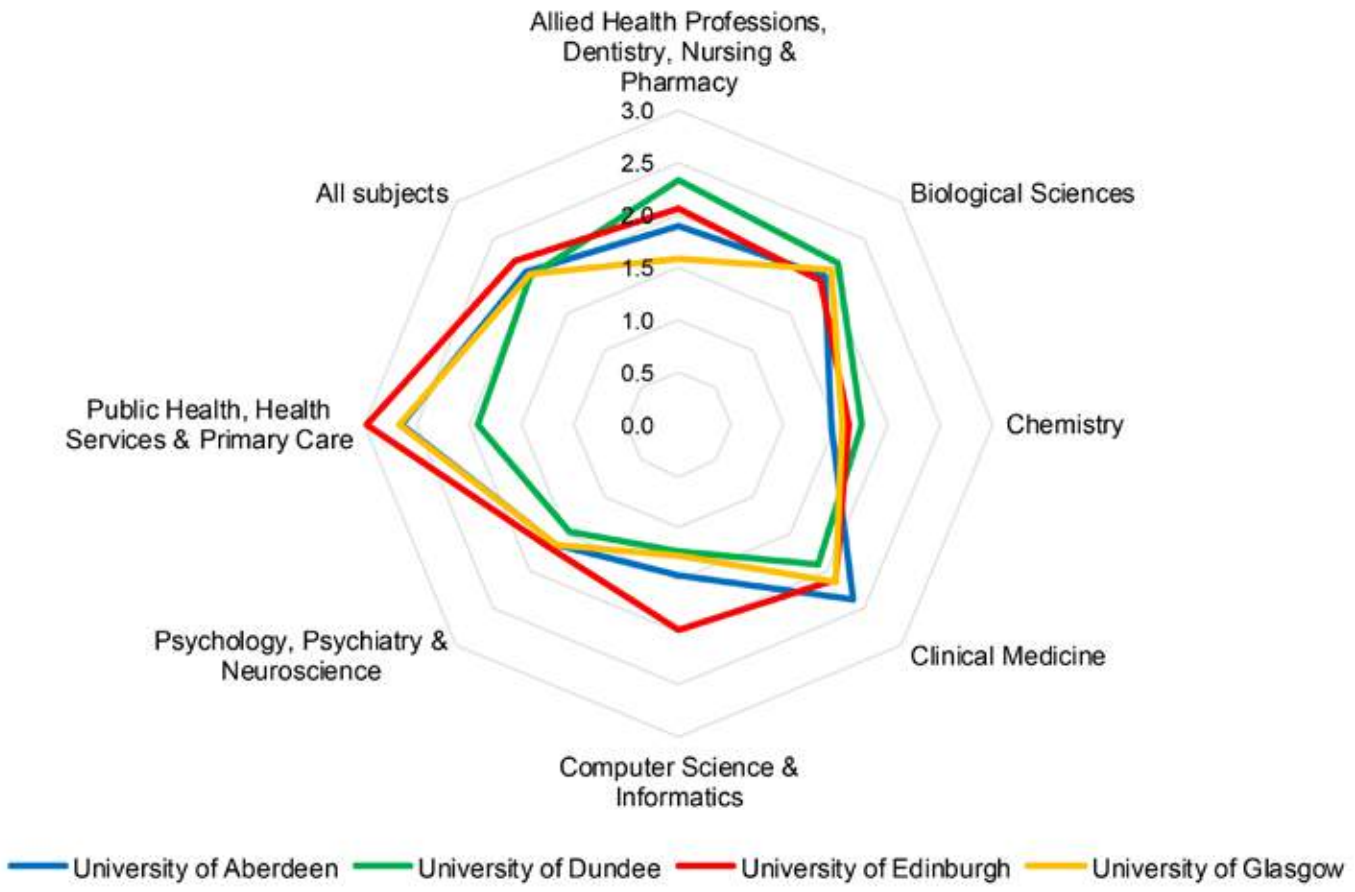
Figure 5-1: Field-Weighted Citation Impact in PM-related subjects (2014-17)



Source: SQW analysis of SciVal data

5.7 Further analysis of the FWCI data shows the relative strengths in the four universities (Figure 5-2). The highest subject score for the University of Aberdeen is 2.7 for Public Health. In the University of Dundee, the highest score is for Allied Health Professions, Dentistry, Nursing & Pharmacy (2.3). For both the Universities of Edinburgh and Glasgow, the top scores are for Public Health (3.0 and 2.7 respectively).

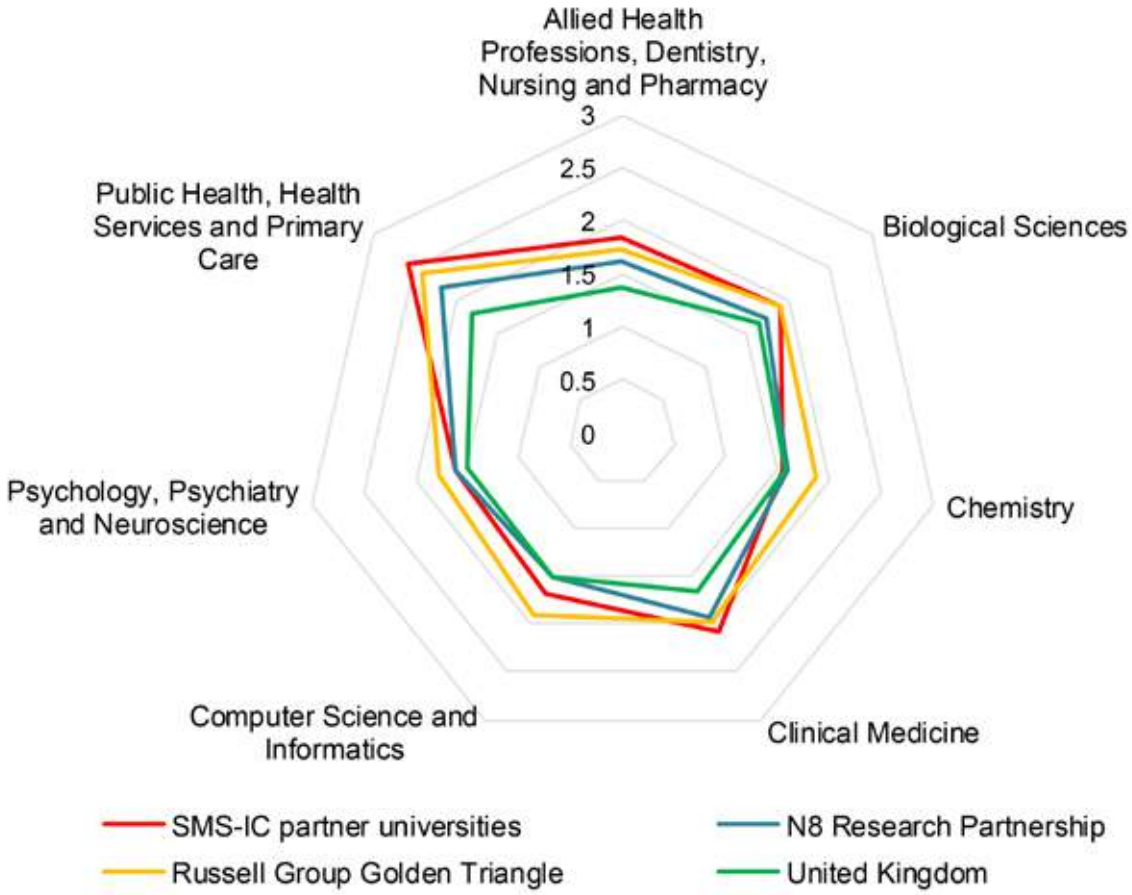
Figure 5-2: Field-Weighted Citation Impact in PM-related subjects (2014-17) by university



Source: SQW analysis of SciVal data

5.8 The performance of the four universities that are partners in SMS-IC in PM related subjects in terms of citation (FWCI) impact compares well with other key university groupings in the UK. Figure 5-3 shows FWCI scores for the SMS-IC universities, the N8 Research Partnership (Northern England) and the Russell Group Golden Triangle universities (the six elite universities in Oxford, Cambridge and London). In four of the seven subject areas, the Scottish universities have a higher citation impact: in Public Health; Clinical Medicine; Biological Sciences; and Allied Health subjects. It is also notable that the Scottish HEIs outperform the N8 institutions in all areas except for Chemistry and 'Psychology, Psychiatry and Neuroscience', where the performance levels are similar.

Figure 5-3: Benchmarking the quality of SMS-IC universities with other key UK university groupings



Source: SQW analysis of SciVal data

5.9 A closer look at the FWCI scores for detailed subject areas at the four universities reveals particular clinical research expertise. Table 5-3 shows the top 10 areas of research based on the FWCI data. However, it should be noted that the scale of research output (number of publications) varies with the Universities of Edinburgh and Glasgow scores based on a much larger number of research outputs during the 2014-17 period. Overall, the data once again highlight the quality of research being produced in the key areas of chronic diseases, pharmacology and genetics that are relevant to PM.

5.10 The REF 2014 offers another important perspective on our university-led research quality. Across all units of assessment, the Universities of Edinburgh and Glasgow are both in the UK top 15 for research power. Six Scottish universities were ranked in the top 50 in the UK for the quality of their research[65].

5.11 In addition, seven of our universities were ranked in the UK top 20 for their research power and/or quality in units of assessment relevant to PM (see Table 5-4). For these universities we have highlighted strong performance in units of assessment that are most relevant to PM. Some key highlights are set out below:

- The University of Edinburgh ranks 4th on power and 6th on quality for Clinical Medicine
- The University of Edinburgh ranks 1st on power and 15th on quality for Computer Science and Informatics
- The University of Glasgow ranks 6th on power and 9th on quality for Clinical Medicine.

[65] Research Excellence Framework 2014 - https://www.ref.ac.uk/2014/

Table 5-3: Top health research subjects based on output (2014-17) by SMS-IC partner university

University of Aberdeen				University of Dundee			
Detailed subject	**Output**	**FWCI**	**UK FWCI**	**Detailed subject**	**Output**	**FWCI**	**UK FWCI**
Biochemistry, Genetics and Molecular Biology	1340	2.12	1.7	Biochemistry, Genetics and Molecular Biology	1643	2.38	1.7
Immunology and Microbiology	449	2.42	1.67	Molecular Biology	533	2.77	1.59
Neuroscience	385	1.57	1.6	Cell Biology	390	3.09	1.76
General Biochemistry, Genetics and Molecular Biology	385	2.11	1.8	Immunology and Microbiology	365	1.89	1.67
Public Health, Environmental and Occupational Health	285	1.54	1.46	Biochemistry	362	1.73	1.43
Molecular Biology	259	3.09	1.59	General Biochemistry, Genetics and Molecular Biology	361	1.88	1.8
Genetics	250	2.12	1.87	Genetics	312	3.07	1.87
Nursing	218	1.84	1.31	Neuroscience	247	1.83	1.6
Biochemistry	204	1.38	1.43	Pharmacology (medical)	193	2.18	1.52
Immunology	185	2.49	1.78	Nursing	178	1.78	1.31
University of Edinburgh				**University of Glasgow**			
Detailed subject	**Output**	**FWCI**	**UK FWCI**	**Detailed subject**	**Output**	**FWCI**	**UK FWCI**
Biochemistry, Genetics and Molecular Biology	4802	2.04	1.7	Biochemistry, Genetics and Molecular Biology	2875	2.18	1.7
Neuroscience	1417	1.99	1.6	Immunology and Microbiology	927	2.07	1.67
General Biochemistry, Genetics and Molecular Biology	1403	1.78	1.8	General Biochemistry, Genetics and Molecular Biology	788	2.2	1.8
Immunology and Microbiology	1287	1.99	1.87	Neuroscience	728	2.07	1.6
Genetics	1222	2.41	1.87	Cardiology and Cardiovascular Medicine	696	2.75	1.81
Molecular Biology	1048	2.34	1.59	Molecular Biology	610	2.32	1.59
Neurology (clinical)	681	2.31	1.81	Biochemistry	536	1.54	1.43
Veterinary	681	1.53	1.54	Public Health, Environmental and Occupational Health	499	1.79	1.46
Cell Biology	672	2.47	1.76	Genetics	478	2.67	1.87
Biochemistry	597	1.48	1.43	Neurology (clinical)	421	2.49	1.81

Source: SQW analysis of SciVal data

Table 5-4: Areas of PM related REF units of assessment

University	Top 20 rankings in REF units of assessment relevant to PM
University of Glasgow	• Biological Sciences – 13th on power • Chemistry – 19th on power and 20th on quality • Clinical Medicine – 6th on power and 9th on quality • Computer Science and Informatics – 10th on power and 16th on quality • Psychology, Psychiatry and Neuroscience – 17th power • Public Health, Health Services and Primary Care – 10th on power
University of Edinburgh	• Biological Sciences – 5th on power and 3rd on quality • Chemistry – 9th on power and 12th on quality • Clinical medicine - 4th on power and 6th on quality • Computer Science and Informatics – 1st on power and 15th on quality • Psychology, Psychiatry and Neuroscience – 3rd on power and 11th on quality
University of Aberdeen	• Biological Sciences – 7th on power • Psychology, Psychiatry and Neuroscience – 19th on quality • Public Health, Health Services and Primary Care – 9th on power and 15th on quality
University of Strathclyde	• Allied Health Professions, Dentistry, Nursing and Pharmacy – 4th on power, 20th on quality • Chemistry – 15th on power, 20th on quality
University of St Andrews	• Biological Sciences – 16th on both power and quality • Chemistry – 12th on both power and quality • Psychology, Psychiatry and Neuroscience – 15th on quality
University of Dundee	• Biological Sciences – 9th on power and 2nd on quality
University of Stirling	• Agriculture, Veterinary and Food Science – 12th on power, 4th on quality • Allied Health Professions, Dentistry, Nursing and Pharmacy – 16th on quality • Psychology, Psychiatry and Neuroscience – 18th on quality

Source: SQW analysis of REF and Technopolis compiled data

Key scientific research projects and initiatives

5.12 **The SMS-IC was set up in 2013 as a consortium of industry, Universities and NHS Scotland, in a £110m investment** in eight new Innovation Centres by the Scottish Funding Council. It has initially focused on a number of exemplar projects in order to showcase Scotland's expertise and demonstrate the applicability of PM in a range of chronic diseases, but has now widened to include large multinational consortium projects. The project summaries presented below illustrate the encouraging level of collaboration that is taking place at SMS-IC, both across academic and NHS partners, but also the strong level of engagement with industry. The examples also show linkages with other parts of the UK and globally. The partners involved at SMS-IC are now looking to broaden the scope of their activity, using the platforms and proof of concept activity to enhance Scotland's expertise in bio-informatics, next generation sequencing, data assimilation, biomarker identification and diagnostics development.

Table 5-5: SMS-IC exemplar research projects

Project	Summary
Oesophageal Cancer – *Identifying Predictive Biomarkers for the Prediction of Gefitinib Response in Oesophageal Cancer*	• Project led by Professor Zofia Miedzybrodzka at the University of Aberdeen and Professor Russell Petty at Ninewells Hospital in Dundee • Using the SMS Innovation Platform, exome panel-based sequencing has been carried out on DNA samples provided by the University of Aberdeen and NHS Grampian. Bio-informatics analysis will be performed using the SMS Innovation Platform. These outputs will then be used to assess for a diagnostic response • The main partners are the University of Aberdeen; NHS Grampian; ThermoFisher Scientific; and Aridhia Informatics Ltd
Ovarian Cancer – *Informing Future Strategies for Treatment*	• Project led by Professor Charlie Gourley at the Edinburgh Cancer Research Centre • This project involves the novel idea of sequencing both tumour and normal DNA from each of 550 real-time ovarian cancer patients in matched pairs • It is anticipated that the data generated as part of this project will flow into the Astra Zeneca collaboration project (Global Genomics Initiative) in order to build a larger patient sequence database • The main partners are University of Edinburgh; University of Dundee; NHS Lothian; NHS Tayside; NHS Greater Glasgow & Clyde; and AstraZeneca
Enabling Stratified Medicine in Early Rheumatoid Arthritis	• Project led by Professor Iain McInnes at the University of Glasgow • The aim of the project was to test the hypothesis that MTX (methotrexate, which is the main RA drug treatment) and toxicity can be usefully predicted by adopting an integrated polyomic approach for the development of predictive/clinical biomarker profiles • The main partners are the University of Glasgow the University of Edinburgh; NHS Lothian; NHS Greater Glasgow & Clyde; Thermo Fisher; Aridhia; and Hologic

Project	Summary
Scottish Dementia Informatics Platform	• SMS-IC are part of the Steering Committee to set up the Scottish Dementia Informatics Platform. The project involves creating an informatics platform with the ability to capture data directly from people with dementia and carers, helping to produce an evidence base for care services, reducing the cost of directly setting up trials • The main partners are the University of Edinburgh, the University of Glasgow; NHS Lothian; Cadgwith Health; Aridhia Informatics Ltd, and Alzheimer Scotland. Several pharma companies are being identified
IBD/COPD - *Early Identification of Patient Variability and Pharmacogenomic: A new approach to the Development of Stratified Medicines*	• The project aim was to offer a new way to link genomics to the prediction of clinical efficacy at an early stage in drug development • The project focused on Biopta's observations that *in vitro* responses to known drugs using human tissue samples collected from patients with irritable bowel disease (IBD), or chronic obstructive pulmonary disease (COPD) can vary quite significantly between patients • The main partners are the University of Edinburgh; University of Dundee; NHS Grampian; NHS Lothian; NHS Tayside; NHS Greater Glasgow & Clyde; Fios Genomics; Sistemic and Biopta
FutureMS - *Developing predictive tools Creating a Scotland-wide informatics, imaging and genetic platform to improve Multiple Sclerosis clinical management and decision-making*	• The aim of the project is to identify clinical, laboratory and genomic predictors of disease activity in people with newly diagnosed relapsing-onset MS using cutting edge informatics and genetic platforms • The main partners are University of Edinburgh; University of Glasgow; University of Dundee; University of Aberdeen; University College London; University of Californaia San Francisco; NHS Grampian; NHS Lothian; NHS Tayside; NHS Greater Glasgow & Clyde; ThermoFisher Scientific; Fios Genomics, and Aridhia Informatics Ltd
NASH Data Commons	• £1.7m award from Innovate UK to develop a NASH data commons, to improve clinical and commercial outcomes for Non Alchoholic Steatohepititis • Pan-Scotland collaborative project including clinical academics, health boards, Safe Havens and Molecular Pathology Nodes • 1000 cases being used, including digital pathology and radiology.

Source: SMS-IC

5.13 One of the best examples of the PM opportunities in Scotland, enabled by SMS-IC, is **Precision-PANC**. This exciting project is led by Professor Andrew Biankin, Regius Professor of Surgery and Director of Wolfson Wohl Cancer Research Centre at the University of Glasgow and was initially funded through the Scottish Government's CSO. In 2016, his team produced a globally significant study that identified for the first time, the existence of four sub-types of pancreatic cancer; a condition which will soon become the second leading cause of cancer death in Western countries. The main aim of Precision PANC is to use the latest technology to find the right trial for the patient and match the best new treatment options for an individual based on the genetic sub-type of their cancer. Biopsy samples taken as part of routine diagnostic care are analysed at the Glasgow Precision Oncology Laboratory (GPOL) based at the University of Glasgow's Wolfson Wohl Cancer Research Centre, which is fully equipped to deliver all forms of nucleic acid sequencing and analysis and is working with the NHS for GCLP/ISO and UKAS accreditation and CE marking of diagnostics. Test results can then inform treatment decisions and/or enrolment into suitable clinical trials across the UK. The project is generating worldwide interest and has attracted significant additional funding from CRUK and industry.

5.14 The Precision-PANC project is happening in Scotland because of Scotland's unique combination of Community Health Index (CHI) numbered health records and an ethical framework which allows secure access to this data. Professor Andrew Biankin relocated from Sydney, Australia, to Scotland because he recognised Scotland's unique strengths for implementing PM clinical trials. Another main reason why this activity is taking place in Scotland is the relatively high prevalence of cancer and Scotland's stable population. Precision-PANC is led by the University of Glasgow, involving academics from the Wolfson Wohl Cancer Research Centre, the Institute of Cancer Sciences, and the Beatson Institute for Cancer Research. The Cancer Research UK Manchester Institute and the University of Cambridge are also important academic partners. Key partnerships with the NHS include the NHS Greater Glasgow and Clyde Biorepository and Molecular Genetics West of Scotland Genetic Services based at the QEUH.

5.15 Scotland leads the International Cancer Genome Consortium (ICGC) with the Secretariat now based in Glasgow under Biankin's leadership. The ICGC was formed to broadly and comprehensively map cancer genomes. The ICGC has evolved significantly since its inception from defining the genomes of 25,000 primary untreated cancers (the **25K Initiative**); to ICGC-ARGO (**A**ccelerating **R**esearch in **G**enomic **O**ncology) where key clinical questions in the management of cancer are addressed. ICGC-ARGO's mission is to provide the world with a unique resource of multi-omic data for people with cancer in clinical trials to accelerate the discovery of new treatments.

5.16 The **IMIDBio-UK** project is led by Professor Iain McInnes at the University of Glasgow. The aim of the project, which commenced in 2017, is to create the world's largest Immune-Mediated Inflammatory Disease (IMID) Biobank (in excess of 40,000 patients). IMIDs cover a range of diseases including psoriasis, psoriatic arthritis, ankylosing spondylitis, inflammatory bowel disease, and rheumatoid arthritis. The MRC funded project brings together researchers from the University of Glasgow, Newcastle University, the University of Cambridge, Queen Mary University of London and the University of Manchester. It will incorporate MRC, National Institute for Health Research and Scottish Government CSO funded biobanks and clinical datasets into one single, searchable and analysable 'superhighway'.

5.17 The **Scottish Genomes Partnership** is a major Scotland-wide genome sequencing research programme set up in 2015 between the Universities of Aberdeen, Dundee, Edinburgh and Glasgow, with NHS Scotland and the four main NHS health boards. The programme is led by Professor Tim Aitman (University of Edinburgh) for inherited diseases and Professor Andrew Biankin (University of Glasgow) for cancer, and is funded by the Scottish Government's CSO and the UK's Medical Research Council. It has involved the installation of 10 state-of-the-art Illumina HiSeqX genome sequencing instruments divided between Edinburgh Genomics Clinical Division and the Glasgow Precision Oncology Laboratory.

5.18 With funding from the Scottish Government, the programme involves the sequencing of more than 10,000 genomes to understand more about the causes of rare genetic disease and cancer, and the diagnosis of rare genetic diseases in a strategic collaboration with the Genomics England 100,000 Genomes Project. In terms of early successes, the programme has produced rare disease academic studies that build on Scotland's outstanding academic track record in gene identification and functional analysis of single gene human disorders. In terms of cancer research, the programme is providing cutting-edge sequencing and analysis for clinically important and recalcitrant cancers from Scottish cohorts.

5.19 In 2016, SMS-IC joined **AstraZeneca's Global Genomics Initiative**. Other partners include the University of Cambridge, the Wellcome Trust Sanger Institute, Genomics England, Human Longevity Inc. in the USA, Columbia University in Canada and Finland's Institute for Molecular Medicine. Through SMS-IC, AstraZeneca will be able to access a range of high-quality data assets and a network of world-class clinical and academic institutions.

5.20 The SMS-IC and Eagle Genomics have been awarded a £1.7m collaborative grant from Innovate UK, for a ground-breaking **NASH project** that could help develop new tests and treatments for patients with non-alcoholic steatohepatitis (NASH), which usually precedes liver fibrosis, liver cancer and premature death. The unified data system bringing together genomic and patient data will be the first in the world for NASH, will lead to a deeper understanding of which tests and treatments are most effective for individual patients. It is already generating significant interest from a large number of the major pharmaceutical companies and it is hoped that such a Data Commons approach can be extended to allow in-depth study of other conditions.

Health economics

5.21 Scotland also has important **expertise in health economics**. In 2018, the University of Aberdeen's Health Economics Research Unit (HERU) and Health Services Research Unit (HSRU) were awarded the Queen's Anniversary Prize for health service research leading to improvements in academic and clinical practice and delivery of health care. At the University of Glasgow, the Health Economics and Health Technology Assessment team (HEHTA) is at the forefront of developing robust economic models on the effectiveness of PM. The team works closely with the University of Glasgow's MRC/EPSRC Molecular Pathology Node and the SMS-IC. Together, they have developed Bayesian statistical models to determine the potential economic value of candidate technologies. In addition, the SMS-IC will increasingly be looking to involve health economists within NHS Scotland (Scottish Health Technologies Group) and other stakeholders in order to establish a mechanism of adoption of new PM therapies/techniques into NHS in Scotland.

[66] http://www.nhsresearchscotland.org.uk/uploads/tinymce/NRS-AstraZeneca%20-%20Facilitating%20ground-breaking%20genomic%20and%20informatics%20research.pdf

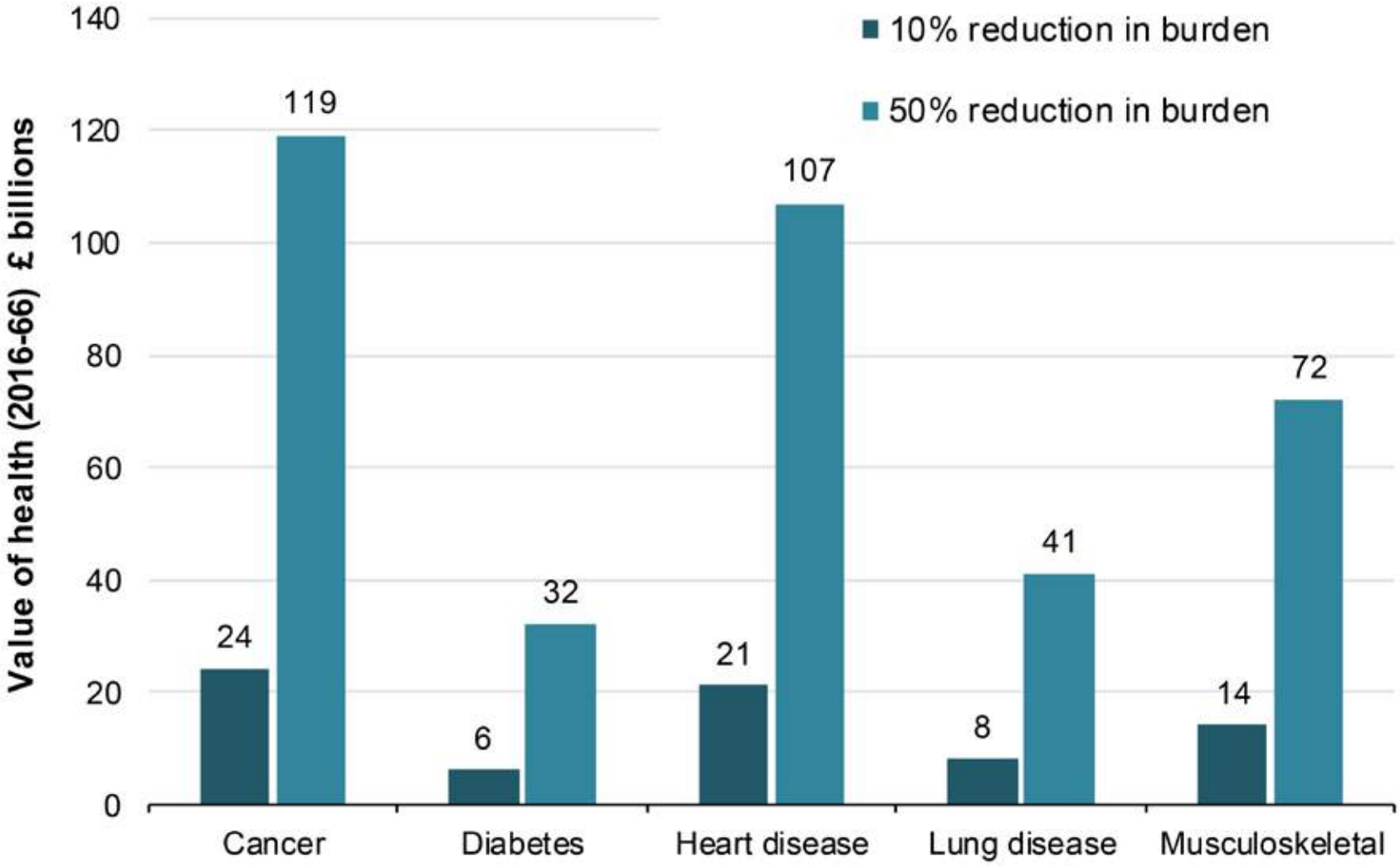
5.22 The HEHTA team has recently undertaken some analysis to quantify the potential health savings from PM in Scotland by replicating an approach carried out by Dr Victor Dzau[67]. In Dzau's original study, he modelled the value, in terms of cost-savings, of PM from hypothetical, personalised PM innovations. The HEHTA analysis took some of the same assumptions in terms of 10% and 50% reductions in disease burden, but applied them to five main disease types in Scotland (cancer, diabetes, heart disease, lung disease and musculoskeletal diseases). The analysis is based on an estimate of £20,000 per quality-adjusted life-year (QALY) which is a generic measure of disease burden, including both the quality and the quantity of life lived.

"Working together with NHS Scotland, Scottish universities and Stratified Medicine Scotland will be a really important part of our strategy. This collaboration will provide access to consented genomic samples, electronic health records and importantly, the ability to recall patients for deeper clinical investigation to help us better understand the underlying causes of disease" **(Mene Pangalos, Executive Vice President, AstraZeneca)[66]**

5.23 Figure 5-4 shows the scale of the potential health savings from reductions generated through PM for the five major disease areas. According to this analysis, over a fifty year period, a 10% reduction in the burden of these diseases would generate cumulative health savings of around £70bn. To put in context, this equates to more than five times the annual budget for the NHS in Scotland. These are clearly estimates and subject to assumptions, so these data must be treated with some caution, but they clearly demonstrate the potential scale of the health savings that could be realised by PM in Scotland.

[67] Dzau et al, The Lancet (2015), Aligning incentives to fulfil the promise of personalized medicine

Figure 5-4: Cumulative value of potential additional QALYs generated by PM in Scotland (2016-66)[68]



Source: HEHTA, University of Glasgow (2018), unpublished data

[68] Uses methodology adapted from Dzau et al, The Lancet (2015) & Annual Burden of Disease from The Scottish Burden of Disease Study, 2015 available from http://www.scotpho.org.uk/media/1474/sbod2015-overview-report-july17.pdf. Assumes 10% and 50% reduction in burden from hypothetical precision medicine innovations in five major disease groups. Additional QALYs valued at £20,000 in line with lower accepted UK threshold

6. Wider market opportunities

Key messages

- There are several market and technology drivers impacting on PM including an ageing population, increasing healthcare costs and the emergence of new disruptive technologies.
- Advances in technology are accelerating a shift in healthcare from reaction to prevention and early stage treatments. This is facilitated by advances in areas such as gene sequencing, companion diagnostics, pharmacogenomics, bioinformatics, and big data analytics.
- Changes to regulation, approvals processes, new business models in the pharmaceuticals sector, and growing demand for non-invasive and personalised treatments are also important contextual developments for PM.
- The global PM market value was estimated at almost $43bn in 2016 and this figure is projected to rise to around $134bn by 2025, so it is a prize worth pursuing for both the Scottish and wider UK economies.
- There are significant global challenges in implementing PM in terms of data privacy, integration of health datasets, regulation, and evidencing impact. However, Scotland has the complementary expertise in clinical research, computer science and informatics to create substantial economic opportunities from these challenges.

Key market and technology drivers of change

6.1 There are several market and technology related global trends driving the exciting transition to PM, which Scotland and the wider UK will need to be alert to. These include for example, an ageing population, increasing costs of healthcare and the emergence of new disruptive technologies (which are converging rapidly, in part through the rising integration of big data healthcare tech firms with pharmaceutical and biotech companies) allowing us to develop more effective, targeted and tailored healthcare solutions. The main factors driving growth in the PM market are summarised in Table 6-1 below.

The global PM market is growing rapidly. . .

6.2 In 2016, the global PM market value was estimated at almost $43bn and this figure is projected to rise to more than $71bn by 2021, based on a CAGR of 10.6%. By 2025, the market value is expected to be around $134bn, so it is certainly a prize worth pursuing for both the Scottish and wider UK economies.[69,70]. There is a high level of global activity especially on genome sequencing projects and it is estimated that by 2030, over 50% of the global population will have had their genome sequenced.

[69] Frost & Sullivan (2017), Global Precision Medicine Growth: Opportunities, Forecast to 2025. Strategies and Tactics for Accelerating Growth in a Transforming Market

[70] As set out in Annex D, there is a range of analyses that seek to quantify the global PM market and predict how it will grow. Although they start from different baselines, the market forecasts all predict that PM revenues will grow each year between 10-15%

Table 6-1: Key drivers of change impacting on precision medicine

Technology drivers	Market drivers
• Shift from reaction to prevention and the adoption of early stage treatments - increased focus on targeted therapy to reduce the amount of trial and error medicine • Advancement of technology for understanding human biology & disease susceptibility such as genome sequencing, companion diagnostics, pharmacogenomics, bioinformatics, and big data analytics • Accessibility of large-scale human genome databases coupled with the advent of next-generation sequencing and computational tools • Rising adoption of 'omics' technologies -exponential growth in the number of targeted molecules in the pipeline, specifically in oncology • More biomarkers identified for on-market drugs, which will allow better stratification through PM • Advances in digital and information technology, including super-computing capabilities • Increased funding for major government initiatives e.g. PrecisionFDA in the US, the French Genome Institute, Germany's Individualized Medicine Action Plan, and Genomics England's 100,000 Genomes Project • Digital radiology, advanced imaging techniques, digital pathology, machine learning and Artificial Intelligence (AI) are all rapidly developing and will integrate with PM. Scotland's use of PACS (Picture Archiving and Communications System) is well advanced and provides rapid access to medical images from multiple modalities	• Growing prevalence of cancer and an ageing population across the globe coupled with a stronger government focus on reducing disease burden costs • Rapidly growing healthcare expenditure coupled with greater adoption of gene sequencing and big data analytics in emerging economies • Payers willing to reimburse the cost of high-value drugs • Growing demand for non-invasive testing procedures and personalised treatment • Growing demand for wearable technology and increasing managements by patients increasingly informed, demanding and active consumer • Increased number of adverse drug reactions cases and ability to reduce adverse drug reactions through pharmacogenomics testing • Global expansion of the medical industry because of larger investments (both from government and industry), better infrastructure, simplified approval processes for drugs and companion diagnostics (e.g. in US) • Ability of industry to patent a molecule along with its companion diagnostics to achieve a competitive edge, profit margin and more usage • Shift to more open and inclusive models of innovation within global pharma as they seek to reduce the costs and risk associated with R&D

Source: SQW summary of Technopolis' desk-based review

6.3 At present, North America dominates the market with over half (54%) of all revenues, followed by Europe (28%) and Asia (13%). North America and Europe are expected to grow at around 10% per annum over the coming years, due in large part to high rates of cancers, a favourable regulatory landscape and major government initiatives in the area of PM. The European market is dominated by Germany, the UK, France, Italy, Spain and Scandinavia. The Asia Pacific region is forecast to grow faster at around 15% per annum driven by China, Japan, India and Singapore.

6.4 An analysis by Frost and Sullivan shows that the UK is well positioned internationally in terms of the strength of its PM ecosystem (see Figure 6-1). As demonstrated earlier, Scotland compares well with other parts of the UK and would therefore rank highly for many of the different PM criteria listed.

Figure 6-1: Precision Medicine Readiness Index by selected countries

Selected Countries	Rx/Dx Co-development Attractiveness	Population Sequencing Investments	In-country Omics Research	Biobank Infra-structure	Integration and Connected Care Readiness	Health System Maturity	Overall Precision Medicine Growth Trend		
							2016	2020	2025
United States									
China									
Japan									
Germany									
United Kingdom									
Italy									
France									
Netherlands									
South Korea									
Canada									
Australia									
Brazil									
South Africa									
India									
UAE									

Current Ecosystem for Enabling Precision Medicine Practice
Low ← → High
1 2 3 4 5

Precision Medicine Growth Trend
Low High

Source: Frost & Sullivan

. . . with the emergence of targeted therapeutics

6.5 In the area of PM technologies, drug discovery currently accounts for the largest market share and is expected to grow by c8% per annum between 2017 and 2024, supported by advances in pharmacogenomics and companion diagnostics[71,72]. Other notable growth areas are Big Data Analytics, Gene Therapy, Bioinformatics and Next-Generation Sequencing[73].

6.6 The key growth areas within PM applications will focus on 'targeted therapeutics' such as oncology, immunology (specifically arthritis), neurology, cardiology and infectious diseases. It is predicted that investment in oncology will continue and will grow to an approximate value of $69bn (USD) by 2024, with a CAGR of over 13.5%. The market value of immunology is expected to reach c.$34bn (USD)[74] by 2024.

Maximising the UK's PM growth opportunity will not be easy

6.7 However, as PM gives rise to new ways of delivering healthcare, there are likely to be some major challenges that will need to be addressed over the coming years in order to maximise the potential beneficial impacts of PM. A selection of the key challenges is summarised below:

- **Data privacy and security** - the success of PM depends on access to genetic and personal patient information to be able to evidence impact. Companies have concerns around gaining secure access to relevant data sources, including genomic data sets, clinical trials and electronic health records[75]. To prove cost effectiveness, improved clinical outcomes or improved quality of care, access to large datasets are needed. However, there are also legitimate public concerns around collecting, processing and storing personal data[76]

- **Evidencing impact** - there is a need for more better quality evidence to demonstrate that PM improves clinical outcomes, increases cost-effectiveness and affordability, and enhances the quality of care across populations[77]

- **Regulatory frameworks** – uncertain legal and regulatory frameworks are likely to impact on the development and adoption of PM[78]. The rate of PM developments is outpacing and redefining what is needed from the regulatory environment and a standardised approach has not yet materialised. This is specifically evident in diagnostics as companies are unsure how to balance validation with cost effectiveness[79]

- **Integration into healthcare** – embedding PM into healthcare systems will require much more powerful IT systems to support meaningful interpretation of high volumes of data, and the various options available to medical staff[80]. Linked to this, there are concerns about the future skills needed to analyse and interpret the data, which may require new forms of collaborations involving big pharma[81].

[71] Global Newswire (2017), Precision Medicine Market growing at 10.5% CAGR to hit $96 bn by 2024
[72] Global Market Insights (2017), Precision Medicine Market Size Report
[73] Zion Market Research (2018). Europe Precision Medicine Market — Europe Industry Analysis, Size, Share, Growth, Trends, and Forecast 2016 – 2024
[74] Persistence Market Research (2017), Global Market Study on Precision Medicine
[75] Strategy& and PwC (2017) Capitalising on the future of precision medicine: How pharmaceutical firms can shape the future of healthcare
[76] World Innovation Summit for Health (WISH) (2016) Precision Medicine, A Global Action Plan for Impact – Report of the WISH Precision Medicine Forum
[77] Ibid
[78] Strategy& and PwC (2017) Capitalising on the future of precision medicine: How pharmaceutical firms can shape the future of healthcare
[79] McKinsey and Company (2013), Personalised Medicine: The Path Forward
[80] World Innovation Summit for Health (WISH) (2016) Precision Medicine, A Global Action Plan for Impact – Report of the WISH Precision Medicine Forum
[81] Strategy& and PwC (2017), Capitalising on the future of precision medicine: How pharmaceutical firms can shape the future of healthcare

Implications for Scotland

6.8 Over the coming years there will be significant growth and investment in PM in all parts of the world as industry and governments strive to provide better, more targeted healthcare for an ageing and increasingly wealthy population. Many existing life science clusters are positioning themselves at the vanguard of PM-led innovation. However, as evidenced through this SIA, Scotland has the academic and clinical excellence, and the supporting ecosystem to be able to compete with these other areas effectively, and become a leading test-bed for the advancement, adoption and mainstreaming of PM approaches. There are some serious challenges ahead for all countries seeking to progress PM, but Scotland has the complementary scientific expertise in clinical research, computer science and informatics to create the conditions for long-term success.

7. Scotland's 'game-changing' opportunities

7.1 This SIA has demonstrated Scotland's strengths and capabilities for realising the transformational opportunities linked to PM, which if seized fully, has the potential to drive economic growth across Scotland for the benefit of the UK. This capability aligns perfectly with the Industrial Strategy's challenge ('from data to early diagnosis and precision medicine') to industry and research to utilise health data to improve early diagnosis and precision treatment of disease.

Potential game-changers – our priority areas for investment

7.2 Building on the evidence and feedback from SIA Steering Group members and framed by the potential high-level benefits outlined above, we have identified opportunities for Scotland to maximise its strengths in PM. These opportunities also align with the original SIA hypotheses.

7.3 In discussion with AstraZeneca, Canon, ThermoFisher, J&J, Siemens Healthineers and other leading companies, we are developing consortia, which could deliver pan-Scottish 'game-changing' PM investments. The opportunities are well aligned with the evidence base demonstrated by the SIA, and flow logically from the strengths and gaps identified, with a strong focus on business and economic growth. These areas for investment are summarised below.

1) The opportunity to combine complementary strengths in data science and PM

7.4 Scotland's strengths and assets in the complementary areas of Data Science and PM have now been robustly evidenced in two BEIS supported SIAs. Firstly, the Edinburgh & South-East Scotland City Region's Wave 1 SIA showcased Edinburgh's rapidly growing strengths in data-driven innovation. This capability in data sciences formed the core of the business case for investment in data-driven innovation through the Edinburgh and South-East Scotland Region City Deal, and promises to deliver substantial opportunities for regional economic growth. Similarly, this Glasgow led Wave 3 SIA in PM has now shone a spotlight on Scotland's significant capabilities in PM, particularly around Glasgow's QEUH campus (and Glasgow City Region City Deal investment in the Imaging Centre of Excellence and Clinical Innovation Zone).

7.5 A key differentiator in Scotland is our high-quality health records – being able to integrate a wide range of patient data with genomics, imaging and other tools to diagnose, prevent and stratify major common conditions, in order to deliver better treatments, has already positioned Scotland ahead of many other countries. Scotland now has a potentially transformational opportunity to combine the regional strengths in Data Science and PM, particularly in Edinburgh and Glasgow, to accelerate the implementation of PM and achieve long-term economic impacts for Scotland through NHS savings, a healthier and more productive workforce, and growing Scotland's PM focused business base.

7.6 There are clearly major challenges in terms of integrating data systems, managing and analysing the data, and ensuring strong ethical governance. However, Scotland has the requisite infrastructure and expertise already in place to overcome these hurdles. With Scotland acting as the test-bed for PM, this will attract major investment from a range of companies including big pharma and new tech start-ups into the UK, thus deliver a net positive impact.

2) QEUH as a 'living lab' to realise the potential of PM and drive economic growth

7.7 The purpose of the "living lab" is to address what in reality is the biggest challenge in PM - translating innovation into standard clinical practice. Our ambitious, but deliverable vision for a Living Lab is framed around the following core elements:

- a state of the art clinical setting of sufficient scale, where innovation and adoption can be integrated and results scaled nationally and internationally. The QEUH campus will become the cornerstone of a globally significant PM business cluster, with linkages across the rest of Scotland, the UK and beyond
- an existing world leading source of PM science, innovation and expertise
- supporting world-class capabilities around healthcare economics, data science, clinical pathways and rigorous evaluation of both the adoption process and the impact of new technologies.

7.8 The QEUH is uniquely placed to realise this ambitious agenda through a combination of early leadership and vision in PM, investment in a unique infrastructure and as a result, unmatched delivery capability in a co-located environment. The QEUH provides an unparalleled delivery opportunity to:

- realise the promise of PM by piloting its adoption within the UK's largest health board
- demonstrate and evaluate the savings to the NHS through the implementation of existing PM diagnostics in Europe's largest hospital. This 'real world' opportunity would encompass PM in its broadest sense, including digital imaging, digital pathology, machine learning and AI, utilise strengths in health economics, and engage companies across Scotland
- accelerate the growth of the life sciences cluster around the QEUH by attracting and supporting the development of companies working in the PM space. This includes diagnostics, medtech, CROs, data security and provenance, health economics; which would complement and add value to investment in other key life sciences hubs such as the Edinburgh BioQuarter
- improve medication safety and efficacy for stratified patient cohorts by demonstrating the beneficial economic and patient outcome impacts of pharmacogenomics in a way that can be scaled up nationally. There is a specific opportunity for QEUH using evidence that Pharmacogenomics (PGx) has moved from 'theory' and 'hypothesis' to demonstrable savings in medication costs, patient outcomes and healthcare economics.

7.9 The concept of the new QEUH as a 'living lab' for PM was central to the vision for the new hospital campus from breaking ground in 2012 to official opening in 2015. This provides a transformational opportunity to deliver beneficial economic impact for Scotland through demonstrating NHS savings and growing Scotland's PM industry base, with a mix of large anchor firms and early stage SMEs. It also provides an opportunity to leverage existing infrastructure investments and foundational capabilities (e.g. the Glasgow City Region City Deal investment and co-location of SMS-IC).

7.10 The QEUH campus is unique in that it combines a £1bn investment in a state of the art hospital with one of the largest and most integrated concentrations of PM focused infrastructure in the UK. This includes the: SMS-IC; Clinical Research Facilities for PM clinical trials; Clinical Innovation Zone for industry, accommodating companies such as BioClavis and Spiritus; 'Safe Haven' for data, tissue biorepository, the Imaging Centre of Excellence; and the UK's largest MRC/EPSRC Molecular Pathology Node.

7.11 The QEUH, which is now Europe's largest hospital, is based in Govan, an area of historically high deprivation in Glasgow alongside chronic diseases and multimorbidity. The estimates of both male and female life expectancy in Greater Govan are below the Glasgow average. The area has a high proportion of people claiming out-of-work benefits and young people not in education, employment or training compared with the Glasgow average. The proposal would grow Scotland's PM industry base around the Govan QEUH site, and demonstrate health economic benefit through NHS savings and a healthier, more skilled workforce.

7.12 A consortium, consisting of the University of Glasgow, NHS Greater Glasgow & Clyde, industry (including ThermoFisher Scientific, Siemens, Aridhia, CGI and others), SMS-IC, Glasgow City Council and Glasgow Chamber of Commerce has already formed to scope and develop this ambitious project, with a focus on economic growth. The consortium is also working with Skills Development Scotland to scope and implement future skills requirements for the project, including for industry, the NHS workforce, and plans for patient engagement.

7.13 Investment in 5G technology will be critical to the Living Lab vision for the QEUH campus. The University of Glasgow, NHS Greater Glasgow and Clyde and the City Council are currently exploring different options with industry partners including Nokia to develop the hospital campus as a 5G testbed. The creation of a 5G test-bed at the campus and wider Innovation District will help to attract SMEs looking to develop new platforms and analytical tools for PM.

"Nokia has been working closely with the University of Glasgow and the City Council over the last year in developing proposals for a 5G test-bed covering the West End Innovation District. Glasgow is well-positioned to become a world-leading centre of excellence for the trialling of 5G technologies. We are excited by the SIA proposal to develop the QEUH campus as a living lab, and the introduction of a 5G network in the city will be critical in providing the necessary bandwidth and computing power to implement Precision Medicine in Scotland" **(Charlie Swan, Account Manager Global Enterprise and Public Sector, Nokia)**

7.14 The anticipated beneficial economic impacts of the project will be as follows:

- An increase in the number of SMEs providing PM technologies, devices and services
- An increase in high quality employment opportunities relating to PM
- More new business start-ups in high growth sectors
- Increased inward investment flows
- Development of a national/internationally competitive PM cluster, thus helping the UK to adopt a leadership position globally in relation to PM (complementing activity in the Golden Triangle and Northern Powerhouse)
- Continued regeneration and reinvention of a deprived area of the Glasgow City Region, supporting more inclusive innovation-led growth.
- Improved knowledge transfer from NHS/academia to industry
- Health economic benefits to NHS Greater Glasgow & Clyde and Glasgow City region.

3) Next generation clinical decision support tools or 'clinical cockpits'

7.15 The true potential of PM to revolutionise the cost and quality of healthcare delivery can only be achieved when new pathways of care have been adopted that embed a more personalised, consistent and quantitative approach to the clinical choices and interventions in the NHS. This model of PM requires a more data driven approach to clinical decision making in which comprehensive patient data about the current individual is compared with prior population data and disease models that aid outcomes prediction.

7.16 These 'precision pathways of care' will require clinicians to be able to access and interpret large quantities of data without this becoming a burden to their daily clinical workload. This requires the development of a next generation of clinical decision support tools (or clinical cockpits) that aggregate patient data from various systems (e.g. radiology imaging, pathology findings, genomics, prescription history and vital signs etc.) and use machine learning and AI algorithms to compare the current patient with relevant population models.

7.17 The design of these decision support tools requires two things which Scotland is ready and able to deliver:

- access to large databases of relevant patient data (with governance through our existing Safe Havens across four Scottish sites) to allow the relevant models of population based precision pathways of care to be built
- access to clinicians in a highly collaborative environment such that they can guide the design and development of these next generation clinical cockpits.

7.18 The adoption of precision pathways of care within NHS Scotland will be transformational in terms of the cost-effective delivery of optimised patient care and targeted use of publicly-funded scarce resources. Once proven to improve NHS healthcare delivery in Scotland, these precision pathways of care will become models that can be readily adopted elsewhere in the UK and by other global care providers. The benefit of clinical cockpits to the growing industry base in Scotland is that they will pull through demand for novel precision diagnostics, decision support system design and artificial intelligence-based algorithms and population modelling from a global market for care, generating IP for companies big and small.

7.19 A strong pan-Scottish consortium has already been established and has developed a proposal to UKRI, utilising AI and machine learning, digital pathology and radiology. The consortium has been coordinated by the CSO and including NHS Scotland, the Universities of Aberdeen, Dundee, Edinburgh, Glasgow and St Andrews, and industry partners (including Canon Medical and Philips).

4) SMS-IC as a gateway to 'Scotland's Ecosystem for PM'

7.20 Scotland's investment in a world-class enabling infrastructure for PM (including the SMS-IC) over the last five years has laid very strong foundations for the implementation of PM, which have been recognised internationally. There is now an exciting opportunity to broaden Scotland's capability in PM even further by positioning SMS-IC as a gateway to the entirety of 'Scotland's Ecosystem for PM' to accelerate and promote Scotland's expertise in this area. The SMS-IC's location within the Clinical Innovation Zone at QEUH provides an opportunity to coordinate large scale, pan-Scottish industry-academic-NHS consortia to:

- develop and utilise PM tools that extend beyond genomics, including other omics (e.g. by partnering with Glasgow Polyomics and Edinburgh Genomics) as well as imaging and digital pathology
- work with the NHS to build expertise around the regulatory aspects of PM to enable the development and use of new diagnostics in a clinical setting, and integrate Scotland's strengths in health economics evaluation
- build on the success of existing projects, including Precision PANC, rheumatoid arthritis and NASH Data Commons to promote Scotland's clinical trials capabilities and attract CROs and Big Pharma to locate and invest in Scotland
- build on the success of the Innovate UK funded NASH Data Commons platform to develop data commons for other disease areas, thereby attracting pharma companies to engage and invest in Scotland.

8. Conclusions

Realising the UK's PM-led growth opportunity in Scotland

8.1 This SIA has highlighted Scotland's competitive advantages in the context of further developing its exciting ecosystem for PM and growing its life science cluster. We have key strengths in the quality of our health records, a single healthcare provider, and a stable population with high incidence of chronic disease. Our academic research is world-class, and we have an emerging cluster of businesses involved in the development of technologies to support the adoption of PM.

8.2 However, it is imperative that both the UK and Scottish Governments support us as we seek to unlock Scotland's full potential and convert this innovation-led growth opportunity into more private sector investment, more frontier firms, more high value jobs, and faster productivity gains for the UK. This requires carefully targeted, but rapid action as other global players have the same aspirations and are moving forward very quickly.

8.3 Above and beyond the obvious economic and productivity growth benefits associated with building a globally significant PM cluster, the evidence points to other factors that provide a strong and convincing rationale for early investment. For instance:

- **Healthcare cost escalation** – there are many studies around the unsustainable nature of healthcare costs and PM is the least 'painful' way to make a material saving for the NHS e.g. the alternatives such as 'less healthcare for everyone' or a higher hurdle to access healthcare, would be very difficult for governments and unpalatable
- **Patient outcomes** – many patients do not have the luxury of time, e.g. for some cancers. We have a moral responsibility to give access to basic mechanisms of stratification that are available today to enable better outcomes. We have practical examples where we can test in a simple and low-cost way to avoid unnecessary treatment for patients that are highly unlikely to get benefits from being prescribed, or will have severe side effects
- **Healthcare cost avoidance/enhanced patient experience** – our expertise in health economics can be used to demonstrate the additional savings and experience improvements that are gained by avoiding (or reducing) adverse drug reactions and/or multiple hospital visits etc. Analysis by the University of Glasgow Health Economics and Health Technology Assessment team suggests that over a fifty year period, a 10% reduction in the burden of five key disease types, through the implementation of PM, would generate cumulative health savings of around £70bn
- **PM provides innovative technology and industry-driven solutions** – a add value to other national agendas such as Realistic Medicine[82], which aims to rationalise the overuse and misuse of healthcare.

[82] Scottish Government, Chief Medical Officer's Feedback Report for 2014/15 - Realistic Medicine
Scottish Government, Chief Medical Officer's Annual Report for 2015/16 - Realising Realistic Medicine
Scottish Government, Chief Medical Officer's Annual Report for 2016/17 - Practising Realistic Medicine

Realising the vision

8.4 As stated earlier, the SIA consortium of public and private partners from across Scotland and international experts are committed to helping Scotland become a global centre of excellence for the advancement, implementation and adoption of PM over the next 10 years. The evidence collated in this SIA validates our original hypotheses and key opportunity areas. Partners are therefore committed to focusing on:

- Growing and developing the PM cluster at the £1bn QEUH campus in Glasgow, which acts as a focal point for Scotland's wider ecosystem for PM with the opportunity to act as a scalable pilot 'Living Lab' for the implementation of PM, delivering substantial clinical and economic benefits to Scotland and the UK more widely
- Driving increased awareness and adoption of PM, as well as the strengthening of our innovation ecosystem to accelerate productivity growth and improved patient outcomes
- Enhancing Scotland's leadership role in the advancement of PM to speed up the take-up and diffusion of PM, providing an internationally significant UK exemplar, attracting FDI and delivering competitive advantage for the UK
- Adding significant economic value by complementing and synergising with other major UK innovation initiatives; including those in adjacent sectors most notably drug discovery and digital tech. Specifically, we will build on existing close relationships with the UK based European Lead Factory, the University of Dundee's Drugs Discovery Unit (DDU) and the Medicines Drug Discovery Catapult. The evidence suggests that PM will give rise to a much better understanding of molecular mechanisms of diseases and therefore will be a prime source of feedback for new druggable targets.

Some final reflections on the added value of this SIA process

8.5 The development of this SIA has been shaped by an open, inclusive and wide-ranging programme of stakeholder engagement and consultation. The shared sense of purpose evident throughout the SIA process has highlighted the support and commitment of partners across Scotland to developing PM and driving productivity growth. Our in-depth consultations with 45 stakeholders and e-survey of 80 organisations have both highlighted the scale of the ambition and enthusiasm for developing the ecosystem for PM in Scotland. Between 80-90% of survey respondents agreed that Scotland has the potential to become a world-leading centre of excellence, that over time will result in significant financial savings for the NHS as well as major economic benefits in terms of high quality jobs and export opportunities for Scottish firms (see Annex E for the full e-survey results).

8.6 We have conducted in-depth case study research to showcase examples of existing and emerging PM excellence and knowledge exchange on the ground, held regular meetings with the SIA Delivery Team, as well as benefitting from continuous 'check and challenge' provided by the high-level SIA Steering Group. We recognise that we are at the start of an exciting journey to scope, define and implement the key growth opportunities for Scotland in the context of a rapidly evolving and highly competitive global PM landscape. Informed by these SIA findings - and indeed the two previous Scotland SIAs, which focused on enabling technologies and data driven innovation - consortium partners are now much better equipped to focus their effort and investment on those niche areas where Scotland is either currently leading the world or has real potential to do so over the next 10 years.

8.7 The process of developing this SIA has increased the profile and understanding of Scotland's areas of comparative advantage for both internal (Scottish) stakeholders and wider UK and international partners. There is now a clearer understanding of the PM opportunity within the Scottish Government and its agencies. The SIA foreword provided by Scotland's First Minister reflects this strong policy support, and plans are being developed for Scotland to host an international Precision Medicine Summit in September 2018, to showcase Scotland's highly differentiated and internationally significant PM focused capabilities.

8.8 Importantly, our consortium is confident and bold enough to know that competitor areas elsewhere in the UK and beyond are also moving fast in relation to PM innovation and adoption. Therefore, we are already using the SIA process and this audit report to help us demonstrate to others where and how Scotland can contribute to this transformational global agenda.

8.9 Indeed, we have a long and proud history of collaborating with the best and we will continue to do this where there are clear complementarities and strong alignment with our strategic objectives. For instance, constructive discussions with the Northern Powerhouse have already taken place and these are giving rise to new partnerships, collaborative ideas and areas of joint working. The partners involved in SMS-IC have also been using the SIA process to highlight Scotland's opportunity and explore new collaborations with partners in Finland, the USA and British Columbia in Canada.

8.10 Encouragingly, the SIA process has energised partners, strengthening their commitment to realise our vision and provided an opportunity for them to foster new relationships across the ecosystem. It has enabled us to shine a spotlight on Scotland's impressive and internationally recognised PM related capabilities.

8.11 Informed by robust evidence, we have identified a number of focused new investment propositions designed to complement our existing activities and take us towards our long-term goal of translating Scotland's well-established scientific excellence into innovation-led inclusive growth. Many of the pre-requisites for success are in place, but this SIA report has revealed some important gaps which we are determined to fill so we can grow a large and dynamic cluster of exporting frontier firms.

Annex A: Members of the SIA Steering Group

Table A-1: Steering Group members

Name	Position	Company	Location
Professor Dame Anna Dominiczak (Chair)	Regius Professor of Medicine; Vice-Principal and Head of College of Medical, Veterinary and Life Sciences	University of Glasgow	Glasgow, UK
	Honorary Consultant Physician & Non-Executive Member	NHS Greater Glasgow and Clyde Health Board	
Dr Victor Dzau	President	US National Academy of Medicine, of the US National Academy of Sciences	Washington DC, USA
Mr Peter Silvester	President – Biosciences Division	Thermo Fisher Scientific	California, USA
Dr Menelas Pangalos	Executive Vice President – Innovation Medicines and Early Development Biotech Unit	AstraZeneca	Cambridgeshire, UK
Dr Ken Sutherland	President	Canon Medical Research Europe Ltd	Edinburgh, UK
	Chair	Scottish Lifesciences Association	
	Industry Advisor to Scottish Government	Life Sciences Industry Leadership Group	
Mr Sinclair Dunlop	Managing Partner	Epidarex Capital	Edinburgh, UK
Mr Ricky Verrall	Head of the Chief Scientists Office	Scottish Government Health Directorates	Edinburgh, UK
Dr Stuart Fancey	Director of Research and Innovation	Scottish Funding Council	Edinburgh, UK
Dr Julia Brown	Portfolio Director - High Value Manufacturing & Health	Scottish Enterprise	
Mr John Brown	Chairman	NHS Greater Glasgow and Clyde	Glasgow, UK
Dr David Sibbald	Chair	Stratified Medicine Scotland Innovation Centre	Glasgow, UK
	Executive Chairman	Aridhia	
Ms Annemarie O'Donnell	Chief Executive	Glasgow City Council	Glasgow, UK
Dr Carol Clugston	Chief Operating Officer, College of Medical, Veterinary and Life Sciences	University of Glasgow	Glasgow, UK

Annex B: Members of the SIA Delivery Group

Table B-1: Delivery Group members

Name	Position	Company
Dr Carol Clugston (Chair)	Chief Operating Officer, College of Medical, Veterinary and Life Sciences	University of Glasgow
Dr Jane Townson	Deputy Chief Operating Officer, College of Medical, Veterinary and Life Sciences	University of Glasgow
Dr Diane Harbison	Chief Executive Officer	Stratified Medicine Scotland Innovation Centre
Dr John Gordon	Entrepreneur in Residence/Director of Commercialisation	University of Glasgow
Ms Alice Gee	Policy & Business Intelligence Manager	University of Glasgow
Dr Susie Mitchell	Programme Director, Glasgow City of Science and Innovation	Glasgow City of Science & Innovation
Mr Michael McNally	Group Manager, Employment & Strategy, Development and Regeneration Services	Glasgow City Council
Dr Sharon McKendry	Head of Trade and Investment for Life and Chemical Sciences	Scottish Enterprise
Dr Ed Hutchinson	Precision Medicine, Strategy Lead, High Value Manufacturing and Health Sector Team	Scottish Enterprise
Mr Luke Delahunty	Director	SQW
Mr John Nolan	Managing Consultant	SQW

Annex C: Stakeholder organisations

C.1 The SIA consortium would like to thank the valuable contributions made by stakeholder organisations to this SIA. More than 40 individuals from the following organisations participated in the stakeholder consultations carried out by SQW:

- Aridhia Informatics
- AstraZeneca UK
- Bioclavis
- Bristol-Myers Squibb Pharmaceuticals Ltd
- Canon Medical Visualization Systems
- CGI Group
- Chief Scientist Office, Scottish Government
- Epidarex Capital
- Farr Institute of Health Informatics Research
- Glasgow Chamber of Commerce
- Glasgow City Council
- Glasgow Polyomics
- GSK UK
- Imaging Centre of Excellence, QEUH campus
- MR Coil Tech
- NHS Greater Glasgow and Clyde
- NHS Research Scotland
- Nokia
- Pfizer
- ReproCELL Europe
- Scottish Enterprise
- Scottish Funding Council
- Scottish Investment Bank
- Scottish Genomes Partnership
- Scottish Life Sciences Association
- Skills Development Scotland

- Spiritus Partners
- Stratified Medicine Scotland Innovation Centre
- Thermo Fisher Scientific Ltd
- University of Aberdeen
- University of British Columbia, Canada
- University of Dundee
- University of Edinburgh
- University of Glasgow
- US National Academy of Sciences
- Usher Institute of Population Health Sciences and Informatics.

Annex D: Detailed science and innovation analysis

Scotland's universities and research institutes

Science and Technology employment

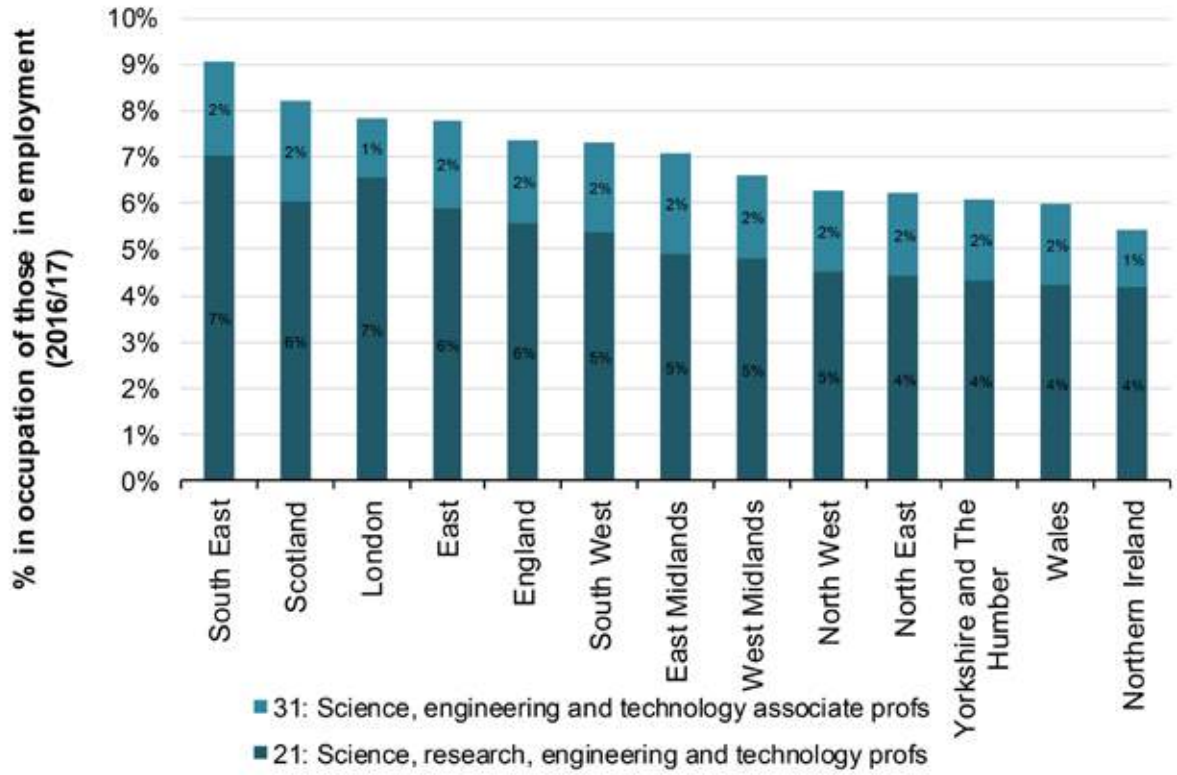
D.1 There were around 154,000 science and technology jobs in Scotland last year. This represents eight per cent of all jobs in Scotland and this is the second highest level of employment across all parts of the UK (Figure D-1).

Table D-1: Enrolment at Scottish Universities in 2016/17

	Undergrads	Postgrads	Total	International students
University of Aberdeen	10,210	3,940	14,150	4,420
University of Abertay Dundee	3,455	390	3,845	545
University of Dundee	10,590	4,800	15,390	2,235
Edinburgh Napier University	10,520	2,390	12,910	2,460
University of Edinburgh	21,645	10,265	31,910	11,490
Glasgow Caledonian University	13,505	2,910	16,415	2,025
Glasgow School of Art	1,585	610	2,195	755
University of Glasgow	20,420	8,195	28,615	8,235
Heriot-Watt University	7,410	3,090	10,500	3,090
Queen Margaret University	3,460	1,750	5,210	1,110
Robert Gordon University	9,065	3,465	12,530	2,250
Royal Conservatoire of Scotland	845	310	1,155	315
University of St Andrews	8,250	2,080	10,330	4,695
SRUC	1,520	100	1,620	80
University of Stirling	8,585	3,480	12,065	2,460
University of Strathclyde	15,590	7,365	22,955	4,190
University of the Highlands and Islands	8,055	665	8,720	300
University of the West of Scotland	13,390	2,565	15,955	1,635
Scotland total	**168,100**	**58,370**	**226,470**	**52,290**

Source: SQW analysis of HESA data

Figure D-1: Science and Technology professions in different parts of the UK



Source: SQW analysis of Annual Population Survey

D.2 The largest concentrations of science and technology jobs are in Edinburgh (37,000) and Glasgow (16,000) where they account for 14% of all jobs in the two cities (Table D-2).

Table D-2: Concentrations of science & technology employment in Scotland (based on local authorities)

Local Authority	Science & Technology employment (2016/17)	% of workforce
Edinburgh	37,400	14%
Glasgow City	16,100	14%
Aberdeen City	14,300	11%
Aberdeenshire	4,875	10%
Fife	4,125	9%

Source: SQW analysis of Annual Population Survey

Quality of research

D.3 The REF 2014 is one of the most important indicators of research quality. Across all units of assessment, the Universities of Edinburgh and Glasgow are both in the UK top 15 for research *power*. Six Scottish universities were ranked in the top 50 in the UK for the *quality* of their research.

Table D-3: Research excellence from REF 2014[83]

	Research Power (overall)	Grade Point Average (overall)
University of Edinburgh	4	11
University of Glasgow	12	24
University of Aberdeen	29	46
University of Strathclyde	31	37
University of St Andrews	32	21
University of Dundee	39	38
Heriot-Watt University	44	33
University of Stirling	52	48

Source: SQW analysis of REF and Technopolis compiled data

Research funding, commercial income & commercialisation

D.4 As research funding is allocated on a competitive basis, the share of Research Council funding awarded to organisations in Scotland is another way to demonstrate excellence and national significance.

D.5 Over the last five years (covering the period 2013 to 2018), 776 Biotechnology and Biological Sciences Research Council (BBSRC) grants have been secured by Scottish based organisation with an aggregate value of £250m. Over 400 of these projects totalling £150m were for the Universities of Edinburgh and Glasgow. Scotland has enjoyed the third highest number of awards out of all UK regions and second highest amount of BBSRC funding during this five year period. The highest number of awards (1052) were to organisations in the East of England.

D.6 Another 250 project grants have been received from the Medical Research Council (MRC) over the same five year period. Around three quarters of these grants were secured by the Universities of Edinburgh and Glasgow. Again, Scotland compares well against other parts of the UK in terms of the number of awards (4th highest) and value (3rd highest). In addition to these awards, the MRC contributed £16m to enable the construction of the University of Glasgow's new £32m Imaging Centre of Excellence at the QEUH, as part of the Glasgow City Region City Deal. The MRC has also supported Scotland's two MRC/EPSRC Molecular Pathology Nodes (in Edinburgh and Glasgow), the UK's largest being located at Glasgow's QEUH. The MRC's investment in Scotland also includes 12 MRC Institutes, Units and Centres

[83] Note that universities are only included if they are in the UK top 20 for research power and/or quality for a precision medicine related subject

Table D-4: BBSRC awards (2013-18)

	No. of awards	Value of awards £m
East of England	1052	302.0
London	873	232.2
Scotland	776	247.3
South East	764	217.6
North West	511	144.4
East Midlands	494	103.9
Yorkshire and the Humber	462	134.2
West Midlands	422	107.5
South West	340	106.8
North East	201	42.0
Wales	152	35.3
Northern Ireland	27	9.6
UK total	**6074**	**1,682.7**

Table D-5: MRC awards (2013-18)

UK region/ country	No. of awards	Value of awards £m
London	871	567.8
South East	340	260.8
North West	261	163.2
Scotland	**250**	**204.6**
East of England	224	162.2
South West	144	67.5
Yorkshire and the Humber	142	87.0
West Midlands	121	62.2
East Midlands	103	62.5
Wales	69	61.7
North East	62	64.8
Northern Ireland	18	11.5
UK total	**2605**	**1,775.9**

Source: SQW analysis of BBSRC grant data

D.7 Scotland has obtained around 13% of all UK funding through these two Research Councils (most relevant to the area of PM). Compared to the c.8% of the UK's population and c.11% of universities that Scotland accounts for, this shows that our institutions 'punch above their weight' in attracting research income.

D.8 In addition, four Scottish universities (Dundee, Edinburgh, Glasgow and St Andrews) are in the top 30 for attracting Wellcome Trust grants. Over the last five years, these universities have received 427 grants totalling £316m from these funds.

D.9 HEBCI data reveal that our universities earned a total of £150m of collaborative research income involving public funding, and a further £111m in contract research income in 2015/16 (12% and 9% of the respective UK totals). The University of Edinburgh generated the 7th largest amount of collaborative research income in the UK, whilst the University of Glasgow had the 10th highest contract research income figure (Table D-6).

Table D-6: Top 5 Scottish universities for research income (2015/16)

University	Collaborative research income £m	UK ranking	University	Contract research income £m	UK ranking
University of Edinburgh	47.6	7	University of Glasgow	36.6	10
University of Strathclyde	38.0	11	University of Strathclyde	13.3	21
University of Glasgow	22.5	20	University of Dundee	12.2	24
University of Aberdeen	18.2	25	University of Aberdeen	12.1	25
University of the Highlands and Islands	8.8	34	University of St Andrews	8.8	31

Source: SQW analysis of HE-BCI data

D.10 Finally, HEBCI data reveal that in 2015/16 there were 179 active spin-offs with some level of Scottish university ownership. At the institutional level, five of Scotland's universities were in the UK top 20 for active spin-offs with some university ownership; Aberdeen, Edinburgh, Glasgow, St Andrews, Strathclyde. In terms of active graduate start-ups, Edinburgh Napier is the most successful Scottish university, and is in the UK top 20, with almost 200 graduate start-ups trading in 2015/16.

Overview of Scotland's economy

D.11 Over the last five years, Scotland's economic output as measured by GVA has increased by 18% to £134bn in 2016 (Table D-7). This represents around 8% of the GB economy.

D.12 Scotland performs very strongly in terms of inward investment and has consistently been the second most attractive part of the UK (after London) for FDI projects over the last 10 years[84]. In 2016, there were 122 FDI projects and over the last decade Scotland has attracted 771 projects. In 2016, there was £75.6bn in sales of goods and services outside Scotland, of which £29.8bn were international exports. Although Scotland has been increasing the number of exporting firms, we still have fewer exporters compared to other parts of the UK.

D.13 The highest levels of GVA growth recently have been seen in tourism related industries (46% uplift), property (27%) and ICT sectors (26%). In terms of current GVA output, the largest sectors in Scotland are property, manufacturing and wholesale and retail. The GVA output from key (high value) sectors such as ICT and professional, scientific & technical services is lower than the GB average.

Table D-7: GVA performance by sector (2016 £m)

	Scotland	GB	Scotland GVA growth 11-16	Scotland % of GB
Agriculture, forestry & fishing (A)	1,621	8,768	5%	18%
Mining, quarrying & utilities (B,D and E)	8,662	49,727	25%	17%
Manufacturing (C)	14,280	170,665	17%	8%
Construction (F)	8,448	106,246	18%	8%
Wholesale, retail trade; motor trade (G)	13,915	186,665	18%	7%
Transport & storage (inc postal) (H)	5,944	75,757	19%	8%
Accommodation & food services (I)	4,439	51,883	46%	9%
Information & communication (J)	5,052	105,155	26%	5%
Financial & insurance (K)	7,695	113,741	4%	7%
Property (L)	16,742	236,101	27%	7%
Professional, scientific & technical (M)	8,485	133,439	21%	6%
Business admin & support services (N)	5,223	79,733	16%	7%
Public administration & defence (O)	8,021	76,789	11%	10%
Education (P)	7,920	98,585	1%	8%
Health (Q)	12,766	124,620	14%	10%
Other services (R,S,T and U)	5,233	71,904	27%	7%
Total	**134,445**	**1,689,778**	**18%**	**8%**

Source: SQW analysis of ONS GVA data

[84] EY (2017), EY's Attractiveness Survey: Scotland

D.14 Scotland has a workforce of just under 2.5m, again 8% of the GB total (Table D-8). Compared to GB as a whole, Scotland has higher levels of employees in mining and utilities, agriculture and fishing, public admin, health, and construction. There is under-representation in sectors such as ICT, professional, scientific & technical services, and business services.

Table D-8: Employees by sector (2016)

	Scotland	GB	Scotland % of GB	Location Quotient
Agriculture, forestry & fishing (A)	36,000	212,000	17%	2.0
Mining & utilities (B,D and E)	68,000	373,000	18%	2.1
Manufacturing (C)	176,000	2,368,000	7%	0.9
Construction (F)	134,000	1,346,000	10%	1.2
Wholesale, retail trade; motor trade (G)	357,000	4,450,000	8%	0.9
Transport & storage (inc postal) (H)	105,000	1,416,000	7%	0.9
Accommodation & food services (I)	182,000	2,169,000	8%	1.0
Information & communication (J)	73,000	1,233,000	6%	0.7
Financial & insurance (K)	86,000	1,035,000	8%	1.0
Property (L)	35,000	478,000	7%	0.9
Professional, scientific & technical (M)	170,000	2,516,000	7%	0.8
Business admin & support services (N)	184,000	2,608,000	7%	0.8
Public administration & defence (O)	154,000	1,260,000	12%	1.4
Education (P)	188,000	2,601,000	7%	0.9
Health (Q)	406,000	3,865,000	11%	1.2
Other services (R,S,T and U)	129,000	1,339,000	10%	1.1
Total	**2,482,000**	**29,268,000**	**8%**	**1.0**

Source: SQW analysis of BRES data

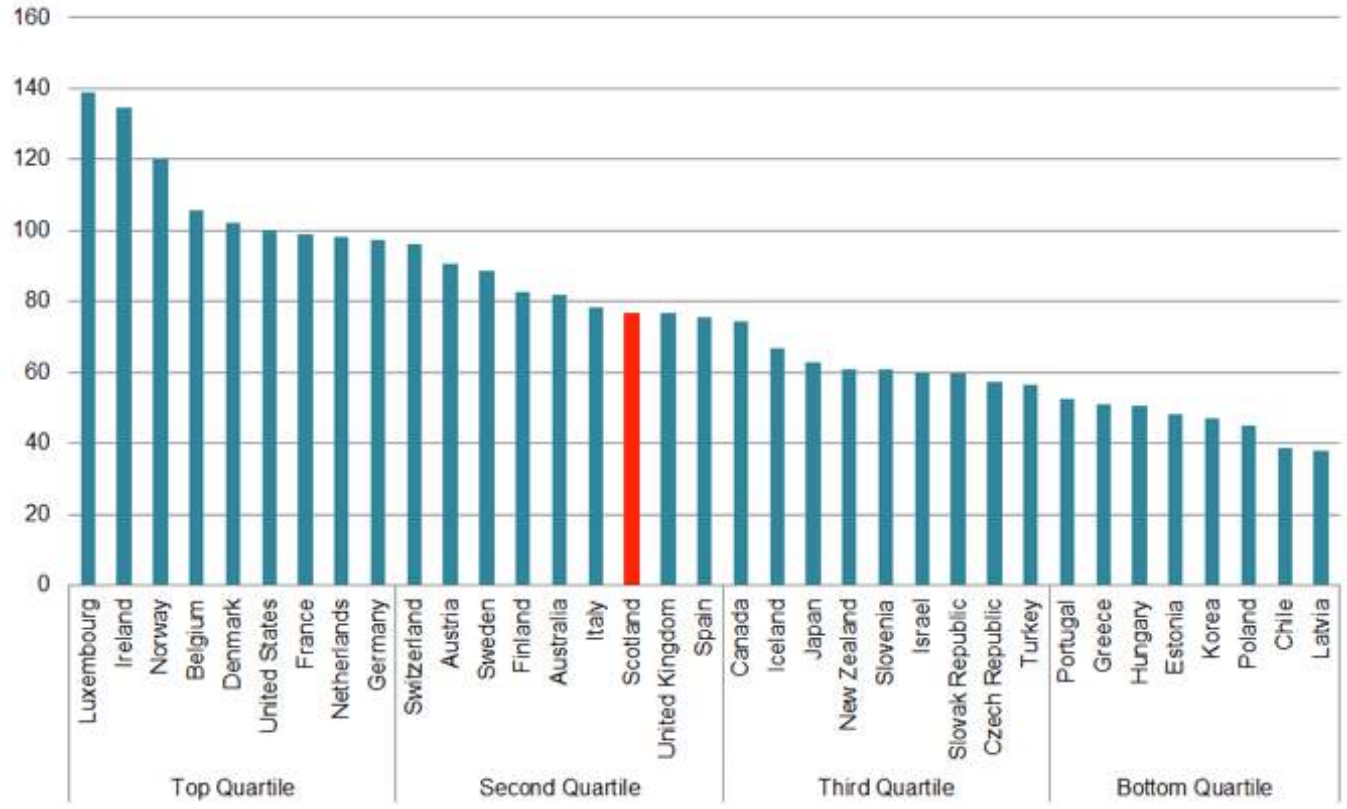
D.15 Over recent years, improving economic productivity has been a key challenge in Scotland and the UK more generally. However, there are encouraging signs of recovery with GVA per filled job increasing by 30% in Scotland over the last decade, compared to growth of 23% observed across the UK more widely. However, GVA output per filled job in Scotland (£52,000) is still slightly lower than the UK average of £53,000. There is a similar story when looking at GVA per hour worked (Figure D-2).

D.16 Internationally, both Scotland and the UK's productivity figures are in the second quartile of OECD countries showing that there remains a lot of work to be done to improve our economic performance. The development of our PM cluster will help create more highly skilled and well paid jobs in Scotland. The average GVA per job in Scotland's life sciences sector is estimated to be around £77,000, significantly higher than across the wider economy[85].

[85] Scottish Government – Growth Sector Database

D.17 Another measure of productivity is Gross Domestic Product (GDP) per hour worked. Scottish Government analysis of OECD data highlighted that Scotland and the UK sit towards the bottom end of the second quartile of OECD countries for productivity.

Figure D-2: GDP per hour worked in OECD countries, 2015 (USA=100)



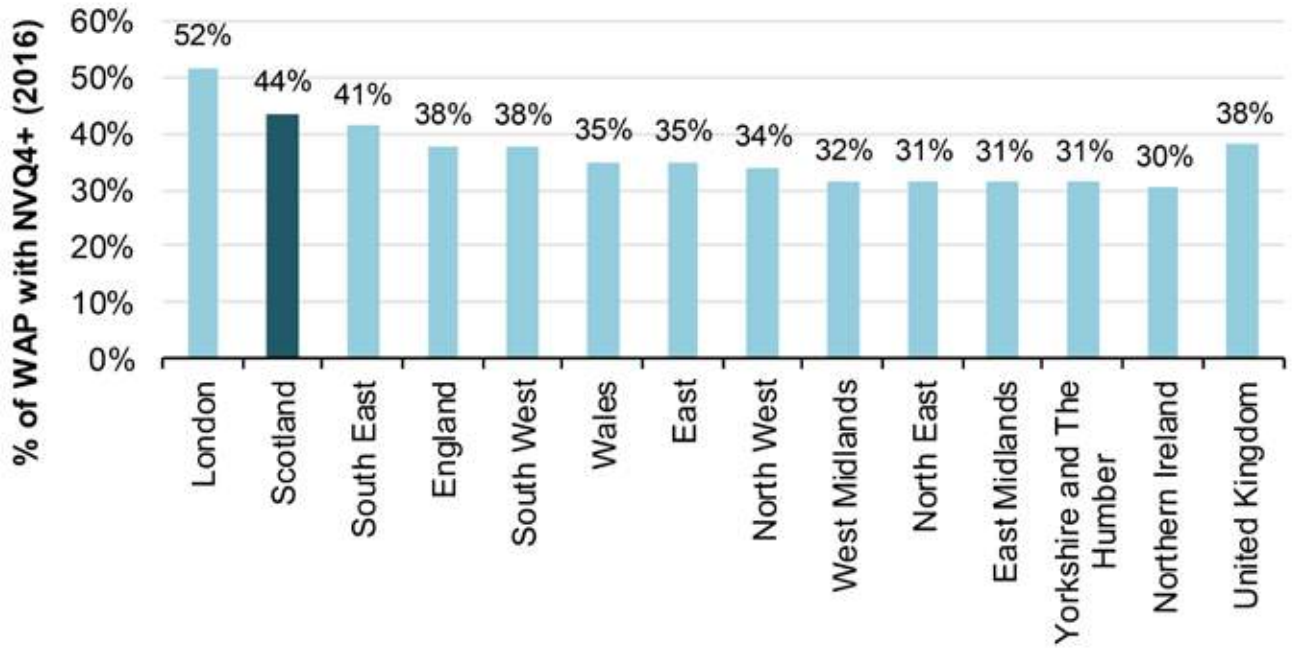
Source: Scottish Government

D.18 Around 77% of Scotland's working age population is economically active, which is broadly in line with the UK average. The South East of England has the highest rate at 81%. In terms of employment and unemployment, Scotland is also close to the UK averages, with 73% in work and 5% currently unemployed (and looking for work)[86].

D.19 One notable strength of Scotland's workforce is around skills with nearly half (44%) of the working age population qualified to NVQ level 4 or above (Figure D-3). This is higher than the UK average of 38% and second to only London across the different parts of the UK.

[86] All 2016 based data from the Annual Population Survey

Figure D-3: Proportion of workforce qualified to NVQ4 or above



Source: SQW analysis of BRES data

D.20 There are wide variations in economic performance across Scotland, driven in large part by population density, the location of key industries, and wider socio-economic conditions. The largest Council areas in terms of population, GVA output and employment are Edinburgh and Glasgow (Table D-9). GVA per job is highest in Aberdeenshire and Aberdeen City, driven in large part by oil and gas related GVA output. Edinburgh is also high due to the presence of a large financial and business services sector.

Table D-9: Summary of key economic metrics (based on local authorities)

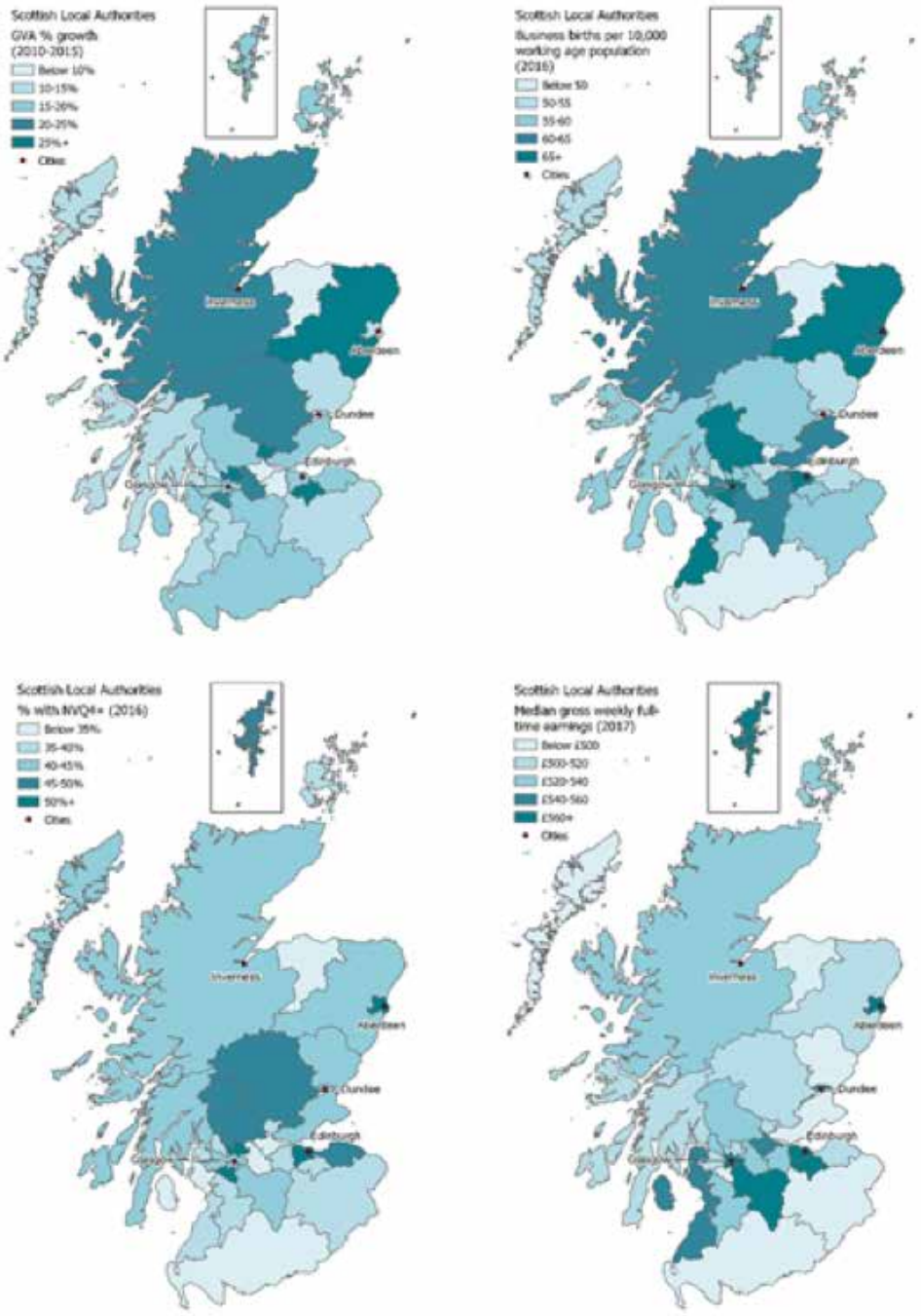
Population (2016)		GVA £bn (2015)		GVA per job £ (2015)		Employment (2016)	
Glasgow	615,070	Glasgow	19.6	Aberdeen-shire	67,200	Glasgow	421,000
Edinburgh	507,170	Edinburgh	18.4	Aberdeen	58,800	Edinburgh	334,000
Fife	370,330	Aberdeen	10.8	Edinburgh	56,500	Aberdeen	179,000
North Lanark-shire	339,390	Aberdeen-shire	7.3	Angus	56,300	Fife	136,000
South Lanark-shire	317,100	Fife	6.7	East Renfrew-shire	56,100	North Lanark-shire	131,000

Source: Annual Population Survey/ ONS/ BRES

D.21 It is recognised that although Scotland produces world-class research, there has been more limited success in commercialising and leveraging this research excellence. Historically, there has been a lower business birth rate in Scotland compared to other parts of the UK. In 2016, there were 22,270 new firms created in Scotland, which represents 64 new firms per 10,000 working age population compared to 100 for the UK. The highest numbers of new firms are in the Edinburgh and Glasgow city regions.

D.22 In terms of economic participation, there are also notable differences with around 90% of the working age population in Shetland and Orkney economically active compared to around 72% in Dundee and Glasgow. There also continues to be higher than average unemployment rates in the former industrial areas of Scotland. Glasgow continues to experience stubborn challenges around socio-economic and health deprivation.

Figure D-4: Differing economic performance across Scotland



Source: Produced by SQW 2018. Licence 100030994. Contains OS data © Crown copyright [and database right] [2018] using data from Annual Population Survey, ONS Business Demography, ONS Regional GVA Income Approach

Economic clusters

D.23 The Scottish Government has identified six 'growth sectors', which cover the country's key sectoral strengths. These are summarised in Table D-10. The GVA output of these six sectors account for a third of Scotland's total GVA of £134bn, but this calculation is based on quite narrow SIC-based definitions.

D.24 Overall, Scotland has a diverse mix of sectoral strengths including tourism and food and drink, energy (primarily oil and gas and renewables) and associated engineering activity, financial and business services, creative industries and most importantly in the context of this SIA, life sciences. Scotland's universities and colleges play an important role in supplying the skills pipeline for these key sectors.

D.25 Scotland also has strong skills and expertise in emerging technologies and data science and these were the focus of two previous SIAs: Enabling and Emerging Technologies in Scotland's Central Belt; and Data Driven Innovation in Edinburgh and the South East Scotland City Region. The development of digital technologies, which were central to these SIAs, is also at the core of our PM proposition.

Table D-10: Scotland's growth sectors

Sector	Key economic metrics	Summary
Life Sciences	• £1.3bn GVA (2015) • £77,000 GVA per worker (2015) • 16,000 jobs (2016) • £1.3bnin exports (2016) • £265m in BERD (2016), 25% of Scotland total	• A wider analysis of the sector by Scottish Enterprise including the supply chain estimates 37,000 people working in the sector and £2bn in GVA • Key employment locations are Edinburgh City, Renfrewshire, Highland, Midlothian, Glasgow City and West Lothian
Food and Drink	• £5.2bn GVA (2015) • £45,000 GVA per worker (2015) • 111,000 jobs (2016) • £10.1bn in exports (2016) • £17m in BERD, 1.8% of Scotland total (2015)	• Key employment locations are Aberdeenshire, Highland, Dumfries & Galloway, South Lanarkshire and Moray
Financial and Business Services	• 232,000 jobs (2016) • £13.2bn in exports (2016) • £145m in BERD (2016), 13% of Scotland total • No GVA data available	• Half of employment is based in Edinburgh and Glasgow

Sector	Key economic metrics	Summary
Energy (including Renewables)	• £16.4bn GVA (2015) • £223,000 GVA per worker (2015) • 70,000 jobs (2016) • £13.9bn in exports (2016) • £101m in BERD (2016), 9% of Scotland total	• Over half of employment is based in the North East of Scotland (Aberdeen City and Aberdeenshire)
Sustainable Tourism (Tourism related Industries)	• £3.8bn GVA (2015) • £18,000 GVA per worker (2015) • 207,000 jobs (2016) • £900m in exports (2016) • £5m in BERD (2015), 0.5% of Scotland total	• Key employment locations are Aberdeen City, City of Edinburgh, Glasgow City, and Highland
Creative Industries (including Digital)	• £4.6bn GVA (2015) • £68,000 GVA per worker (2015) • 84,000 jobs (2016) • £2.9bn in export (2016) • £165m in BERD (2016), 15% of Scotland total	• Key employment locations are Aberdeen City, City of Edinburgh and Glasgow City

Source: SQW analysis of Scottish Government Growth Sector Database and Sector Briefings

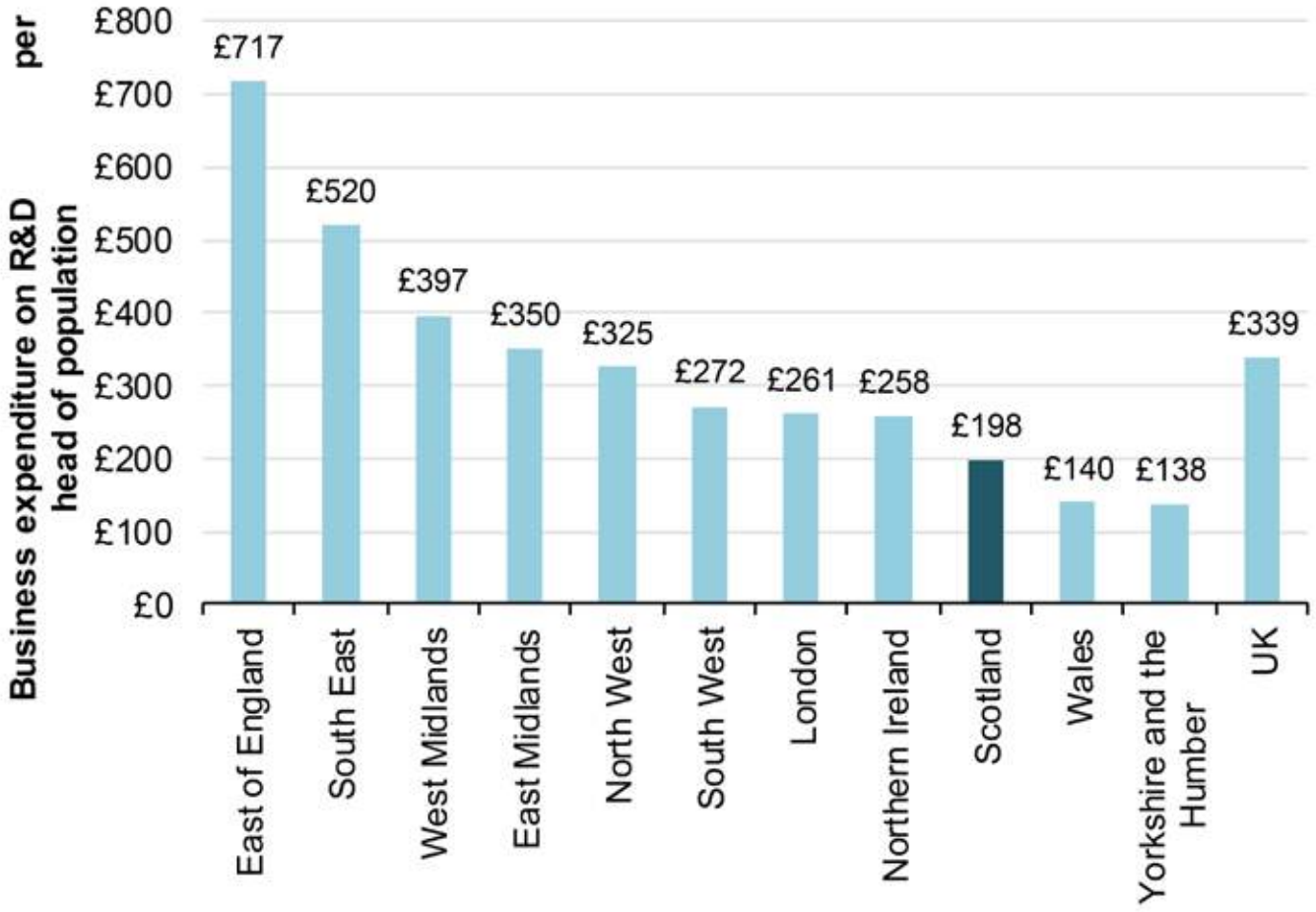
Business innovation

D.26 The amount that businesses spend on R&D (BERD) is one of the main indicators of the level of innovation within an economy. Scotland has traditionally had lower levels of BERD than other parts of the UK, but there has been significant progress made over the last 10 years. During this period, Scotland's BERD increased from £460m in 2006 to £1.07bn in 2016 - impressive growth of 133% compared to a UK increase of 57%.

D.27 Scotland's figure equates to just under £200 per head of population, which is some way down on the UK average of £340 (Figure D-5). The latest results from the UK Innovation Survey[87] also show a lower proportion of 'innovation active' enterprises in Scotland - 50% compared to 53% of UK enterprises.

[87] Scottish Government (2016), UK Innovation Survey 2015 - Results for Scotland

Figure D-5: Business expenditure on R&D per head of population



Source: SQW analysis of ONS Gross Expenditure on R&D

D.28 Innovate UK (now part of UK Research and Innovation) provide various types of grants through the Catapults, Catalysts and Industrial Strategy Challenge Fund to support businesses and research organisations to drive innovation. Over the last five years, Scotland has secured just over 1,300 projects (around 8%) totalling £163m (5% of the total grant value). This is broadly in line with what would be expected, given Scotland's GVA is 8% of the UK total and it accounts for c.6% of the UK's business base. The highest number of IUK projects were funded in London (3,021 grants) and South East England (2,873) with Scotland ranked 8th out of all UK nations and regions.

Table D-11: Innovate UK grants 2013-18

Region	No. of projects	Total value of grants offered £m	Av project value £
London	3,021	786.4	260,300
South East	2,873	521.2	181,400
East of England	1,935	295.4	152,700
North West	1,599	132.0	82,500
South West	1,564	786.4	260,300
West Midlands	1,487	303.7	204,200
East Midlands	1,348	786.4	167,500
Scotland	1,339	162.7	260,300
Yorkshire and the Humber	1,167	786.4	174,500
North East	649	179.8	260,300
Wales	573	61.5	107,400
Northern Ireland	239	42.6	178,400
UK total	**17,794**	**3,371.6**	**189,500**

Source: SQW analysis of Innovate UK data

D.29 Scotland performs better in terms of Health and Life Science grants from Innovate UK. Over the past five years, we have secured 11% of all grants and 6% of the total value. For these grants Scotland is ranked 4th across the UK, behind London, South East and East of England.

Table D-12: Health and Life Science Innovate UK grants 2013-18

Region	No. of projects	Total value of grants offered £m	Av project value £
London	284	188.6	664,000
South East	281	72.6	258,400
East of England	251	50.7	201,900
Scotland	196	188.6	139,300
East Midlands	141	16.2	114,600
North West	136	25.5	664,000
South West	117	188.6	349,000
Yorkshire and the Humber	98	16.4	167,800
West Midlands	97	12.8	131,500
Wales	79	11.3	143,400
North East	57	7.4	129,400
Northern Ireland	32	7.1	221,400
UK total	**1769**	**476.6**	**269,400**

Source: SQW analysis of Innovate UK data

Innovation ecosystem

D.30 Scotland has a well-established innovation support ecosystem including NHS Research Scotland, individual NHS Health Boards, universities, the enterprise agencies (SE, HIE, SDI), Skills Development Scotland, Scottish Funding Council, Further Education colleges, Business Gateway, local councils, trade bodies and Chambers of Commerce. There is a range of business finance products available from providers including the Scottish Investment Bank (debt and equity finance), local authority loan funds, and a strong network of angel investors.

D.31 We also have a network of eight Innovation Centres, which was set up to support collaboration between universities and businesses in emerging technology areas. Four of these centres have key roles to play in supporting our PM efforts: the Stratified Medicine Scotland Innovation Centre (SMS-IC); the Centre for Sensors and Imaging Systems; DataLab; and the Digital Health and Care Institute. Scotland is also well engaged with Innovate UK's Catapult network, particularly in terms of High Value Manufacturing, Offshore Renewable Energy and Satellite Applications. Glasgow is a recognised Innovate UK Centre of Excellence in Precision Medicine.

Annex E: PM market review

Size of market opportunities in Precision Medicine

E.1 The following estimates have been gathered from reports by different market intelligence agencies. As the full reports are behind a paywall, we are unable to comment on the methodology for estimation and how the markets have been defined in the report. Moreover, the baseline from which the expected market size is being calculated differs greatly from report to report, resulting in high variability in the estimates of future market size. Nevertheless, the compound annual growth rate (CAGR) is expected to be around double digits over the next 5 to 8 years (range, 9.7% to 14%), putting the market size around the period 2023 to 2026 at approximately 7.75 to $172.95bn USD.

Table E-1: Size of market opportunities in Precision Medicine

Year	Expected market size (billion USD)	Expected compound annual growth rate (CAGR)	Baseline Year (amount in billion USD)	Reference Number
2023	NA	9.70%	2015 (15.0)	8
2023	7.75	11.90%	2016 (3.5)	2
2024	35.50	13.00%	2014 (33.0)	11
2024	NA	10.56%	2016 (43.6)	5, 6
2024	172.95	14.00%	2016 (56.0)	9, 10
2025	112.62	11.20%	2016 (NA)	1
2026	141.70	11.56%	2017 (NA)	3

Source: Technopolis

Main growth areas

Market segmentation

E.2 The PM market is frequently segmented in three different ways: by technology, by application and by end user.

E.3 **Segments by technology:** Drug discovery (e.g. targeted therapeutics), gene sequencing, big data analytics, bioinformatics, companion diagnostics and others [1, 3, 6, 8, 11]

- Additional segmentation of the market by areas such as Biomarkers, Pharmacogenomics, 3D printing and Consumer Genomics [1, 3] is also found in some analyses.

E.4 **Segments by application**: Oncology, Respiratory, Immunology, Central Nervous System (CNS) or Neurology, other [6, 8, 9, 11]

- Cardiology and Infectious disease [1, 9] are sometimes included as separate segments.

E.5 **Segments by End User**: Pharmaceuticals, Biotechnology, Diagnostics, Healthcare IT/Big Data and Clinical Laboratories. [1, 11]

Areas of growth

E.6 Overall, the areas currently dominating the market are expected to continue to do so in the next five to ten years. They are expected to grow in line with the growth of the market as a whole. Specifically, across the three segmentation types, the strongest areas are Oncology in terms of applications [3, 6,] drug discovery [5, 6] and big data analytics[11] in terms of applications and diagnostic tools companies in terms of end users [11].

E.7 Among the technology segments, Drug Discovery accounts for the largest market share and is expected to grow by 8.3% CAGR between 2017 and 2024 supported by advances in pharmacogenomics and companion diagnostics [5, 6]. Other growth areas are Big Data Analytics, Gene Therapy, Bioinformatics and Next-Generation Sequencing [5, 6, 9]. Big Data Analytics is expected to dominate the market by 2024 according to one report [11].

E.8 Some of the technologies that are gaining momentum or are expected to see growth by 2025 are. [1, 4]

- Companion diagnostic biomarkers and targeted therapeutics
- Genomics technologies for precision diagnostics e.g. for Cancer and Alzheimer's disease
- Next generation sequencing informatics solutions
- Artificial Intelligence (AI) and machine learning
- Digital radiology and digital pathology
- Next-generation monoclonal antibody-based platforms
- Molecular imaging diagnostics and informatics solutions
- Brain imaging techniques
- Human specimen and imaging biobanking services – Global integration of biobank networks/hubs into healthcare systems is essential for the future of precision medicine
- Remote patient monitoring solutions
- Exogenous factors and lifestyle monitoring – Lifestyle and exogenous factors contribute >50% of data towards patient stratification
- Clinical decision support systems
- Other new IT technologies.

E.9 As already mentioned, oncology is the dominant area in terms of revenue among the application segments and this trend is expected to continue [3, 6]. The CAGR has been estimated at about 10.4% up to 2026 [3] and >13.5% (reaching about $69bn) until end 2024 [9] in two separate reports. In addition to Oncology, Immunology applications are expected to show significant growth [3, 9, 11]. According to one estimate, while Oncology is expected to command the largest share of the market, the highest CAGR is expected in the Immunology segment with the market reaching $11.27bn USD in 2026 [3]. Another, reports that the Immunology market will grow mainly on the back of arthritis related R&D[10]. The Respiratory segment is another growth area [6]. Haematology, Ophthalmology, Endocrine Diseases, Cardiovascular Diseases, Renal Disease, Metabolic Disease, Skin and Psychiatric Diseases have also been mentioned as major areas of interest for PM [1].

Key geographic markets

E.10 Geographically, the market is divided into the usual regional sectors of North America, Latin America, Europe, Asia Pacific and the Middle East and Africa (MEA).

E.11 The PM market is dominated by North America (>35% of market share[9]) and is expected to grow at a CAGR of 8.5%, 9.66% or >13.5% depending on the estimate[3, 8, 10]. The US constituted the largest regional share in 2016 and is expected to drive growth in the region along with Canada, courtesy of a high incidence of cancer, favourable regulatory scenario and government initiatives in the area of PM [6, 8].

E.12 Germany dominates the European market (over $2.6bn USD market in 2016) and along with UK, France, Italy, Spain and Scandinavia will drive growth in this region (estimated CAGR >13%) [6, 10, 11]. Germany is very influential in the European market because of a wide range of solutions and services being offered[11].

E.13 However, the Asia Pacific region is expected to grow faster, at a projected CAGR of 15.09% according to one estimate and >14%, according to another[3, 10]. China, Japan and India are expected to drive this growth, while Singapore is also a market of interest[6, 9]. In the next 5-8 years, China is expected to be the epicentre for the Asian region targeted therapeutics market[4].

E.14 Growth in Latin American market is also expected[9]. The major countries to look out for here are Brazil and Mexico, and in the MEA they are Saudi Arabia, Qatar, UEA and South Africa[6].

Overview of key market and technology drivers and barriers

Technology drivers

E.15 The following are the most important drivers for technological innovation in PM:

- Shift in medicine from reaction to prevention and adoption of early stage treatments along with an increased focus on targeted therapy to reduce the amount of trial and error medicine[3, 11]
- Advancement of technology for understanding human biology & disease susceptibility such as gene sequencing, companion diagnostics, pharmacogenomics, bioinformatics, and big data analytics[3,11]
- Accessibility of large-scale human genome databases coupled with advent of next-generation sequencing (NGS) and computational tools coupled with the rising adoption of 'omics' technologies has led to exponential growth in the number of targeted molecules in the pipeline specifically in oncology[5, 6, 9, 10]
- More biomarkers identified for on-market drugs[7]
- Advances in gene therapy which enables medics to target anticancer agents without damaging normal tissues and substitute the non-functional gene with the functional one[5, 6]
- Advances in digital and information technology
- Increased funding and favourable government initiatives[5, 6] – For example:
  - > In the US, 'precisionFDA', a community platform established by the FDA for evaluation of next generation sequencing assays, investment of USD 70m by NIH and the Precision Medicine Initiative (PMI) set up by President Barack Obama in 2015 for developing

innovative solutions for chronic diseases such as cancer based on genomic, environment and lifestyle characteristics of patients [3]

> In Germany, Individualized Medicine Action Plan by the German Federal Ministry along with rising usage of electronic health records for better healthcare outcomes

> In China, government initiatives and investment in research and development for novel biomarkers used to treat cancer

> In UK, stratified medicine initiative in 2011 with €60m budget focused on biomarker, patient cohorts, genomic and phenotypic analysis and 100,000 Genomes Project (in 2012 by Genomics England) with €250-300m funding for genomics.

Market drivers

E.16 The following are the most important drivers for technological innovation in PM:

- Growing prevalence of cancer and increase in ageing population across the globe coupled with rising government focus on reducing disease burden costs [2, 5, 6, 9, 10, 11]
- Rapidly growing healthcare expenditure coupled with rising adoption of gene sequencing and big data analytics in emerging economies [5, 6, 9, 10]
- Payers willing to reimburse the cost of high-value drugs [11]
- Growing demand for non-invasive testing procedures and personalised treatment [3, 11]
- Increasingly informed and active consumer [7]
- Increased number of adverse drug reactions cases and ability to reduce adverse drug reactions through pharmacogenomics testing[3]
- Global expansion of the medical industry because of larger investments (both from government and industry), better infrastructure, simplified approval processes for drugs and companion diagnostics (e.g. in US)[2, 5, 6, 9, 10]
- Ability of industry to patent a molecule along with its companion diagnostics to achieve a competitive edge, profit margin and more usage.[9, 10]

Barriers

E.17 Both R&D of new PM products and their market are being slowed down by the following barriers:

- Clinical, economic, ethical and regulatory conditions[3, 7, 11]
- Data storage and data privacy issues[3, 9, 10]
- Interaction between genes, between genes and environmental factors and between environmental factors can contribute to large variations that are analytically complex to explain[3]
- The high cost of PM (drugs as well as drug discovery)[5, 6, 9, 10]
- Reimbursement landscape in countries like UK and Italy is more restricted, which can restrict

adoption of new innovations in personalised medicine – France, which has a broader reimbursement landscape, has higher diagnostics penetration.[7]

Overview of potential "size of prize" economically

E.18 The growth of PM can be broadly categorized along two dimensions – the number of drugs with companion/associated diagnostics, and the use of advanced diagnostic techniques for screening and risk identification[7]. The first dimension can be further sub-divided by markers for sensitivity/efficacy, safety and resistance, for both new and on-market drugs.

E.19 Interviews conducted by McKinsey & Company (2013) show that many experts believe that although the number of new drugs with associated diagnostics will follow linear growth patterns, the use of advanced diagnostics for therapy selection will have exponential growth. On the drug side, they expect to see a two to three times increase in the number of drugs with companion diagnostics over the next five years. Beyond that, however, growth is likely to accelerate as nearly half of the pre-clinical and Phase 1 candidates in the pharma pipeline have associated diagnostics, especially in oncology, immunology and CNS. Moreover, the identification of markers for safety, sensitivity and resistance for on-market drugs will drive growth to a larger extent in the near term. The identification of markers for on-market drugs will be driven not only by pharma, but also by academic medical centers and health systems. In addition, major pharma/healthcare companies are collaborating with bioinformatics and big data/healthcare IT companies and start-ups to develop new, marketable solutions for handling big data generated from genomics[3]. All these areas present immense economic opportunities, however, the exact "size of prize" is more difficult to determine as there is an ongoing debate over where monetary value will accumulate within the healthcare system.

E.20 From a healthcare payer perspective, diseases such as cancer and rheumatoid arthritis, significant value can be generated by applying markers which predict response and reduce wastage of drugs on non-responders[3, 9.] From a pharma perspective, some high-value drugs will see their market share decline as markers for sensitivity and safety are identified, whereas other drugs will capture greater value through a higher price and duration of treatment for a defined population[7]. Diagnostics will also capture value, but unless the model for reimbursement of diagnostic tests changes drastically, diagnostics companies will only capture a fraction of the value created through advanced personalised diagnostics[7]. Data/IT players will also capture meaningful value by developing solutions for diagnostic data interpretation, clinical decision support, use of AI- and machine learning- generated algorithms, and analytics for R&D[3].

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[88] Please note this item provides market figures for segments of the PM market, however, we noted the apparent figures are in the millions rather than billions which seem inconsistent with the PM market value as a whole

Review of key global PM initiatives

E.21 The objective of this exercise was to provide a summary of the key learning points and success factors from 11 significant PM initiatives from around the world – interventions that have accelerated innovation, adoption within health systems and delivered beneficial impacts including PM cluster development. We conducted online searches with keywords to identify relevant initiatives. We focused on countries that are known to be leading on PM research and implementation. While we found national level programmes in many countries, most were research funding programmes with very similar aims or initiatives with very little information. Rather than including these, we selected initiatives that are more diverse and holistic in nature (e.g. including commercialisation and/or implementation aspects), and which present opportunities for learning or participation. Thus, we have included accelerators, international networks, national initiatives and regional initiatives in this review.

Accelerators

Table E-2: Kraft Precision Medicine Accelerator, United States

Scope	Development of an open-access business model for the entire cancer ecosystem to follow in order to accelerate new therapies to oncology patients
Start Date	2016
Geographic Coverage	Not specified
Funding	US $20m endowment from the Robert and Myra Kraft Family Foundation, Inc.
Main Delivery Partners	Multiple Myeloma Research Foundation & Multiple Myeloma Research Consortium, Harvard Business School
Progress to date	• Developing a business framework that encourages all cancer organisations to align on shared goals, collaborate with one another, and create a collective impact • Identifying and engaging high-performing organisations in the precision medicine ecosystem to collaborate and drive progress • Four workstreams identified to address blockages in the current system: Direct-to-patient, data and analytics, clinical trials and investment • Existing models and new, venture-based models for creating and delivering personalised medicine are being evaluated • Innovations to the typical clinical trial design are also being explored

Learning, if any	• Success factor: Using a business-analysis approach to address inefficiencies in the development of precision medicine rather than a medical research approach • By creating a better end-to-end consumer experience, organisations can engage more patients and encourage them to share their data, resulting in a larger, deeper pool of data to draw on and drive progress in new therapies • Most research organisations protect their data, as it represents a substantial investment of time and money. This bottleneck can be circumvented by forming business partnerships around specific questions, and then identifying and combining existing datasets to answer those questions. Providing incentives and protecting proprietary information as needed can also help.
Weblink	• https://www.hbs.edu/kraft-accelerator/Pages/default.aspx • https://hbswk.hbs.edu/item/a-better-business-model-for-fighting-cancer

Source: Technopolis

Table E-3: Inova Personalized Health Accelerator (IPHA), United States

Scope	Starting, building, commercializing, growing, investing in and exiting medical technology companies in order to deliver superior returns to investors and strategic partners
Start Date	2016
Geographic Coverage	United States, mainly Washington DC and metro area
Funding	From Inova Health System, a not-for-profit healthcare system based in Northern Virginia, and its strategic investment division, Inova Strategic Investments
Main Delivery Partners	Inova Health System (parent organisation), involving a network of hospitals, primary and specialty care practices, medical research institutes, and health and wellness initiatives; IPHA Mentor community consisting of experienced health system executives, medical practitioners, medical researchers, health sciences angel and institutional investors, technology services executives, legal and financial professionals and successful health sciences entrepreneurs
Progress to date	• Investing in companies on a rolling basis with training sessions for them on campus in spring and autumn. Programme involves working closely with the IPHA team to evolve initial stage prototypes to validated products, mature business models and go-to-market plans • HeMemics Biotechnologies, Inc. (HBI) selected as the first IPHA portfolio company. HBI has developed a diagnostic test platform for various bacterial and viral pathogens that can be used for point-of-care diagnostics
Learning, if any	• Success factor: Providing training in addition to investment for companies • This bespoke approach enhances med-tech entrepreneurs' efforts to accelerate new companies through the early stages of product design, capital formation and commercialization

Weblink	• https://www.inovapha.org/

Source: Technopolis

International networks

Table E-4: Global Alliance for Genomics and Health (GA4GH)

Scope	Enabling genomic data sharing for the benefit of human health
Start Date	2013
Geographic Coverage	Worldwide
Funding	Core funding from Canadian International Data Sharing Initiative (Can-SHARE), NIH and Wellcome Trust. Other funders include Australian Genomics Health Alliance, Genome Canada, Cancer Research UK, ELIXIR, Sanofi, Intel, Vertex Pharmaceuticals and Beijing Genomics Institute
Main Delivery Partners	Organisational members from 500 public and private institutions in 45 countries
Progress to date	• Projects funded under technical and foundational (covering data security, regulation and ethics) work streams • Developed Framework for Responsible Sharing of Genomic and Health-Related Data in 2014 • BRCA Exchange, a web portal that pools data on BRCA1/2 genetic variants and corresponding clinical data from around the world, launched in 2015 • In 2017, GA4GH's Matchmaker Exchange platform was used to identify the mutations that cause a rare disease (neuro-immuno-skeletal dysplasia) for the first time • By 2018, 15 of the world's leading genomic research and medicine initiatives (Driver Projects) brought in to collaborate with GA4GH workstreams to help develop international standards for genomic data sharing
Learning, if any	• Success factor: Embedding active contributors from each Driver Project on the Work Streams was instrumental in the development of a Roadmap focused on creating specific, international standards and frameworks for genomic data sharing and helped make it relevant for the community's needs • A federated network (GA4GH) rather than a single database allows different actors around the world to compete and innovate on how best to generate, store and interpret data.
Weblink	• https://www.ga4gh.org/

Source: Technopolis

Table E-5: International Consortium for Personalised Medicine (ICPerMed)

Scope	A platform to initiate and support communication and exchange on personalised medicine research, funding and implementation. The platform will enable global alignment of research and funding activities, and definition of a suitable framework in terms of infrastructures, resources and regulatory procedures to foster the development and implementation of personalised medicine

Start Date	2016 (based on the FP7 project, PerMed, that ran from 2013 to 2015)
Geographic Coverage	Europe and beyond
Funding	Horizon 2020 funding for Secretariat function
Main Delivery Partners	ICPerMed members
Progress to date	• Recommendations of PerMed refined • Public and private 'not-for-profit' health research funding and policy organisations came together to develop a common Action Plan with actionable research and support activities in all areas related to personalised medicine - this will be the basis of ICPerMed's work programme until 2019 - "actionable research items" can readily be converted to research funding programmes on national, regional, European or even international level • "Best Practice in Personalised Medicine" Award launched • "Innovative Concepts on Data Generation and use for Personalised Medicine Research" workshop in 2017 where experts and funders discussed and developed Precision Medicine-related solutions
Learning, if any	• Success factor: High level of participation from all over Europe and beyond, which enables ICPerMed to efficiently map the scientific and political landscape • PerMed showed that real progress in personalised medicine can only be achieved when research and implementation efforts are covering the entire value chain
Weblink	• https://www.icpermed.eu/index.php

Source: Technopolis

National initiatives

Table E-6: Precision Medicine Initiative, United States

Scope	Cancer treatments, creation of a voluntary national research cohort, data privacy, regulatory landscape, public-private partnerships
Start Date	2016
Geographic Coverage	United States
Funding	US$215 million from federal budget
Main Delivery Partners	NIH, FDA, Office of the National Coordinator for Health Information Technology
Progress to date	• Funding allocated towards establishment of biobanks, data and research centres, health care provider organisations (to collect data), participant centres, participant technology systems centres and communications and engagement • NIH "All of Us" Research Programme being beta tested ahead of launch in Spring 2018 – This is a biobank initiative with participants as partners in research, governance and oversight and the NIH is engaging a wide variety of partners across many different communities

Learning, if any	• First Beta testing of the "All of Us" platform uncovered its weaknesses and strengths and also highlighted areas for improvement in terms of participant experience and messaging • Lower participation in initial "All of Us" beta phase than anticipated with some volunteers declining to provide health records because of concerns about privacy and an hour-long online consent process
Weblink	• https://obamawhitehouse.archives.gov/the-press-office/2015/01/30/fact-sheet-president-obama-s-precision-medicine-initiative • https://www.medscape.com/viewarticle/886988

Source: Technopolis

Table E-7: Genomic Medicine Sweden

Scope	To build a new type of infrastructure within Swedish Healthcare that implements Precision Medicine at a national level
Start Date	2017
Geographic Coverage	Sweden
Funding	Swedish Government through Swedish Innovation Agency (Vinnova)
Main Delivery Partners	Key societal stakeholders, Swedish healthcare system, academia and SciLifeLab (a collaboration between Karolinska Institutet, KTH Royal Institute of Technology, Stockholm University and Uppsala University)
Progress to date	• Start-up meeting in September 2017 with Swedish clinicians, diagnosticians and technicians to influence the design of the programme • Preparatory study ongoing – looking at ways to organise and finance the new infrastructure, developing a comprehensive strategy for diagnosing rare diseases and cancer, creating a National Information Platform, and performing health economics calculations regarding the implementation of personalised medicine in healthcare • Initially focussing on rare inherited diseases and cancer (later on complex diseases and microbiome)
Learning, if any	• Potential success factor: The plan to build on existing structures such as national biobanks, regional cancer centres and national quality registries should most probably enable smoother implementation of precision medicine across the health system
Weblink	• https://ki.se/en/mmk/new-national-initiative-for-precision-medicine-genomic-medicine-sweden

Source: Technopolis

Table E-8: Individualized Medicine Action Plan, Germany

Scope	Basic research to applied and clinical research to improve diagnostics and therapeutics for patients; innovations in the health industry; research and information and discussion platforms to tackle questions of ethics, law and economics
Start Date	2010
Geographic Coverage	Germany
Funding	Federal Ministry of Education and Research (up to €360 million from 2013 to 2016); supplemented by institutional funding

Main Delivery Partners	All six German Centres for Health Research, universities, clinics, industry
Progress to date	• Over €40 million funding by 2016 supported the validation of biomarkers and implementation of personalized therapies into clinical trials • The German National Cohort launched in 2013 • E:Med initiative funded since 2014 to establish systems medicine network in Germany and promote informatics-oriented research of diseases
Learning, if any	• Action Plan seen as a driver for regional growth in precision medicine
Weblink	• https://www.gesundheitsforschung-bmbf.de/files/Action_Plan_IndiMed_englisch.pdf • https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4932462/ • www.sys-med.de/en/ • https://www.gminsights.com/industry-analysis/precision-medicine-market

Source: Technopolis

Table E-9: Transforming Genetic Medicine Initiative, United Kingdom

Scope	Collaborative research, development and promotion for integrating large-scale genome sequencing into mainstream medicine Specific areas of focus: Gene-disease map; Clinical annotation reference system for consistent annotation and reporting of genomic data; integrated approaches that use multi-source, multi-population data to deliver the fast, automated, large-scale, high-throughput gene variation interpretation; processes that maximise the research and clinical utilities of genetic testing
Start Date	2016
Geographic Coverage	United Kingdom
Funding	Wellcome Trust (£5.3 million over four years)
Main Delivery Partners	Research groups and organisations whose interests are strongly aligned with the initiative e.g. Institute of Cancer Research, EMBL-EBI, Wellcome Trust Sanger Institute, University of Manchester, Imperial College London, Genomics England, The British Society for Genetic Medicine, NHS Trusts, MRC Human Genetics Unit, etc.
Progress to date	• Outputs include projects, tools and resources such as • Genome sequencing annotation and analysis tools such as OpEx, DECoN, ICR96 Exon CNV validation series • CoverView, a user-friendly sequencing quality evaluation tool
Learning, if any	• NA
Weblink	• http://www.thetgmi.org

Source: Technopolis

Table E-10: Personalised medicine programme 2016-2020, Estonia

Scope	Implementation of personalised medicine in Estonia to improve population health through implementing the results and innovations emerging from Estonian and international R&D
Start Date	2016
Geographic Coverage	Estonia

Funding	Estonian government
Main Delivery Partners	Managed by the Ministry of Social Affairs National partners: University of Tartu, Tallinn University of Technology, Ministry of Education and Research, Ministry of Economic Affairs and Communications, Estonian Family Physicians Association, Tartu University Hospital, North Estonia International partners: PerMed ERA-NET, ICPerMed (International Consortium)
Progress to date	• Clinical flagship projects funded. Results from these will feed into the design and testing of an organisational and technical environment allowing the complex use of health and genetic data, which will in turn be used to develop a personalised medicine service model. • 100,000 people being recruited for a biobank as a first step to developing personalised medicine. Eventually, the government wants to offer genome-wide genotyping to all its residents for use in everyday medical practice via its national e-health portal.
Learning, if any	• Success factor: Programme based on learnings from a preliminary pilot study that identified core areas that need strengthening • Implementing personalised medicine will be achieved only by training the health professionals and by supplying them with appropriate tools • Personalised medicine is possible only if good quality health data is available
Weblink	• https://www.sm.ee/en/personalised-medicine#Preliminary%20study • https://150sec.com/estonia-offers-free-genetic-testing-to-develop-personalized-medicine/ • https://www.sm.ee/sites/default/files/content-editors/eesmargid_ja_tegevused/Personaalmeditsiin/feasibility_study_for_ personalised_ medicine_in_estonia.pdf

Source: Technopolis

Table E-11: American Heart Association's Precision Medicine Platform

Scope	The AHA Precision Medicine Platform is a cloud-based data resource that revolutionizes how the research community accelerates solutions for cardiovascular diseases. It provides unprecedented, open access to cardiovascular data sets, cutting-edge tools and forums for collaboration. Researchers can search, filter and unlock the data that matters most to their work - allowing them to find new solution for big health improvements faster than ever before. The Precision Medicine Platform is powered by Amazon Web Services and is a strategic initiative of the American Heart Association's Institute for Precision Cardiovascular Medicine
Start Date	2016
Geographic Coverage	United States
Funding	AHA Institute for Precision Cardiovascular

Main Delivery Partners	Data collaborators for the AHA Precision Medicine Platform, powered by Amazon Web Services include: • AstraZeneca • Cedars Sinai Heart Institute • Dallas Heart Study • Duke Clinical Research Institute • Intermountain Medical Center Heart Institute • The International Stroke Genetics Consortium • National Heart, Lung and Blood Institute (NHLBI) • Stanford Cardiovascular Institute
Progress to date	• The $5 million initiative with Amazon Web Services to fund more than a dozen data research grants to power the AHA's Institute for Precision Cardiovascular Medicine. The Institute is using vast and diverse patient data — from a person's genes to environment and lifestyle — to find personalized approaches to prevent and treat cardiovascular diseases. • Its cloud-based Precision Medicine Platform is speeding toward finding solutions to fight the world's most deadly diseases.
Weblink	• http://institute.heart.org/

Source: AHA website

Regional initiatives

Table E-12: Personalized Medicine Initiative at Pacific Health Innovation eXchange (PHIX), Canada

Scope	• Introduce personalized medicine in British Columbia (BC) and Canada • Establish a coalition of stakeholders to drive the systemic change required in policy, privacy protection, health care data handling and funding priorities • Take advantage of near-term opportunities and build on established strengths in the practice of personalized medicine in BC and Canada • Construct a clinical database that includes molecular-level data clouds for 25,000 Canadians to improve preventive health and to better match disease to treatment
Start Date	2011
Geographic Coverage	British Columbia and Canada
Funding	From clinical, academic, government and industry partners
Main Delivery Partners	Currently based in the Life Sciences Institute at UBC Delivered by collaborative community comprising leaders in research, technology, clinical testing, and population health delivery

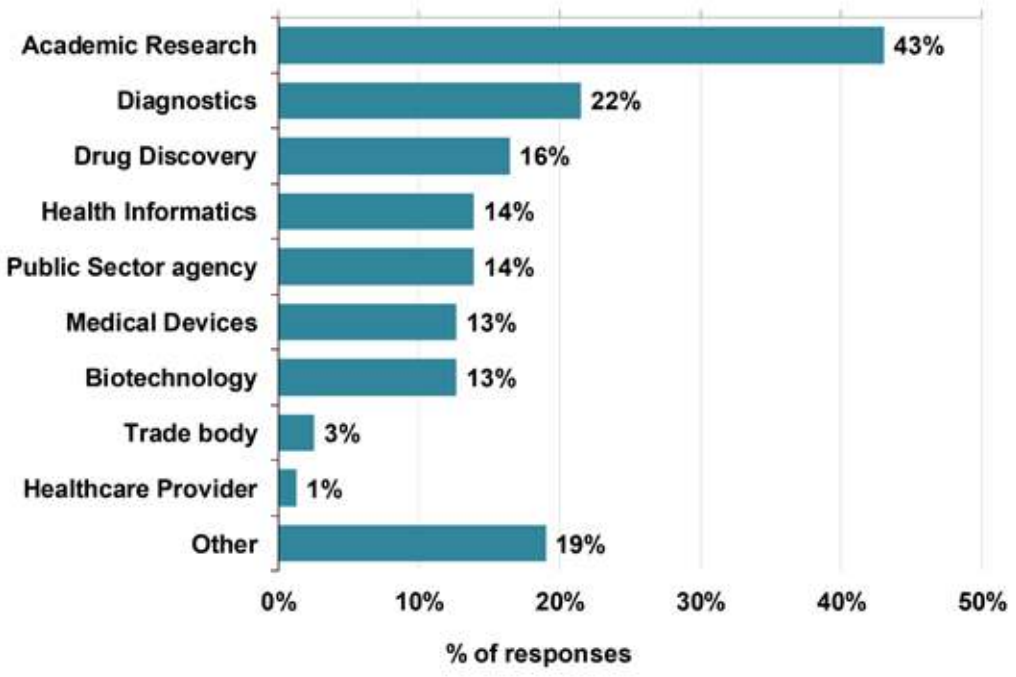
Progress to date	• Ten implementation projects underway – five aimed at establishing the necessary infrastructure and four outreach projects to educate the public and healthcare professionals as to the benefits of personalised medicine • Pursuing another precision health initiative – Molecular You Corporation (MYCO). MYCO is conducting longitudinal studies that characterize participants at the molecular level over large populations in states of health or disease. The large database being generated by MYCO will be a valuable source of information to develop biomarkers indicating health status and early transitions to disease and potentially new therapeutic targets. • Ongoing activities - Weekly meetings where the perspectives of stakeholders in government, industry, health care and academia are presented - Annual summit on personalised medicine - Sourcing funding, preparing teams and assisting in project management, product commercialisation support for new technologies
Learning, if any	• Success factor: System-wide, collective commitment of resources and efforts as the initiative is set up to act as a focal point for collaboration amongst technological and clinical communities, industry, policy makers, and patient groups. • It is necessary to cultivate expertise and efforts to drive and implement personalised medicine into the frontlines of health care, to ensure the realization of economic benefits and to lead the necessary system change in health care delivery and policy.
Weblink	• http://phix.ca/projects/personalized-medicine-initiative-pmi/ • http://apo.org.au/system/files/130321/apo-nid130321-573526.pdf

Source: Technopolis

Annex F: PM in Scotland e-survey results

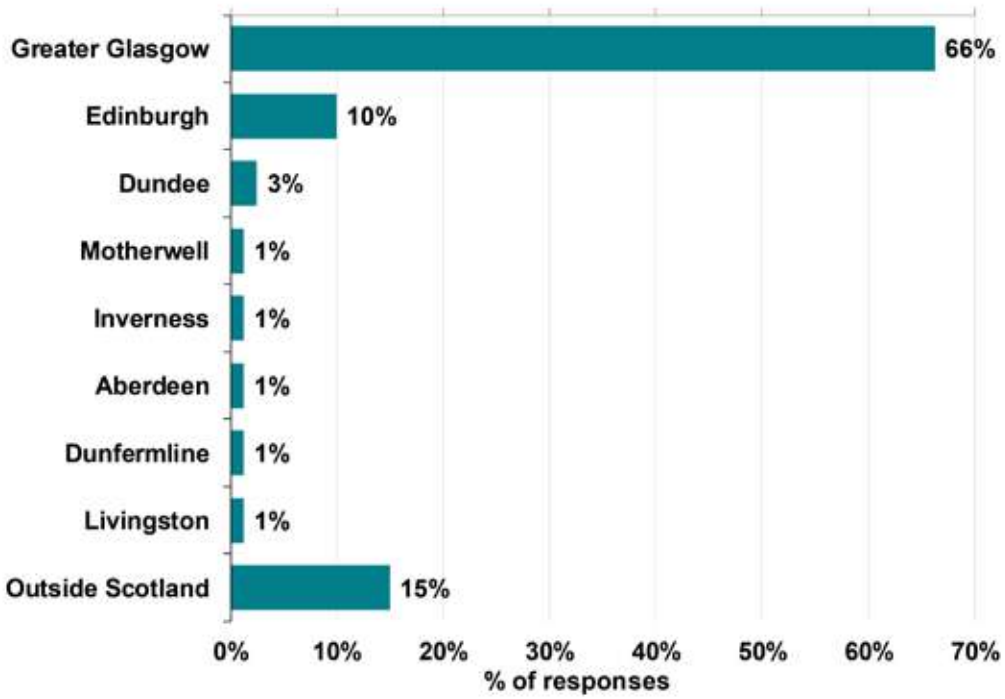
F.1 In mid-May 2018, the PM SIA consortium launched an e-survey to capture feedback from a range of academic, NHS, industry and public sector partners on the exciting opportunities to grow the ecosystem for Precision Medicine in Scotland. The survey was promoted at Scotland's Life Sciences Dinner & Annual Awards (16 May 2018), through the Life Sciences Scotland newsletter, and the University of Glasgow's 'Collaboration for Innovation' Industry Day (5 June 2018). The survey closed on 8 June and in total, 79 completed responses were received. The key findings from the survey exercise are presented below.

Figure F-1: What is the main activity of your company / organisation? (Multiple choice)



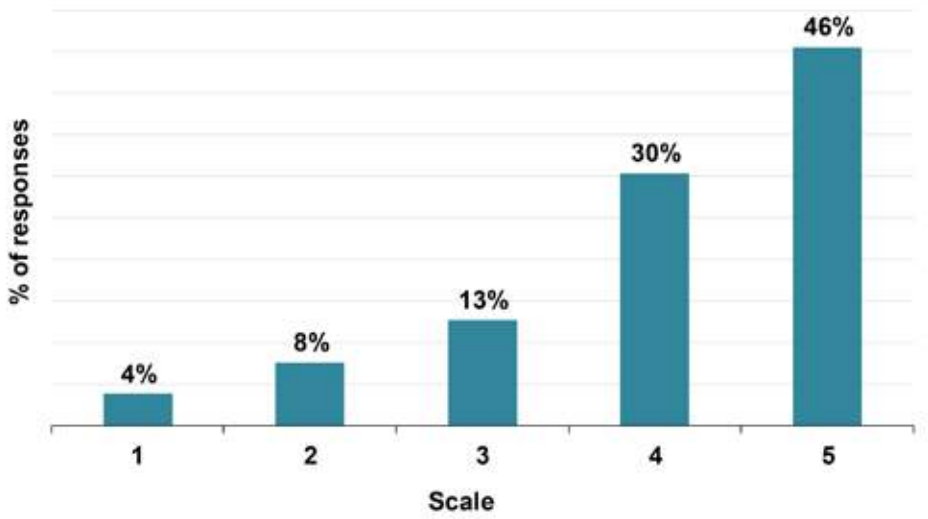
Source: SQW analysis of PM SIA survey (n=79)

Figure F-2: Where is your main place of work?



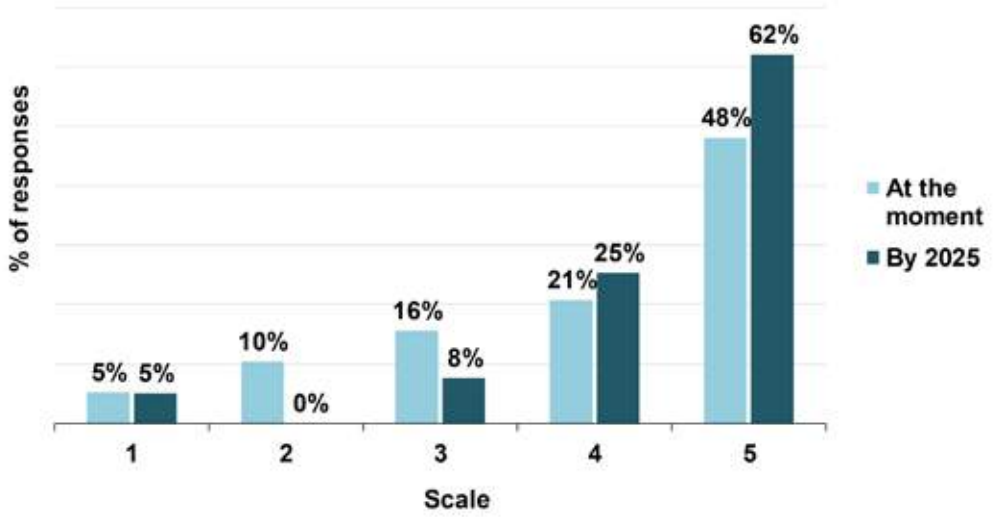
Source: SQW analysis of PM SIA survey (n=78, NB. Some respondents gave multiple answers)

Figure F-3: On a scale of 1 to 5, how well do you understand Precision Medicine? (1 = I do not understand PM, 5 = I have a clear understanding of PM)



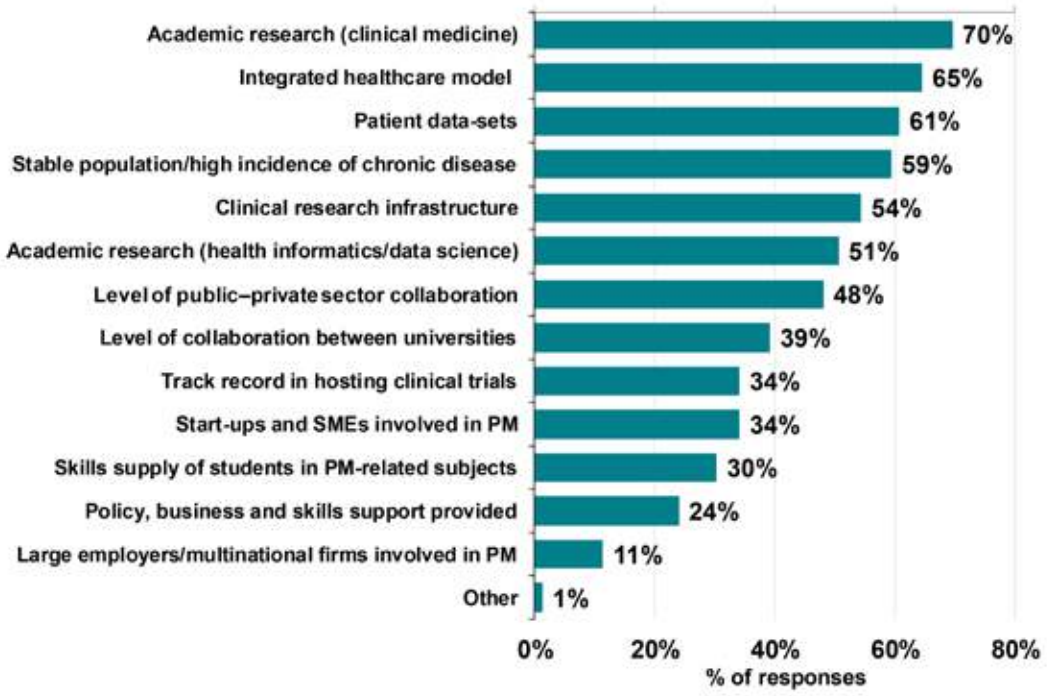
Source: SQW analysis of PM SIA survey (n=79)

Figure F-4: On a scale of 1 to 5, how important is PM to your company/ organisation at the moment, and how important will it be by 2025? (1 = not important, 5 = very important)



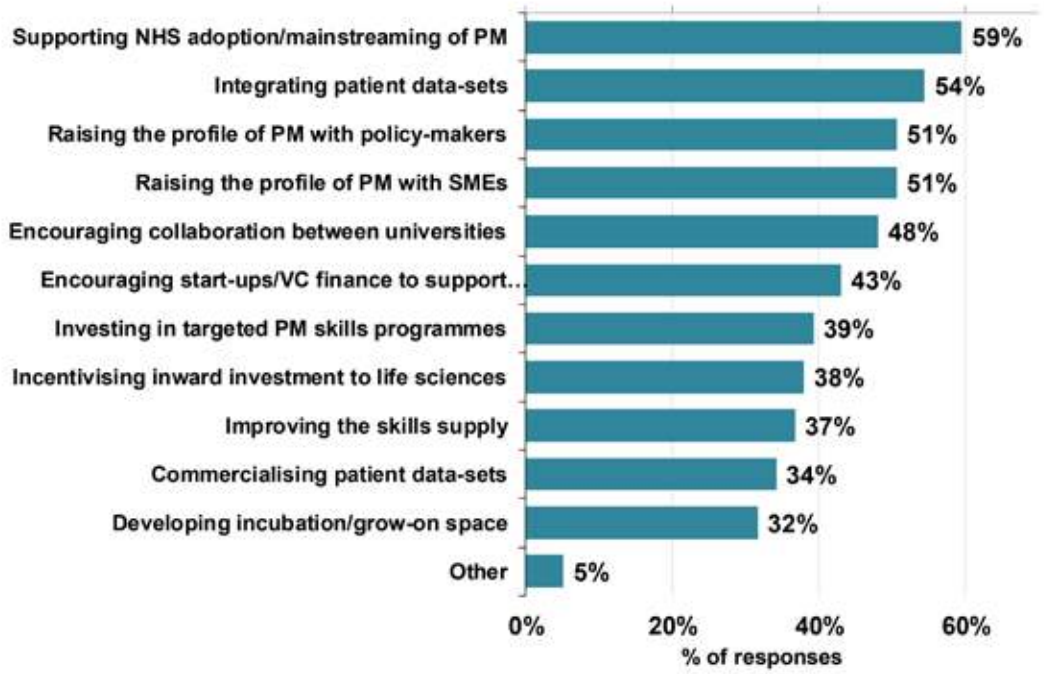
Source: SQW analysis of PM SIA survey (n=77; n=79)

Figure F-5: Which of the following elements of Scotland's PM Ecosystem are the key strengths that differentiate Scotland from other leading life science clusters? (Multiple choice)



Source: SQW analysis of PM SIA survey (n=79)

Figure F-6: As we seek to grow and develop the PM Ecosystem in Scotland, what do you think are the main priority areas for improvement? (Multiple choice – tick all that apply)



Source: SQW analysis of PM SIA survey (n=79)