Research Priority Areas

2018 to 2023

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Ministerial Foreword

Minister for Business, Enterprise and Innovation, Ms Heather Humphreys T.D., and Minister of State for Training, Skills, Innovation, Research and Development, Mr John Halligan T.D.

Research and Innovation are critical to maintaining continued social and economic progress. We are determined to ensure that Ireland achieves its ambition of becoming a Global Innovation Leader and building excellence in strategically important research areas of relevance and impact to the economy and society is a crucial element in delivering this ambition.

Research Prioritisation reflects the Government's commitment to placing innovation at the heart of enterprise policy so that we can continue to capitalise on the opportunities that exist in the global marketplace and expand as the global economy continues to recover. Our prosperity, sustainable economic development and societal progress are dependent on our ability to innovate.

Technology continues to develop at an ever-increasing pace, bringing radical changes throughout almost every industry. Cutting edge research and innovation will ensure Ireland optimises the opportunities arising from new science and technology developments and disruptions.

Since the launch of Research Prioritisation in 2012, there have been a range of significant developments including the increased development of disruptive technologies, Brexit, and Ireland's adoption of the UN Sustainable Development Goals. The challenge for small open economies like Ireland is to remain agile and resilient. Enhancing the innovative capacity of Irish based firms along with their ability to diversify into new markets has become all the more critical.

The objectives of Research Prioritisation remain relevant and valid - to create research activities of critical mass in areas of importance to Ireland; to efficiently extract maximum value from our national research investment; and to take research to market faster than in other jurisdictions.

We are developing our innovation ecosystem to ensure that enterprises can collaborate with researchers and to engage effectively in areas of impact to innovate and develop new products, services, solutions and new business models to underpin leadership positions in international markets and to meet global and societal challenges.

The revised areas of focus under Research Prioritisation offer us exciting new opportunities including Robotics; Artificial Intelligence, Augmented and Virtual Reality; Health and Well-being; Smart and Sustainable Food Production and Processing; Decarbonising the Energy System; Sustainable Living; and Advanced and Smart Manufacturing.

We will continue to drive this important agenda - keeping innovation centre stage to drive a strong sustainable economy and a better society.

Executive Summary

In 2012, Government introduced **Research Prioritisation**, which aligns the majority of competitively awarded public investment in research with 14 priority areas. *Innovation 2020,* Ireland's strategy for research and development, science and technology, commits to reviewing the priority areas to ensure that they are still valid and to refresh and revise them, if necessary, in the light of changed circumstances. The objective is to ensure that Ireland is favourably positioned to benefit from global opportunities now and into the future, by responding to worldwide megatrends and challenges that are shaping the global economy and Ireland's place in it.

A rigorous exercise including extensive consultation was undertaken to develop the evidence base to inform the refresh exercise. While the evidence demonstrated that for many of the priority areas, the focus remains as relevant in 2018 as it was for the 2012 - 2017 cycle, there have been several revisions and updates to both the themes and the priority areas to reflect changing circumstances in that period.

- The ICT priority areas have been broadened to reflect the changes in technology since 2012 and now include **Robotics, Artificial Intelligence (including Machine Learning), Augmented Reality and Virtual Reality.**
- With the focus on preventive health measures and the increasing emphasis on well-being, which is evident across all the health-related priority areas, the Health theme has been has evolved to reflect these drivers and is renamed **Health and Well-being**.
- The Sustainable Food Production and Processing priority area is broadened to reflect the evolution in technology since 2012 and the key emerging priorities in the EU initiative Food 2030, particularly the need for climate smart and environmentally sustainable food systems and the need for circularity and resources efficiency of food systems and is renamed **Smart and Sustainable Food Production and Processing**.
- The most significant changes have been to the Energy theme. Based on developments since 2012, including the increased urgency to address climate change and sustainability challenges, alongside the increased opportunities for enterprise within this wider context, the Research Priority theme has evolved to reflect these drivers and is renamed **Energy, Climate Action and Sustainability**, and the two priority areas have been updated to **Decarbonising the Energy System;** and **Sustainable Living.**
- To reflect the impact of technological change and the digitisation of manufacturing since 2012, the Manufacturing Competitiveness priority area is renamed **Advanced and Smart Manufacturin**g (which will also include Processing Technologies) and Processing Technologies and Novel Materials is renamed **Manufacturing and Novel Materials**, acknowledging that Novel Materials underpin and enable other priority areas, presenting particular challenges for the manufacturing sector.
- The services sector in Ireland is a major part of Ireland's economy and is increasingly participating in innovative activities and the **Innovation in Services and Business Processes** research priority remains unchanged.

Refreshed Priority Areas 2018 – 2023

Theme	Priority Area
ICT	Future Networks, Communications and Internet of Things
	Data Analytics, Management, Security, Privacy, Robotics and Artificial Intelligence (including Machine Learning)
	Digital Platforms, Content and Applications, and Augmented Reality and Virtual Reality
Health and Wellbeing	Connected Health and Independent Living
	Medical Devices
	Diagnostics
	Therapeutics
Food	Food for Health
	Smart and Sustainable Food Production and Processing
Energy, Climate Action and Sustainability	Decarbonising the Energy System
	Sustainable Living
Manufacturing and Materials	Advanced and Smart Manufacturing
	Manufacturing and Novel Materials
Services and Business Processes	Innovation in Services and Business Processes

Introduction

Innovation 2020 sets out a vision for Ireland to become a Global Innovation Leader, driving a strong sustainable economy and a better society underpinned by:

- Excellent research in strategically important areas that has relevance and impact for the economy and society.
- A strong innovative and internationally competitive enterprise base, growing employment, sales and exports.
- A renowned pool of talent both in Ireland's public research system and in industry that maximises exchange of talent and knowledge.
- A coherent joined-up innovation ecosystem, responsive to emerging opportunities, delivering enhanced impact through the creation and application of knowledge.
- An internationally competitive research system that acts as a magnet and catalyst for talent and industry.

Research Prioritisation 2012

In 2012, Government introduced Research Prioritisation, which aligns the majority of competitively awarded public investment in research with 14 priority areas. The process of determining the priority areas was rigorous, aided by the expert knowledge of Government departments and agencies that fund Research, Development and Innovation (RDI), the research community, the enterprise sector and other expert stakeholder groups.

The report of the Research Prioritisation Steering Group, established to oversee the 2012 exercise, noted that the proposed areas were broad enough to involve the full continuum of research – from basic through to applied – and could involve researchers across all disciplines including arts, humanities and the social sciences as well as science, technology, engineering and maths. The selection of 14 areas for prioritisation did not imply parity in the allocation of investment between each of those areas. The scope of public investment in RDI as addressed in the Research Prioritisation report relates to publicly funded research awarded on a competitive basis and performed in Irish Higher Education Institutions and public research organisations.

Two important categories of expenditure deliberately excluded from consideration:

- the element of the "block grant" to higher education institutions which supports research, and
- funding for in-company performed RDI, as this is company specific.

In addition, there are two other over-arching goals of public investment in RDI which are needed to attain prioritisation but do not draw from the prioritised programme areas, specifically **Research for Policy** and **Research for Knowledge**. It is recognised that in order to meet the vision of *Innovation 2020* and achieve a renowned pool of talent and an internationally competitive research system, support for Research for Policy and Research for Knowledge is essential.

Commitment to reviewing the priority areas

Innovation 2020 commits to reviewing the priority areas of focus to ensure that they are still valid and to revise them, if necessary, in the light of changed circumstances. The objective is to evolve the priority areas to ensure that Ireland is favourably positioned to benefit from the global opportunities now and into the future, by responding to worldwide megatrends and global challenges that are shaping the global economy and Ireland's place in it.

Developments since 2012

Since 2012, there have been many developments that have a bearing on the future focus of research, including Ireland's adoption of the United Nations Sustainable Development Goals in 2015 which seeks to end poverty, protect the planet and ensure prosperity for all as part of a new sustainable development agenda, and Ireland's adoption and ratification of the 2015 Paris Agreement on Climate Change.

The challenges of climate change and sustainability have increased markedly in importance over the last five years, as evidenced by significant policy developments at national and international level. Countries and companies are adopting more ambitious policies, regulations and strategies in relation to energy, to mitigate climate change by reducing their Greenhouse Gas Emissions (GHGs) and adapting to the emerging and projected impacts of climate change. The National Mitigation Plan 2017 recognises that RDI will play a key role in Ireland's transition to a low carbon economy and society by 2050.

A linear economy built on the principles of 'take, make and waste' is not sustainable and alternatives need to be found. The **transition to a circular economy** involves separating growth from the use of scarce resources through production models based on long life products that can be renewed, reused, repaired, upgraded or refurbished and requires significant changes from product design to new business and market models, new ways of turning waste into a resource to new modes of consumer behaviour.

As the global population continues to grow, so too does the **demand for food**. At the same time, there has been an increase in the changing diets of consumers, diet-related diseases, and growing individualism and demand for personalised food products. The food supply chain is currently being significantly impacted by climate change, the requirements of sustainability, and digitalisation in food markets, where there has been a resultant impact in GHG emissions, competing uses of land and sea, and the rise of ethical consumer habits relating to food sources.

Technology continues to develop at an ever-increasing pace, bringing not only new technological developments, but also the **diffusion of ICT -** including the potentially disruptive effect of Artificial Intelligence and Machine Learning - bringing radical changes throughout almost every industry in manufacturing, production processes, services provision and across whole value chains and business support activities, as well as driving the development of new markets.

A number of key drivers are **revolutionising manufacturing** worldwide. The rapid pace of technological change is enabling novel production and organisational processes, and new

business models. Additive manufacturing, also known as 3D printing, has the potential to dramatically shift industrial manufacturing methods away from traditional technologies and democratise the production of manufactured goods.

In an era of **ageing populations** and growing health expenditures, medical innovations are needed to improve the quality of people's lives and increase the efficiency of health care systems and contribute to significant cost savings and economic growth.

Evidence Base for the Refresh of Research Prioritisation

The refresh exercise examined whether there has been a significant shift in global or national societal challenges; global markets in which Irish-based companies are, or are expected to, compete; critical technologies that will impact on Ireland; and, finally, Ireland's research strengths. The refresh exercise also recognises that Ireland's priority areas can form part of the basis for strategic engagement by Irish-based researchers and innovators with the European Framework Programme for RDI, Horizon 2020 and its successor, Framework Programme 9.

Criteria

The process of determining the refreshed priority areas involved utilising the following four high level criteria:

1. The priority area is part of, or associated with, a large global market or markets in which Irish-based enterprises already compete or can realistically compete.
2. The priority area requires publicly performed RDI to complement private sector research and innovation in Ireland.
3. Ireland has built or is building objectively measured strengths in research disciplines relevant to the priority area.
4. The priority area represents an appropriate approach to a recognised national challenge and/or a global challenge to which Ireland should respond.

Three reports were undertaken to inform the review of priority areas: a horizon scan of global markets; a technology futures exercise; and an audit of progress under the current priority areas.

(i) Horizon Scan of Global Markets and Identification of Opportunities for Ireland and Irish-based Enterprise.

This report identifies and profiles market opportunities for Irish-based enterprises based on the scale of the global opportunity; Ireland's capability and capacity (including RDI); and the potential impact on Ireland. Extensive consultation with stakeholders, in particular with enterprise representatives, was undertaken to identify the key market opportunities.

(ii) Technology Futures Exercise – Identification and assessment of technologies that are critical to Ireland's societal and economic development until 2035.

This report identifies a list of critical technologies that will have an impact on Ireland's economic and social development out to 2035 and that are potentially disruptive in nature.

The report assesses the course and potential impact of technologies; the potential for Ireland to obtain major benefits for the economy and society as a whole; and the broad implications for public policy. The scope of the report was to identify technologies that would have an impact on Ireland regardless of whether or not RDI performed in Ireland contributes to their development. Again, there was wide national and international consultation with stakeholders including with public research organisations and enterprise, through Delphi surveys and workshops.

(iii)   Audit of Progress under Research Prioritisation

The *Audit of Progress under Research Prioritisation* was undertaken internally by the Department of Business, Enterprise and Innovation DBEI with the support of the research funding agencies. This report captures the investment and performance based on data provided by the funding agencies under each of the priority areas.   The audit also identifies research strengths outside of those areas. It draws heavily on the bibliometrics report commissioned by the Higher Education Authority and carried out by Trinity College Dublin.

The findings from these reports along with views elicited from stakeholders representing academia, enterprise and the public sector at a Consultation Forum in November 2017, have informed the refreshed priority areas as set out below:

Refreshed Priority Areas 2018 – 2023

Theme	Priority Area
ICT	Future Networks, Communications and Internet of Things
	Data Analytics, Management, Security, Privacy, Robotics and Artificial Intelligence (including Machine Learning)
	Digital Platforms, Content and Applications, and Augmented Reality and Virtual Reality
Health and Wellbeing	Connected Health and Independent Living
	Medical Devices
	Diagnostics
	Therapeutics
Food	Food for Health
	Smart and Sustainable Food Production and Processing
Energy, Climate Action and Sustainability	Decarbonising the Energy System
	Sustainable Living
Manufacturing and Materials	Advanced and Smart Manufacturing
	Manufacturing and Novel Materials
Services and Business Processes	Innovation in Services and Business Processes

Science and Technology Platforms

The 2012 Research Prioritisation exercise recognised that the priority areas need to be underpinned by research across many fields. The science and technology platforms that underpin the priority areas remain unchanged and are: Basic Biomedical Science, Nanotechnology, Advanced Materials, Microelectronics, Photonics and Software Engineering. As pointed out in 2012, this is not an exhaustive list. Researchers from any discipline should, in principle, be eligible to submit proposals for calls that issue in respect of the priority areas provided the impact on the priority areas is evident and the appropriate connections to the focused projects are made.
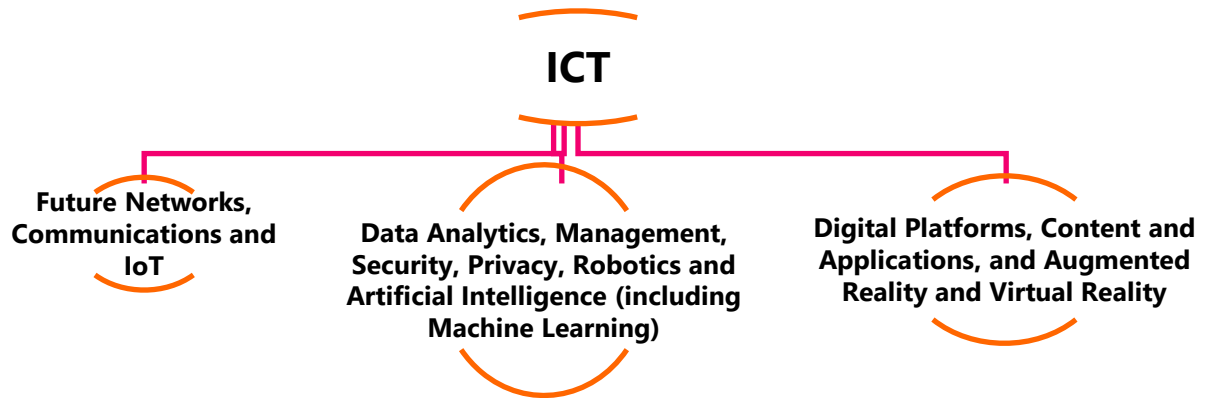
Disruptive Technologies Innovation Fund

The revised priority areas will be of particular relevance in the context of the new €500 million Disruptive Technologies Innovation Fund announced by the Government as part of the National Development Plan 2018-2027. This Fund will be implemented through the Department of Business, Enterprise and Innovation and its agencies, working with other research funding bodies. As identified in Project Ireland 2040, disruptive technologies are transforming business models in a broad range of areas including healthcare, financial services, energy and food production, and business services. It can be expected, therefore, that many of the areas that will be the focus of research prioritisation for the coming years will feature strongly in projects supported through the Disruptive Technologies Innovation Fund. The design of the Fund is currently being progressed through the Department of Business, Enterprise and Innovation and relevant funding bodies will be consulted in due course. As indicated in Project Ireland 2040, the Fund will help to drive collaboration between our world class research base and industry as well as facilitating enterprises to compete directly for funding in support of the development and adoption of these technologies, and seeding a new wave of start-ups.

> ## Refreshed Priority Areas

ICT

Figure 1: ICT Research Priority theme: Research Prioritisation 2018-2023

ICT

Future Networks, Communications and IoT

Data Analytics, Management, Security, Privacy, Robotics and Artificial Intelligence (including Machine Learning)

Digital Platforms, Content and Applications, and Augmented Reality and Virtual Reality

ICT has transformed society over the last 30 years through the pace of technological change and processing power, resulting in connected environments, the Internet of Things, and the creation of large volumes of data. ICT not only spearheaded the information age, but ICT-based technologies have also been instrumental in enabling the research, development and growth of technologies in many other fields such as applied science, engineering, health, climate change, environment and transport. Growth in ICT has expanded its scope to ease and improve our daily lives, while addressing significant societal challenges such as demographics, climate change and urbanisation through the better delivery of services across health, energy, environment and transport. ICT developments and adoption are a key focus at European level through the development of the Digital Single Market and the research and development support for ICT in Horizon 2020.

ICT not only is a critical research priority theme but, arising from the pace of developments and diffusion of technologies since 2012, it is also a key enabler that supports developments and advancements across the other five Research Priority themes.

The ICT Research Priority theme is sustained and the three priority areas are broadened to reflect the changes in technology since 2012.

The ICT Research Priority theme includes three priority areas:
- ➢ *Future Networks, Communications and Internet of Things*
- ➢ *Data Analytics, Management, Security, Privacy, Robotics and Artificial Intelligence (including Machine Learning)*
- ➢ *Digital Platforms, Content and Applications, and Augmented Reality and Virtual Reality*

Future Networks, Communications and Internet of Things

The internet has become a critical infrastructure that forms a key element of our social and economic fabric. While technologies continue to evolve rapidly and significantly, the importance of Future Networks and Communications as an integral underlying component of business and enterprise has remained indisputable. The key areas which present large global markets in which Irish-based enterprises already compete or can realistically compete are the Internet of Things (IoT) - the inter-networking of physical devices that enables the collection and exchange of data, including IoT devices, wearables, routers, sensors, actuators, and associated IT services and platforms. A further key market is Anything-as-a-Service (XaaS) consisting of ST(orage)aaS, SEC(urity)aaS, U(nified) C(ommunications)aaS, N(etwork)aaS, D(ata)B(ase)aaS, and B(ackend)aaS, or, typically, back-end platform development.

Data Analytics, Management, Security, Privacy, Robotics and Artificial Intelligence (including Machine Learning)

Driven by advances in ICT and the generation of large volumes of data the applications for data analytics are becoming ubiquitous. The potential benefits from data analytics in the broad life sciences and healthcare sector are high in terms of personal healthcare, population health, genomics, and the economics of healthcare. The application of data analytics has great potential too in the agriculture, marine and food production sector for increasing quality and productivity. In the climate change and environment areas, this priority area can facilitate availability and access to underlying data sets and undertake modelling of potential impacts and assessment of capability.

Artificial Intelligence and Cybersecurity are large global markets in which Irish-based enterprises already compete or can realistically compete. Artificial Intelligence consists of deep learning, advanced robotics, digital personal assistants, querying methods, natural language processing, neural networks, and context aware processing. This area will also support opportunities in markets that span a large number of sectors such as such as Fintech, Pharma, Digital Health and Analytics, Digital Media, Biopharma, XaaS, Augmented Reality and Virtual Reality, Smart Manufacturing and Investment Management and Administration.

Continued developments in the semantic web, and evolution towards Artificial Intelligence in key technology areas such as natural language processing and understanding, machine learning, and advanced machine vision, will allow for improved decisions based on holistic data, overcoming inefficiencies in energy demand, mobility and transport. Technologies identified that are relevant for IT and data security includes data encryption technologies, data anonymisation technologies, multi-biometrics and cyber forensics.

Ireland's membership of International Research Organisations LOFAR (Low Frequency Array) and the European Southern Observatory will support and enhance Ireland's world-leading capability in big data and data analytics. Handling the enormous datasets that are generated from astronomy research will also lead to the creation of advanced enterprise

relevant skills for emerging data rich sectors such as retail, health, transport, agriculture and public services.

Digital Platforms, Content and Applications, and Augmented Reality and Virtual Reality

This priority area can contribute to addressing key global and national challenges by increasing quality of life through eHealth, eTransport, eEnvironment, eLiteracy, eLearning and eAgriculture applications and services. While Digital Media, eGames, eLearning, Creative Industries and Animation remains as market opportunities, this priority area is now considered to include Augmented Reality and Virtual Reality which includes Mixed Reality, with AR and VR used in hybrid (AR/VR/MR), Application Development and Space Related Software and Remote Sensing (SRS/RS), all of which are large global markets in which Irish-based companies already compete or can realistically compete. Digital Media consists of digital video, music downloads and streaming, digital games, digital publishing and marketing. Ireland is ideally positioned to realise opportunities in creating, operating and delivering across every stage of the Digital Media value chain, originating from identification of novel concepts to distribution of finished hardware, software, and media, e.g. film and video production, computer animation and special effects services, leveraging Ireland's landscape for digital tourism marketing, the design of computer games, or creating next generation AR/VR/MR content.

The Augmented Reality and Virtual Reality market consists of Helmet Mounted Display, Heads-Up Display, handheld devices, gesture tracking, projector and display wall, and associated components, as well as AR/VR/MR. Ireland is ideally positioned to realise opportunities in concept identification and proof of concept testing within the AR/VR/MR industry.
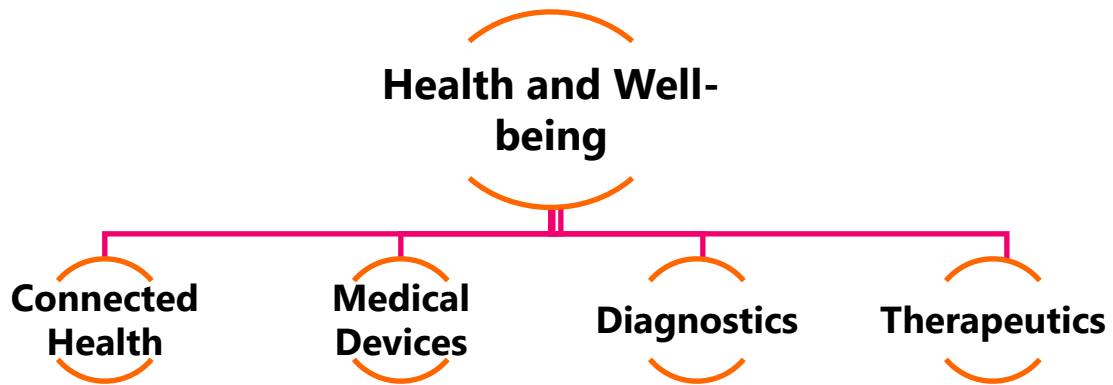
Application Development incorporates the development of applications (apps) which are designed to run on smartphones, tablet computers and other mobile gadgets. Ireland is ideally positioned to realise opportunities in the manufacturing and distribution of Application Development.

SRS/RS consists of applications relying on embedded satellite signals (e.g. GPS devices and location based services) and/or data (e.g. meteorology, ocean and earth observation, and commercial GIS software and geospatial products).

Other areas where Ireland can benefit from investment in this priority area are largely captured under the priority area of Innovation in Services and Business Processes (e.g. Fintech, Environmental Monitoring, Experiential Tourism, the Sharing Economy, CorpTech and Smart Learning.)

Health and Wellbeing

Figure 2: Health and Well-being Research Priority theme: Research Prioritisation 2018-2023

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                    Health and Well-
                         being

  Connected     Medical      Diagnostics    Therapeutics
   Health        Devices
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Government policy will continue to focus on improved health and well-being outcomes for all, and on ensuring that healthy lives and well-being for all are recognised as essential to sustainable development as per the United Nations Sustainable Development Goals. Ireland adopted its National eHealth Strategy in 2014, recognising the importance of technology-enabled solutions for improving population well-being, health service efficiencies and economic opportunity.

With the focus on preventive health measures and the increasing emphasis on well-being, which is evident across all the health-related priority areas, this Research Priority theme has evolved to reflect these drivers and is renamed Health and Well-being.

The Health and Wellbeing Research Priority theme includes four priority areas:
- ➤ *Connected Health and Independent Living*
- ➤ *Medical Devices*
- ➤ *Diagnostics*
- ➤ *Therapeutics*

Connected Health and Independent Living

The Connected Health and Independent Living priority area aims to contribute to the solutions for the range of national and global health challenges. Of particular focus for the Connected Health and Independent Living priority area is the challenge arising from the increase in the ageing population and the accompanying increase in the prevalence of chronic illness and neurological disease. There is also an increasing prevalence of chronic disease due to other non-age-related issues.

The Connected Health and Independent Living priority area arises from the opportunities created by the convergence between two of Ireland's core strengths, ICT and life sciences,

and the market benefits from close adjacencies with markets such as IoT, AI, Digital Media, In-Vitro Diagnostics, Drug Delivery Devices, Implantable Devices, Personalised Medicine.

In the 2012 Research Prioritisation Exercise, the key markets for this priority area were considered to be Hospital Information Systems, Telemedicine and Mobile Healthcare. The most recent Market Horizon Scan captures the opportunity as Digital Health and Analytics, which presents a large global market in which Irish-based enterprises already compete or can realistically compete.

The Digital Health and Analytics market consists of digitised health systems, telemedicine, connected health, and health analytics. Ireland is ideally positioned to leverage its corporate services and data analytics capabilities within the Digital Health and Analytics industry.

Medical Devices

Innovation in medical devices aims to contribute to the continued improvement of patient safety and outcomes at affordable cost. This priority area aims to position Ireland as a driver in developing medical device technologies, which will provide affordable transformative solutions for chronic diseases, such as heart disease, diabetes and musculoskeletal diseases, to meet this challenge.

Medical devices are becoming increasingly complex and sophisticated, and technological advances are increasingly relying on continued developments in material science and engineering. Developments in coating technologies, such as bioactive coatings, are of vital importance to improve biocompatibility and increase the effectiveness of healthcare treatments. Other technologies – such as 3D printing technologies – and the rise of nanotechnology, advanced diagnostics and combination devices are also driving innovations across the industry. Engineered implants, such as bioengineered tissues and organs, or developments in artificial skin or 3D printing of body components, will also be a set of key technologies that will drive innovative applications in healthcare.

Drug Delivery Devices (including drug-eluting stents, nebulisers, pre-filed syringes, and IV packs) is a core relevant market. Implantable Devices (dental implants, orthopaedic implants, cardiovascular implants, breast implants, intraocular lens, orthobiologics, and other implantable products), also represents a large global market in which Irish-based companies already compete or can realistically compete.   Some of the prominent trends include 3D medical printing and biocompatible silicone for next generation implantables. Ireland is ideally positioned to realise Implantable Devices opportunities in all stages of the value chain, from concept development to product development, manufacturing and distribution.

Diagnostics

The Diagnostics priority area focuses on the development of next-generation biomedical diagnostic devices for diagnosing disease and sustaining human health. Diagnostic products form a critical part of healthcare delivery, enabling the early and accurate detection that is vital in ensuring successful treatment, and reducing health costs.

This priority area aims to help address a range of national and global health challenges. Changing disease patterns and increased health spending are posing challenges for healthcare systems worldwide. Infectious diseases and anti-microbial resistance are predicted to make treatment more difficult in the future. Simultaneously, the world is expected to experience more non-communicable and lifestyle diseases and more neuro-diseases, as a result of longer lifespans and ageing populations. Next generation diagnostics will play a critical role in addressing these challenges.

The core market identified for this priority area is around In-Vitro Diagnostics and builds on Ireland's strengths in adjacent markets captured under Therapeutics and Medical Devices priority areas and provides opportunities across the health and life science sector.

Advanced diagnostics techniques (such as targeted molecular imaging diagnostics, non-invasive diagnostics or point-of-care diagnostics) are more patient-friendly and lower risk than traditional approaches. Similarly, tracking and transmitting data from inside the human body through the use of sensors and biomarkers make it easier to track disease development and progression and enables timely intervention. Because of the sensitive nature of the data being generated and transmitted, IT and data security technologies are key underpinning technologies.

Medical imaging and advances in image analysis software closely related to data visualisation technologies is also driving this sector. Other technology clusters relevant to this priority area include in-body chips and engineered implants and the use of diagnostics to enable personalised medicine and personalised nutrition.

Therapeutics
The Therapeutics priority area aims to play a role in addressing critical health challenges. Slow progress is being made in treating infectious diseases. Progress has been made in the battle against some infectious diseases such as tuberculosis, HIV/AIDS and malaria. However, future progress in countering infectious diseases may become harder to achieve due to increased urbanisation, climate change and excessive current use of antibiotics which are already reducing the effectiveness of drugs against some communicable diseases. The total annual number of deaths from non-communicable diseases (NCDs) is projected to increase from 38 million in 2012 to 52 million by 2030. This epidemic of NCDs is being driven by demographic ageing, rapid unplanned urbanisation, and the globalisation of unhealthy lifestyles. In addition, cases of neurological disease, spurred in particular by rising longevity and the anticipated rapid ageing of societies in the coming decades, are expected to multiply.

The key markets under this priority area with strong potential for Ireland are considered to be Human and Animal Pharma (the manufacture and discovery of small molecules and veterinary pharmaceuticals) Biopharma (biopharmaceuticals such as monoclonal antibodies, vaccines, recombinant hormones and proteins, and cell and gene therapy in applications across infectious diseases, oncology, immunology, autoimmune diseases), Biotechnology, Regenerative Medicine (product and process development and

manufacturing stages in cell therapy, gene therapy, immunotherapy, tissue engineering, and stem cells) and Personalised Medicine (companion diagnostics and targeted therapeutics).

New, innovative therapeutics make it possible to prevent, treat and possibly cure a wider range of diseases than before, delivering better clinical outcomes and improving quality of life for patients. Gene editing technologies like CRISPR-Ca9 could make it possible to stop disease development completely and help address genetic disease predispositions. Targeted drugs such as anti-obesity or dementia-preventing drugs, as well as immunotherapeutics to treat debilitating diseases, will increase the ability to address this growing healthcare challenge. Countering antibiotic resistance will be crucial to ensure effective drug treatment overall. Technologies such as anti-microbial resistance countering will be important to minimise and stop the spread of anti-microbial resistance.

Advances in drug delivery systems for optimisation and personalisation will be driven by innovations in advanced materials, such as coating technologies and smart materials, with nanotechnology being utilised in medicine for therapeutic drug delivery and the development of treatments for a variety of diseases and disorders. Developments in advanced genomics is driving personalisation of medicine. Technologies such as pharmacogenomics and organs-on-chips are enabling effective targeted medical treatment. These are closely linked to technologies in advanced materials such as smart sensors, 3D printing and nano- and micro-electronics, and the use of bio-marker identification technologies.

Food

Figure 3: Food Research Priority theme: Research Prioritisation 2018-2023

Food

Food for Health

Smart and Sustainable Food Production and Processing
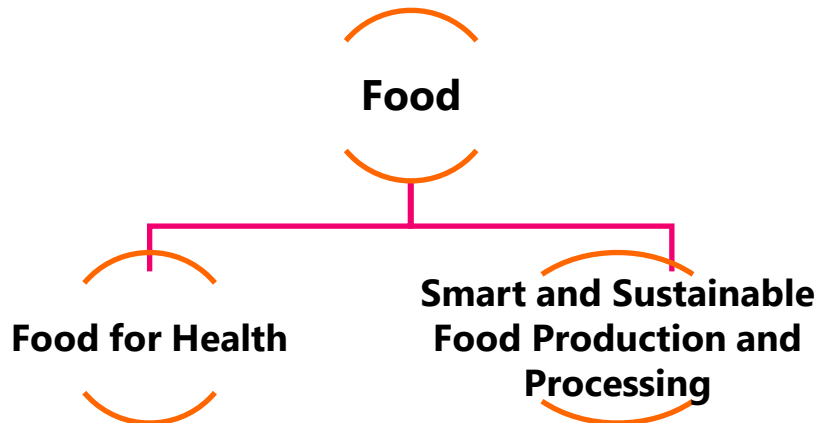
As the global population continues to grow, so too does the demand for food with a predicted 70% increase expected over the next 40 years. The food supply chain is currently being significantly impacted by climate change, the requirements of sustainability, and digitalisation in food markets, where there has been a resultant impact in GHG emissions, competing uses of land and sea, and the rise of ethical consumer habits relating to food sources. At the same time, there has been an increase in the changing diets of consumers, diet-related diseases, and growing individualism and demand for personalised food products.

Research seeks to address national agri-food challenges by improving the competitiveness of agriculture, food and the wider bioeconomy, to support sustainable farming and the environment, and to encourage diversification of the rural economy and enhance the quality of life in rural areas.

Under the Department of Agriculture, Food and the Marine's Food Wise 2025 Strategy, key priorities for 2017-2018 include improving the environmental footprint of the agri-food sector and the roll-out and expansion of Origin Green, the national sustainability programme. The Department of Agriculture, Food and the Marine's SHARP – Sustainable Healthy Agri-Food Research Plan, provides the blueprint to guide the future direction of research funding in the Research Prioritisation areas of Sustainable Food Production and Processing and Food for Health.

The Food Research Priority theme is sustained and the priority area for Sustainable Food Production and Processing is broadened to reflect the evolution in technology since 2012 and the key emerging priorities in the EU initiative *Food 2030*, particularly the need for "climate smart and environmentally sustainable food systems" and the need for "circularity and resources efficiency of food systems".

The Food Research theme includes two priority areas:
> ➢ *Food for Health*
> ➢ *Smart and Sustainable Food Production and Processing*

Food for Health

The increasing world population, changing demographics (particularly the increase in the ageing population), the increase in diet-related diseases and the demand for health and wellness food products across the life-course from childhood to old age are key challenges relevant to the Food for Health priority area. The priority area reflects the focus on changing diets and the health benefits of food and diet, as reflected in *Food 2030*. Technology under this priority area has a wide range of applications, from health and disease prevention, to personalised nutrition, food production and food safety. Personalised nutrition, such as personalised dietary supplements or personalised food delivery systems, have the potential to address public health-related and ageing population challenges, as well as the potential to lead to optimised human health and performance.

The key market identified under this priority area is Nutraceuticals and Functional Foods, which presents a large global market in which Ireland already competes, and can realistically compete into the future. It is highly probable that the pharma industry will want to enter the functional foods market. The regulatory structure and supply chain is already in place to accommodate this in Ireland, which has a strong established RDI structure in this area and many existing centres of excellence.

Published in 2016, the Teagasc Technology Foresight 2035 report highlighted the opportunity for new technologies in food processing. Many of these are directly related to food for health, and include non-thermal processing which will maintain nutritional quality of food without compromising safety; fractionation of food into different nutritional components (e.g., phospholipid, oligosaccharide or protein enriched milk); generation of new ingredients to support healthy microbiome development; staged nutrition and impact of food on health status at different life stages; food structure and chemistry analysis to allow reductions in salt, sugar and fat while retaining taste perception and satiety effects; and health benefits of pasture-fed dairy and meat products.

Ireland's agri-food and beverage and biotechnology sectors are in a strong position to lead innovation in the Food for Health area, building on existing capability in genomics, specialised nutrition and functional foods, coupled with complimentary expertise in areas such as ICT and 3D printing, and supported by the publicly funded research in these areas.

Smart and Sustainable Food Production and Processing

This broadened research priority area reflects the role of ICT in farming systems.

Research in this priority area seeks to improve the competitiveness of agriculture, food and the wider bioeconomy, to support sustainable farming and the environment, and to encourage diversification of the rural economy and enhance the quality of life in rural areas. In addition, research in this priority area is relevant to the bioeconomy which addresses the

production of renewable biological resources and their conversion into products and bio-energy.

This priority area also contributes to enabling our marine potential to be realised, which is a key objective under Harnessing Our Ocean Wealth (Ireland's Integrated Marine Plan) and the national Marine Research and Innovation Strategy. Research in Sustainable Food Production and Processing is also contributing to Ireland's response to climate change and aims to help achieve Ireland's 2020 greenhouse gas emissions reductions target and the longer-term goals to 2050.

Sustainable Food Production and Processing area has evolved with the changing needs of society over time and the key markets today are considered to be Sustainable Food (including seafood), Dairy Products, Meat Products, Precision Farming (including guidance systems, remote sensing, variable rate technology, hardware automation and control systems, and sensors and monitoring devices), Biotechnology, Alcoholic Beverages, Premium Food Products, Agribiologicals, Feed, and Advanced Animal Breeding.

Technologies related to Sustainable Food Production and Processing are being developed in response to minimising agriculture's impact on the environment, and supporting the efficient and sustainable use of resources (e.g. water, soil and fertilisers) in the food production process over the long-term. Technologies include the production of alternative fertilisers and precision fertiliser management, as well as soil management and the use of animal and soil microbiota. Other technologies relevant to this priority area and covered under Food for Health are food safety and traceability technologies and technologies around novel inputs, such as alternative protein and food processing technologies. Water treatment technologies are also particularly relevant to this area in managing nutrient pollution from agricultural primary production and food processing sources.

The Teagasc Technology Foresight 2035 focused on the identification of emerging technologies that will drive the competitiveness and sustainable growth of the Irish agri-food industry and bioeconomy sector over the following 20 years. This identified the following five priority technology themes for the agri-food sector: Plant and Animal Genomics and Related Technologies; Human, Animal and Soil Microbiota; Digital Technologies; New Technologies for Food Processing; Transformation in the Food Value Chain System.

Energy, Climate Action and Sustainability

Figure 4: Energy, Climate Action and Sustainability Research Priority theme: Research Prioritisation 2018-2023
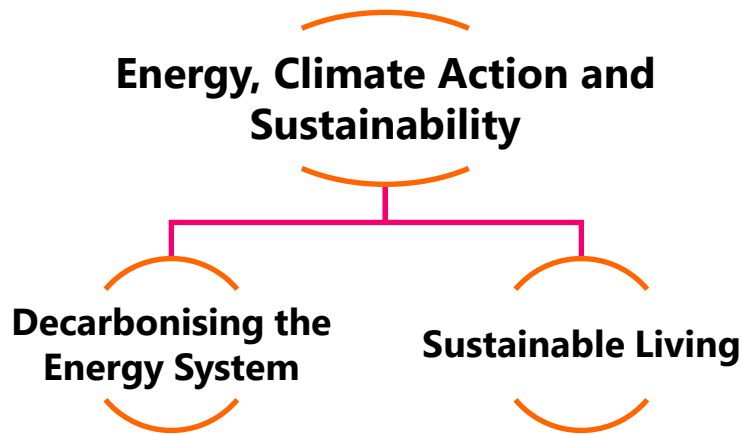
Energy, Climate Action and Sustainability

Decarbonising the Energy System

Sustainable Living

The challenges of climate change and sustainability have increased markedly in importance over the last five years, as evidenced by significant policy developments at national and international level. Both countries and companies are increasingly adopting more ambitious policies, regulations and strategies to mitigate the causes of climate change and to adapt to emerging and projected climate change impacts. The 2015 Paris Agreement to the United Nations Framework Convention on Climate Change marked a major progression in the global response to climate. The EU 2030 Climate and Energy Framework builds on the 2020 Climate and Energy Package on its transition roadmap to 2050. Ireland's National Mitigation Plan 2017 recognises that RDI will play a key role in Ireland's transition to a low carbon economy and society, stating that "The development and adoption of new and existing green technologies will be vital in areas ranging from energy efficiency, to electricity generation, transport and agriculture".

Previously, these priority areas focused on Marine Renewable Energy, and Smart Grids and Smart Cities. Based on developments since 2012, including the increased urgency to address climate change and sustainability challenges, alongside the increased opportunities for enterprise within this wider context, the Research Priority theme has evolved to reflect these drivers and is renamed Energy, Climate Action and Sustainability, and the two priority areas have been updated:
- ➢ *Decarbonising the Energy System*
- ➢ *Sustainable Living*

Decarbonising the Energy System
This priority area contributes to addressing the societal challenge of decarbonisation of Ireland's energy system, the development of indigenous energy supplies, and the move towards sustainability, and to making Ireland a world leader in the energy transition. Decarbonising the Energy System while increasing its resilience to climate impacts will incorporate the former Marine Renewable Energy priority area, expanding to include the research, markets and technologies associated with the broader low carbon energy

transition required across electricity, transport and heat. It will seek to realise the enterprise opportunities across these areas in sectors including ICT, renewable energy, mobility for growth, resource efficiency, and smart construction, while simultaneously achieving the goals set out in Ireland's National Mitigation Plan 2017 and the National Adaptation Framework 2018.

A range of technologies are relevant to this area including marine renewable energy, wind power solutions, solar, low power wireless networks, smart and context-aware sensors, ultra-resilient electronics, energy storage technologies, micro-energy harvest solutions and advanced building fabrics. From a sustainability perspective key technologies include water treatment technologies, air purification technologies and the development of sustainable materials. Relevant markets include marine, solar and wind energy, energy storage, microgeneration, electric transport, biorefining and bioconversion, smart construction, and environmental and systems monitoring.

Sustainable Living

The UN Sustainable Goals reflect the improved quality of life for all through the development of sustainable cities and communities and the efficient use of resources through the circular economy. A further goal is around ensuring sustainable consumption and production patterns and the EU Action Plan on the Circular Economy (2015) is positioned as being instrumental in reaching this goal. Using sustainable materials is a vital lever to enable closed-loop recycling systems and to underpin waste management, recycling and recovery.

Sustainable Living will incorporate the former Smart Grids and Smart Cities priority area, expanding to include the research, markets and technologies associated with the broader transition to more sustainable living, in cities, rural areas, and communities. It will seek to realise the opportunities in enterprise sectors including the circular economy, new emerging markets in waste, water and infrastructure management, and the non-food elements of the Bioeconomy (e.g. biorefining).

As technology has evolved, driven by global challenges such as climate change and urbanisation, today's key markets are considered to be Electric Vehicles, Biorefining and Bioconversion, Energy Storage, Microgeneration, Solar Energy, Smart Construction, Low Carbon Construction, and Environmental Monitoring. Connected vehicles, e-commerce, autonomous driving and the industrial internet have emerged as major driving factors of automotive digitalisation which is set to radically transform our transport and mobility patterns globally.

Manufacturing and Materials

Figure 5: Manufacturing and Materials Research Priority theme: Research Prioritisation 2018-2023

Manufacturing and Materials

Advanced and Smart Manufacturing

Manufacturing and Novel Materials
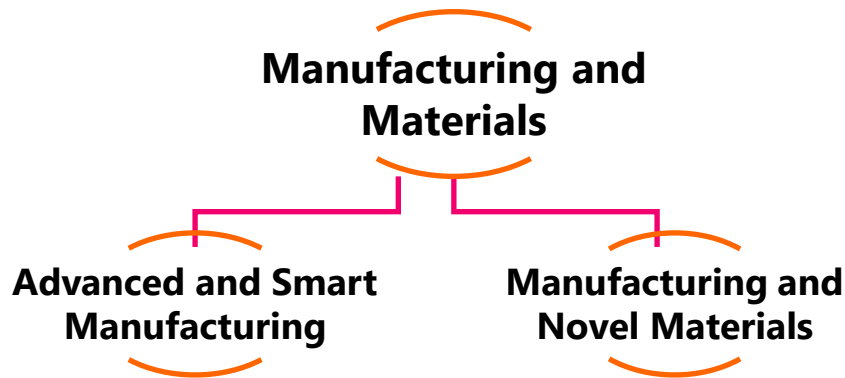
Manufacturing is a driver of innovation and technological advancement and a number of key drivers are revolutionising manufacturing worldwide. The rapid pace of technological change is enabling novel production and organisational processes, and new business models. In addition, as a result of climate change and pollution, the manufacturing sector is faced with a demand for goods and production processes that are designed to reduce a product's environmental footprint.

To reflect the impact of technological change and the digitisation of manufacturing since 2012, the Manufacturing Competitiveness priority area is renamed Advanced and Smart Manufacturing (which will also include Processing Technologies) and Processing Technologies and Novel Materials is renamed Manufacturing and Novel Materials, acknowledging that Novel Materials underpin and enable other priority areas, presenting particular challenges for the manufacturing sector.

The Manufacturing and Materials Research Priority theme includes two priority areas:
- ➢ *Advanced and Smart Manufacturing*
- ➢ *Manufacturing and Novel Materials*

Advanced and Smart Manufacturing
The rapid pace of technological change with the rise of digitisation across the manufacturing sector can be keenly seen in the growing importance and pervasive nature of cloud computing, additive manufacturing, automation, artificial intelligence and nanotechnology which are enabling novel production and organisational processes, and new business models. The imperative for sustainability within this area, given growing resource and energy efficiency demands, is placing sustainable resource management at the centre of government agendas. The increased scarcity of minerals and metals, alongside pollution, is driving efficiencies in applications, in recycling and is driving the development and manufacturing of novel materials.

Ireland has recognised capability in this sector, underpinning the competitiveness of its manufacturing base, which is also associated with large global markets such as Global Engineering Services Outsourcing and Biotechnology.

Other markets where Irish-based enterprises can leverage opportunities are in Smart Manufacturing, Advanced Composites and Materials, Machine Vision and Applied Nanotechnology. A wide range of technology clusters will impact on the manufacturing competitiveness of the industrial base in Ireland, relating primarily to advanced materials and engineering, biotechnology and nanotechnology, optics and photonics. The cross-sector applications range from health and industrial manufacturing to food, energy and the environment, including buildings and construction.

ICT-related technology platforms such as data analytics, augmented reality and cyber security will also support the evolution of advanced manufacturing processes. The deployment of technologies to enhance the manufacturing competitiveness of the industrial base in Ireland will require underpinning research and development in the publicly funded research system.

Manufacturing and Novel Materials
This priority area aims to develop new materials, such as coatings, polymers, composites, advanced functional materials and biomaterials, in the manufacture of products.

Future technologies – battery and communication technologies, fuel cells, displays, thin film solar, various renewable energy applications, and magnetic applications – will require significant amounts of rare earth elements. Experts expect massive shortages by 2035 if current trade and extraction patterns do not change. Research in this area will address the global challenge of the depletion of mineral and resources and will also contribute to the emergence of the Circular Economy, which seeks to contribute to "closing the loop" of product lifecycles through greater recycling and re-use, bringing benefits for both the environment and the economy. Research in this area can also yield advanced materials which enable new products and enhanced performance of existing products. Examples include the development of 2D nanosheet materials for applications in electronics, energy devices, and packaging; the development of next generation implants and tissue engineered constructs targeting specific clinical problems for improved health; and the development of new thermoplastic composites for applications ranging from wind-turbines and automotive parts, to aircraft. Success in this area would include a strengthening of the manufacturing base in Ireland exporting new products based on novel materials.

As technological capabilities have evolved over time, the key markets today are recognised as Advanced Composites and Materials (ceramics, glasses, polymers, composites, and metals and alloys with applications in the medical devices, automotive, aerospace, electricals, electronics, industrial and power sectors) Applied Nanotechnology (carbon nanotubes, nanocomposites, nanomaterials, nano-coatings, and their application), and Biotechnology. These markets have a high level of adjacency with markets under the Advanced and Smart Manufacturing priority area.

Innovation in Services and Business Processes

Figure 6: Services and Business Processes Research Priority theme: Research Prioritisation 2018-2023

Innovation in Services and Business Processes

The Services and Business Processes Research Priority theme comprises one priority area:

> ➤ *Innovation in Services and Business Processes (ISBP)*

There has been a fundamental change in the nature of innovation within both manufacturing and services firms world-wide, from selling products based solely on technical innovation, to providing customer focused solutions involving a mix of product and services and innovating around delivery methods and business models. Augmented Reality and Virtual Reality will be critical technologies impacting on services.

The type of research relevant to ISBP differs in a number of important respects from research that is traditionally supported by RDI funders. These differences include the fact that the timescale for research is much shorter, end users are centrally engaged, the research is typically multidisciplinary in nature, and the innovation often happens during the process of taking a product or service to market.

This priority area is focused on enabling both the manufacturing and service sectors to innovate their service offerings, service delivery, and business processes. Examples include servitisation of manufacturing, smarter commerce, business model innovation, risk governance, and sustainability.

The enabling role of ISBP, given that it impacts on the operation of businesses across all sectors, points to the potential for this priority area to enable other priority areas, helping maximise the impact of the overall prioritisation initiative. Research areas relevant to ISBP include services innovation management, business model innovation, value chain management, user interface design, and behavioural economics.

Digitalisation is a key driver in this area, especially through the development of new products, processes and services, and the delivery of disruptive business models, in which the growth of volumes of data and data analytic capabilities are a major factor. Major technologies that are enabling innovation in services and business processes include

advanced computing and storage, sensors, AI, data visualisation technologies, machine learning, and self-organising and reconfigurable architectures.

There are significant global market opportunities where Irish-based enterprise have established or are establishing strengths, including Fintech, Experiential Tourism, Investment Management and Administration, the Sharing Economy, IT Technology Consulting and Support, International Education Services, Smart Learning, CorpTech, and Business Process Outsourcing.