Report of the

Research Prioritisation Steering Group

Minister's Foreword

The last decade has seen consistent and considerable public and private investment in Science, Technology and Innovation and the result has been the establishment of a strong base of research expertise, with research excellence in a number of key strategic areas. It is now time to build on that base, build on the strengths that have emerged from past investment and target future investment in areas that link directly to current and likely future economic and societal needs. We need to leverage what we have built by targeting public investment towards research based on potential for economic return, particularly in the form of jobs.

The process of identifying the areas with the greatest potential was challenging. I would like to convey sincere and personal thanks to the Chairman of the Steering Group, Jim O'Hara, for his commitment and drive to getting this done and done well. I would also like to thank the members of the Steering Group and the Secretariat as well as all those who participated in the thematic working groups that fed into the final analysis, for their expertise and the considerable amount of time they dedicated to this exercise. The quality of inputs by all involved is clear when we see the standard of the final report.

This Government has an ambitious agenda for Ireland to become the best small country in the world in which to do business. This will require transformation of all sectors of our society and the prioritised research areas will have a key role to play in this transformation. The recently published 'Action Plan for Jobs' starts to lay the foundations on which we will rebuild a growing and sustainable economy that will provide jobs and opportunities for generations to come. Research Prioritisation is the very first action in that Plan. This reflects the Government's continued commitment to placing science, technology and innovation at the heart of enterprise and jobs policies so that we are favourably positioned to capitalise on the opportunities that will arise as the global economy recovers. A key objective is to accelerate the delivery of economic outcomes from Government investment in public research organisations by implementing the recommendations contained in this Report on Research Prioritisation. We will do this by aligning future public investment by research funders to the 14 areas of opportunity that have been identified.

In order to make this happen we need appropriate cross-Governmental, coordinated oversight and independent review mechanisms which will take stock of implementation. My colleague with specific responsibility for Research and Innovation, Minister Seán Sherlock, will personally chair a Prioritisation Action Group to drive implementation which will include system change to ensure efficient and effective delivery of programmes.

The Government recognises the critical role of research for policy making and the fundamental role of research for knowledge. However, we must target the majority of future investment in Research, Development and Innovation in order to ensure that we get the greatest economic return for our investment. We must target that investment on areas that are most likely to create economic value and jobs.

Richard Bruton T.D.

Minister for Jobs, Enterprise and Innovation

Chairman's Foreword

I am pleased to introduce this report which summarises the deliberations of the Research Prioritisation Steering Group which met between October 2010 and September 2011. The group was asked to make recommendations to Government on areas of focus for the next phase of Ireland's science, technology and innovation strategy.

Significant investment has taken place in science, technology and innovation in recent years with much of this investment centred on building up research capacity within higher education institutions and research institutes. The investment has been driven in large part by a desire to compete in the 21st century knowledge based economy.

As a group, we share the view that investment in science, technology and innovation has served us well. There is much to point to now in terms of the research and innovation landscape in the country that simply didn't exist ten years ago.

We are equally of the view that the time is right now to increase the focus of this investment. In making our recommendations about priority areas of focus, we need a new over-riding policy objective to accelerate the delivery of specific economic outcomes from our investment in research.

As per the mandate we were given, we recommend areas around which future investment in research with a direct economic motive should be focused. We position these in a wider context that recognises the need for investment in underpinning research and platform science and technology, the need for integrating infrastructure, the need for research to support Government policy and the need for some level of untargeted research to address new and unanticipated areas.

Identifying priority areas will not, in itself, be enough to accelerate the delivery of specific economic outcomes. Therefore, we make recommendations also on some system changes that should be put in place with immediate effect. Taken together with recommendations from other groups advising on specific aspects of the STI system in Ireland, there is the potential now to improve significantly the functioning and wellbeing of the overall STI ecosystem in Ireland.

This has been a challenging process. I would like to acknowledge the commitment and contributions from Government Departments and agencies who fund R&D, the research community, the enterprise sector and from other stakeholder groups that provided input to this process. Importantly, I would like to thank all of my colleagues on the Steering Group who have generously contributed their time, significant expertise and insights. I would particularly like to thank Marion Coy, Brian Hayes, Tom McCarthy and Maurice Roche for chairing the working groups that we established for the exercise and all of the additional work that this entailed. Finally, I would like to thank Forfás who managed the process on behalf of the Steering Group.

Jim O'Hara

Chairman, Research Prioritisation Steering Group

November 2011

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Executive Summary

This report sets out the recommendations of the Research Prioritisation Steering Group which met between October 2010 and September 2011. We were asked by Government to identify a number of priority areas around which future investment in publicly-performed research should be based. These priority areas should deliver sustainable economic return through their contribution to enterprise development, employment growth, job retention and tangible improvements in quality of life.

Based on our deliberations, a number of significant studies undertaken by Forfás and direct input from the research community, the enterprise sector and research-funding Departments and agencies, we make recommendations in this report on 14 priority areas of focus and on the wider science, technology and innovation (STI) ecosystem.

Context for the Exercise

The context for this exercise is well understood and well accepted across all of the stakeholders we engaged with during our process:

- The Government embarked on a strategy from the late 1990s onwards of significantly enhancing the scientific, technological and innovative capacity of the enterprise sector and the country as a whole. This strategy involved directly supporting research and innovation capacity within the enterprise sector and significantly scaling up the research capacity and science and technology infrastructure in Ireland's higher education institutions (HEIs) and other public research organisations.

- These endeavours built on many years of support from the European Union (EU) through Structural Funds and access to European research programmes. The national endeavours also connected to a more general European policy goal to raise European research and development (R&D) levels to those of its global competitors.

- There is general acceptance that the recipients of Government support for research and innovation in both the public and private sectors delivered very well on what they were asked to do. There is evidence that the quantity and quality of publicly-performed research has increased significantly as judged by most of the key STI indicators (e.g. R&D intensity, publication rates, citation rates, human capital, etc.). In most cases, we have moved from a below world average position to being at or above the relevant world averages.[1]

- Business expenditure on R&D has kept pace with public investment in research and the private sector now accounts for two thirds of R&D investment in the country. There is

[1] *Research Strengths in Ireland - a bibliometric study of the public research base*, Forfás and HEA, Nov 2009 and the *Extension Report: the PROs*, May 2010.

evidence also that research and innovation is a factor in explaining productivity growth and export performance within the enterprise sector.

Government policy in the area of research and innovation has served us well but it is appropriate to move towards a more top-down, targeted approach at this point:

- The broad areas around which budgets have been oriented to date (e.g. ICT, biotechnology etc.) were appropriate for building a broad base of expertise in fundamental, underpinning science and technology (S&T). We now need to build on the strengths that have emerged from the investment that has taken place. We need to target investment so that we have critical mass in areas that link more precisely to current and likely future societal and economic needs.

- We need to examine more closely the manner in which we expect investment to translate into outcomes that will bring benefits to the people of Ireland. At the top of the list are sustainable economic activity and jobs.

- Government investment in research is likely to remain under severe pressure in the years ahead, and yet research needs to stay centre stage in the Government's economic strategy. This combination of limited resources and crucial need means that we must focus investment in those areas that are most likely to give demonstrable returns in the medium term. At the same time, we must maintain a sustainable STI system that is looking to longer term national prosperity and wellbeing.

Our Interpretation of the Terms of Reference

Before reporting on the outcome of our deliberations, we clarify in our report a number of matters relating to our terms of reference:

- Priority areas should derive from economic and societal needs and, for the most part, will be areas where there is a combination of enterprise relevance for Ireland and research strength in Ireland. We were not asked to prioritise one research area or field of science over another. We want research across many disciplines to contribute to the needs of the economy.

- The scope of the exercise relates mainly to publicly funded research awarded on a competitive basis and performed in Irish HEIs and public research organisations. Two important categories of expenditure deliberately excluded are:

  - the "block grant" to higher education institutions which supports research, and

  - funding for in-company performed R&D.

- There are multiple objectives associated with the Government's *Strategy for Science, Technology and Innovation*. We identify three over-arching goals:

  - Research oriented towards the Irish enterprise base;
  - Research for policy;
  - Research for knowledge.

- The Steering Group has deliberately focused its attention on publicly-funded research that is oriented to the Irish enterprise base (i.e. natural resource sectors, manufacturing sectors and market services sectors of the economy). This has always accounted for, and should continue to account for, the largest proportion of Government investment in R&D. In relation to research oriented towards the Irish enterprise base, we propose a new high level national objective to accelerate the delivery of specific economic outcomes from our investment in research.

- Our understanding of the five year timeframe that is mentioned in our terms of reference is two-fold: the priority areas we recommend should set the agenda for the coming five years; furthermore, given that we are building on at least ten years of sustained investment, we expect that there will be real and demonstrable economic impacts from each of the priority areas we recommend within a five year period.

- The proposed areas are broad enough to involve the full spectrum of research from basic through to applied and can involve researchers across all disciplines and sciences: physical and life sciences, technology, services, engineering, arts, humanities and social sciences.

- We call on the research community and the enterprise sector to continue to pursue their endeavours in the context of the wider European and international system within which Irish research is positioned. The areas that we recommend cannot and should not be pursued within an exclusively national context. In most instances, they already connect to established European and global research agendas. The areas we recommend provide a basis for strategic engagement in international research programmes, in particular Framework Programme 7 (FP7) and its successor programme, Horizon 2020. They should also link as appropriate to R&D priorities in emerging economies, where many of the new intellectual and business opportunities are likely to be found.

Priority Areas

Drawing on exercises in other countries, the Steering Group put in place its own process to combine a strong evidence base with expert judgment. At the core of our process are four key criteria (Table 1) that we established as a mechanism for assessing and evaluating proposed priority areas.

Table 1: The Four High Level Criteria for Assessment of Priority Areas

1. The priority area is associated with a large global market or markets in which Irish-based enterprises already compete or can realistically compete
2. Publicly performed R&D in Ireland is required to exploit the priority area and will 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

Based on the criteria employed, the table below summarises the 14 areas that we are recommending should become the focus of future investment directed towards economic outcomes.

Table 2: The Priority Areas

	Priority Area	Description
A	**Future Networks and Communications**	This priority area will address the challenges of scalability, capacity, throughput, mobility and trust of the internet, including: ▪ Network and Service Management – how to best manage and serve the network given new demands from devices and applications; ▪ Internet Technologies – the software and protocols to support the network; ▪ Fixed, Mobile and Wireless Communications – enabling connection and collaboration.
B	**Data Analytics, Management, Security and Privacy**	This priority area is focused on turning data into information and ultimately knowledge that can be exploited for both economic and social benefit ("Smart Data"). It has two major components: ▪ Data Analytics and Data Management – managing data as a resource and converting it into useful information; ▪ Security and Privacy – protection of information and regulation of data.

	Priority Area	Description
C	**Digital Platforms, Content and Applications**	This priority area is focused on the development of platforms that enable the commercial exploitation of ICT research and the development of ICT based public services. It includes: ▪ Digital Content and Applications – content development and the development of applications in areas such as eGaming, eEnvironment, eLearning and eTourism; ▪ Human-Machine Interface, multi-media, multi-modal service creation environment.
D	**Connected Health and Independent Living**	This priority area is focused on technologies that facilitate remote delivery of healthcare and assisted living, moving the emphasis of care to the patient in their own home. Connected health and independent living technologies have the potential to transform healthcare and service delivery, thereby reducing burdens on health systems and improving the quality of life and independence of our ageing populations. This is an emerging area and there is an opportunity to position Ireland as a 'proving ground' for connected health solutions.
E	**Medical Devices**	This priority area is focused on further strengthening Ireland's position as a hub for medical devices, through integrating existing enterprise and research strengths to drive development and manufacture of next generation medical devices here.
F	**Diagnostics**	This priority area is focused on ensuring that research strengths developed over the last decade of investment are fully exploited. Ireland has developed significant research capacity in a range of areas that underpin development of diagnostics, including biomedical research, nanotechnology, materials and photonics. There are opportunities for commercialisation in emerging growth areas such as personalised medicine/companion diagnostics, nutrition related diagnostics, veterinary diagnostics and point-of-care devices. Applications in connected health can also be promoted through focused investment and/or coordination.
G	**Therapeutics - Synthesis, Formulation, Processing and Drug Delivery**	This priority area is focused on developing competence and activity in pre-manufacturing research, technology and development areas responding to industry needs in Ireland in therapeutics/pharmaceuticals (for example, the manufacture and formulation of small molecules and bioprocessing research). Drug delivery is also an opportunity for further enterprise development based on innovative drug delivery systems.

	Priority Area	Description
H	**Food for Health**	This priority area is focused on building the capacity to develop and produce functional foods or ingredients in Ireland. The challenge is to ensure full integration of the research base and enterprise to enable product development and validation of product claims to meet regulatory requirements.
I	**Sustainable Food Production and Processing**	This priority area is focused on sustainable, competitive and efficient: ▪ Agri-food production; ▪ Marine fisheries and seafood; ▪ Food processing including manufacture of safe, value added & innovative foods.
J	**Marine Renewable Energy**	The focus of this priority area is to position Ireland as a research, development and innovation hub for the deployment of marine renewable energy technologies and services. This would facilitate the creation of an early stage industry and research cluster and open up the possibility of becoming a significant exporter of electricity. The development and testing of ICT applications in a marine environment (based on the Smart Ocean concept) could be supported to enable this priority area.
K	**Smart Grids and Smart Cities**	This priority area is focused on the development of Smart Grids and Smart Cities using a layer of technologies (including software, sensor hardware and control and interface systems) and design solutions to more effectively and efficiently manage complex infrastructure systems, enable greater resource efficiency and help move to a low carbon society.
L	**Manufacturing Competitiveness**	This priority area is focused on the development and application of technology and knowledge management systems to reduce costs, eliminate waste, drive resource efficiency and improve product quality for increased competitiveness.
M	**Processing Technologies and Novel Materials**	This priority area is focused on enabling the Irish manufacturing base to transition into one with enhanced capabilities in processing technologies and materials science and engineering.
N	**Innovation in Services and Business Processes**	This priority area is focused on enabling both the manufacturing and service sectors to innovate their service offering, service delivery and business processes. Examples include: servitisation of manufacturing, smarter commerce, business model innovation and risk governance.

Positioning the Priority Areas within the Wider STI System

The priority areas that we are recommending need to be underpinned by research across many fields. Some of the important science and technology platforms that will underpin the priority areas are identified in our report: Basic Biomedical Science, Nanotechnology, Advance Materials, Microelectronics, Photonics and Software Engineering. This is not an exhaustive list. As made clear in our mandate, 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.

The priority areas, together with underpinning research undertaken in direct support of the priority areas, should account for the majority of future Government investment in publicly performed research and development in HEIs and public research organisations. However, this majority share should also allow for some element of infrastructure spend. Given the significant investment in physical infrastructure that has taken place in recent years, there will be significantly less investment required in new buildings and equipment in the coming years. Investment in the years ahead should be targeted at the maintenance of equipment and specific integrating infrastructure required for the priority areas (e.g. data repositories, clinical research infrastructure, "e-infrastructure" etc.).

The terms of reference for the exercise points out that the minority share of the funding (i.e. the share not oriented towards the priority areas) would leave room for evidence-based, policy research. As this research is not driven principally by a commercial motive, it did not fall within the direct scope of the prioritisation exercise. Examples here are research that provides the basis of regulatory actions designed to promote the health, safety and quality of life of individuals and address key societal challenges (see Section 4 - Research for Policy and Annex 2).

We also envisage that some element of non-targeted research (which we refer to as "research for knowledge") would continue to be funded in Ireland through competitive calls. This is an important part of a sustainable, well functioning STI system. Together with the other broad categories of research we identify (research oriented towards the Irish enterprise base and research for policy), it helps to develop the human capital that is required for a sustainable, competitive STI system including postgraduate and post-doctoral training of researchers and the recruitment and retention of world class senior researchers.

Implementing the Priority Areas into the STI System

A list of priority areas is, in itself, only one of the ingredients needed to transform the STI system to one that is focused more on outcomes and impacts. Based on deliberations summarised in the report, we put forward 13 recommendations aimed at bringing about a step change in the efficiency and effectiveness of the current STI system. The Steering Group recommends that:

1. Government should re-state its objectives for science, technology and innovation policy with clear goals and metrics for each element of this policy. Our report will

assist in this regard. In the first instance there is a need to set a new over-riding national objective to accelerate the delivery of specific economic outcomes from our investment in research.

2. The policy goals and objectives that are set should be underpinned by a set of national indicators that reflect the goals and objectives (e.g. R&D intensity of enterprise; number of research personnel per 1000 employees) and this should include indicators of economic impact. These indicators should help to clarify programme level objectives and targets and the allocation of resources. There should also be clarity in the allocation of roles and responsibilities to achieve the high level targets.

3. The Department of Jobs, Enterprise and Innovation (DJEI) should annually monitor performance, with independent oversight, on behalf of the Government. These regular reviews should report timely and consistent data that will determine the allocation of resources at a system level and inform and underpin future priority setting exercises. Difficulties in monitoring performance at the system level can be addressed by introducing standard measurement and reporting systems across funding programmes.

4. The funding mechanisms that will be used to give effect to the priority areas should be assessed to ensure that they are fit-for-purpose in terms of delivering economic impact. Programmes that focus on commercialisation and innovation leading to economic outputs should integrate the core principles of programmes that identify needs, invent solutions and commercialise products or services.[2]

5. Applications for funding under the priority areas will require at least a two-stage process. The applications should be screened based on demonstrated relevance to the priority areas, clarity of deliverables and, where appropriate, end-user engagement. Applications that pass the test of relevance to the priority area should be reviewed against the criteria of excellence and originality based on established peer review processes.

6. There should be an ongoing review of all funding programmes to ensure continued relevance and clarity of purpose, that programmes have sufficient scale and that unnecessary duplication is avoided. The review should ensure that the costs of the programme are commensurate with the benefits achieved. New programmes should be avoided if the objectives can be achieved through the adaptation of existing programmes.

7. Given the number of funding bodies and programmes, departments and agencies should agree to a coherent and consistent approach to the administration of funding programmes. Differences of approach in areas such as auditing add to the administration costs for agencies and research organisations.

8. Funding programmes for physical infrastructure should adapt to recognise the current priority to maintain and support the operation of existing infrastructure while also incentivising the sharing of resources, thereby utilising their full capacity. A key requirement to achieve this will be a national inventory of all significant publicly funded infrastructure and equipment.

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[2] One such example in Ireland is the Bioinnovate Programme at NUIG.

9. Policies and procedures for the commercialisation of intellectual property arising from publicly funded research should be fast, predictable and consistent.

10. Research centres with a mandate to engage with industry, including CSETs (Centres for Science, Engineering and Technology), SRCs (Strategic Research Clusters) and public research organisations must develop a distinctive industry-focused culture. They should have the breadth of multidisciplinary research activity and the range of expertise (including business development skills) to partner with industry. A key performance indicator for such centres will be the proportion of funding leveraged from enterprise. Developing such centres will require alignment around the priority areas and, for HEI based centres, sufficient autonomy to prioritise an industry-oriented mission.

11. Innovation activity should be recognised by the system for career progression for academic staff within HEIs and public research organisations.

12. A consistent quality framework should be developed for postgraduate education and training incorporating the Structured PhD model. Responsibility for monitoring of the output and quality of Masters and PhD training and education should rest with the Department of Education and Skills (DES). Indicators of the quality of postgraduate education and training should be developed by DES and integrated into the Government's overall framework for monitoring science, technology and innovation.

13. Initiatives to improve further and keep under continuous review the alignment between the supply of trained researchers from academia and the demand for such skills from the enterprise sector are imperative:

    - A proportion of PhD funding should be earmarked to support the development and rollout of the industrial PhD model in Ireland.

    - A proportion of PhD funding should be redirected towards the development of industry driven Masters programmes.

    - Technology Transfer Offices within the HEIs should develop a coherent and integrated programme of support for PhD students and early stage post-doctoral researchers that enables them to identify and exploit commercial opportunities arising from their research.

1. Introduction

Context for the Exercise

Ireland's international competitiveness performance, and ultimately our ability to generate wealth, increasingly depends on our ability to sell differentiated, high-value products and services to global markets. The knowledge content of the goods and services produced here has over time, increased significantly. The evolution in Ireland's enterprise base towards such knowledge based activities has also been reflected in the research, development and innovation (RDI) policy landscape and the high level goals and objectives for RDI policy in Ireland are set out in the *Strategy for Science Technology and Innovation* 2006-2013 (SSTI):

- Build a world class research system within higher education;
- Strengthen the system of knowledge transfer;
- Strengthen the RDI base of enterprise;
- Increase the number of Science, Technology, Engineering, and Maths (STEM) graduates; and
- Leverage public sector research for economic and social development.

Having come from a low base, Ireland has made very significant progress over the past decade in building a research infrastructure that in some instances is amongst the best in Europe; in retaining and attracting top level researchers; and in achieving closer synchronisation between research endeavour in HEIs, Government agencies, and industry. The quality of research output as measured by citation impact has improved and Ireland's citation impact is now 25 per cent above world average[3]. The transfer of research knowledge and capacity from the HEIs to the wider economy has increased through research graduates finding employment in industry and through industry-academic collaboration. The increased public investment in R&D is impacting positively on the commitment to research and innovation in the business sector - approximately two thirds of Ireland's gross R&D expenditure is privately funded and one third is publicly funded.

However, as with any STI system, challenges remain to optimise efficiency and achieve maximum return on investment. Ireland needs to align publicly funded research more closely with industry and societal needs, achieve critical mass in a small number of areas and facilitate the transfer of knowledge between academia and industry, while maintaining its commitment to excellent research.

[3] *Research Strengths in Ireland - a bibliometric study of the public research base,* Forfás and HEA, Nov 2009 and the *Extension Report: the PROs,* May 2010.

In order to identify a number of areas around which future public investment in STI should be focussed in the years ahead, the Government established the Research Prioritisation Steering Group (the Steering Group) in October 2010.

The process was managed by Forfás who assembled the evidence bas upon which the findings and conclusions are drawn.

This report:

- Identifies a number of priority areas of focus that have come through the deliberative process;
- Positions the recommended areas within the wider STI system; and
- Offers a number of recommendations to the Government that will help to fine-tune the existing STI system so that it becomes even more outcome focused than heretofore.

Structure of this Report

The report is structured as follows:

- Section 2 sets out the terms of reference of the Steering Group and addresses a number of issues that have been prompted by the Terms of Reference;
- Section 3 provides a brief overview of the process that was designed in order to deliver on the mandate that was given by Government;
- Section 4 provides an overview of the 14 areas that are recommended as priority areas of focus for the years ahead, identifies critical enabling areas of research and indicates how these should be positioned within the wider STI system;
- Section 5 identifies a number of issues relating to the governance, management and administration of publicly funded research in Ireland and the recommendations for implementing the priority areas into the STI System;
- Annex 1 provides more detailed descriptions of the 14 priority areas of focus to highlight their fit with the criteria employed and to draw attention to details that should be taken into account in translating these areas into research agendas around which future calls can be based;
- Annex 2 gives examples of policy research in the context of Thematic Working Group deliberations;
- Annex 3 gives examples of integrating infrastructure required as part of a sustainable science, technology and innovation system;

- Annex 4 gives a detailed account of the process put in place to deliver on the Terms of Reference;
- Annex 5 lists the membership of the Research Prioritisation Steering Group;
- Annex 6 lists the membership of the Thematic Working Groups; and
- Annex 7 provides a list of acronyms.

2. Principles Guiding Research Prioritisation

Terms of Reference

The terms of reference for this project required that the Steering Group do the following:

- Aim to develop consensus on a number of priority areas and/or approaches to tackling national challenges which need to be underpinned by future investment in publicly funded STI;
- Identify and articulate, as far as possible, a non-exhaustive list of supporting fields of science and technology that will underpin the priority areas and/or approaches to national challenges in the medium term (5 years) and beyond; and
- Identify actions required for each of the priority areas put forward including goals to be realised in the medium term (5 years) and beyond.

The following guidance was given around the Terms of Reference:

- The prioritisation exercise should take account of fields of research activity where Ireland has built significant strength to date and particularly areas that have the greatest potential to deliver sustainable economic return through enterprise development, employment growth, job retention and tangible improvements to quality of life;
- The exercise should also identify fields of science where new strengths could be developed in support of priority areas;
- It is expected that somewhere between 10-20 priority areas will be identified and become a focus for further concentration of Irish research and development effort aligned with the attraction and embedding of foreign direct investment (FDI), development and growth of indigenous enterprise and direct commercialisation of research results;
- The exercise should take account of complementary developments at EU level and other international initiatives. Alignment with the Seventh EU Framework Programme (FP7) and with European initiatives in respect of "joint programming" are particularly important but the exercise should also take into account future plans in respect of research and innovation policy in Europe and globally;
- Following this initial exercise, the majority of the total STI Programme budget will be focused on these priority areas with scope left to pursue other policy focused evidence-based research;
- The selected areas will be reviewed on a regular basis to ensure their continued relevance and to also ensure that new opportunities are identified; and

- As with similar exercises in other countries, the process by which areas will be identified will involve extensive and structured stakeholder engagement in order to secure both the best possible evidence base for the task as well as "buy-in" to the final outcome of the exercise.

The Terms of Reference and the related guidance notes prompted many issues with regard to STI policy in Ireland and the role of the prioritisation exercise therein. The Steering Group spent a considerable amount of time, particularly in the early phases of the project, deliberating on the issues prompted by the Terms of Reference. These deliberations have a direct bearing on the manner in which the work was approached and, consequently, the recommendations made in this report. In the section below, we set out our interpretation of the terms of reference so that there is clarity as to what we have done and what we have not done in the course of this exercise.

Our Interpretation of the Terms of Reference

Scope of this Exercise

The first point to clarify relates to the funding that comes within the scope of the prioritisation exercise. While there will always be issues at the margin, this exercise relates in broad terms to funding allocated from exchequer resources specifically for research performed within HEIs and public research organisations (PROs). For the most part, it relates to funding that is allocated on the basis of competitive calls for proposals. There are two significant categories of Government research expenditure that are outside the scope of this exercise:

- A proportion of the "block grant" allocated to HEIs supports research activity. This imputed amount is based on the share of time spent by salaried academic staff on research. Our understanding is that the prioritisation exercise will not impact directly on the manner in which the "block grant" is administered and, therefore, is outside the scope of our exercise; and

- Government support for R&D activities performed within the enterprise sector does not come within the scope of this exercise. These R&D supports (administered in the main by Enterprise Ireland and IDA Ireland) are based on proposals put forward by the enterprises concerned and it is our understanding that the processes and procedures for supporting this in-company R&D activity will not be impacted directly by our recommendations.

The exchequer investment that falls within the scope of this exercise supports a range of goals as articulated in the SSTI and subsequent statements of policy including the *Programme for Government*. In essence, however, we believe that there are three high-level objectives for Government investment in publicly performed research:

Research Oriented towards the Irish Enterprise Base

This includes investment in publicly performed research with the main goal of underpinning the scientific, technological and innovative capacity of the productive sectors of the economy leading to productivity improvements and other economic outcomes (e.g. enterprise development, sustainable growth, job retention, etc.) across the natural resources sectors, manufacturing sectors and the market services sectors.

Research for Policy

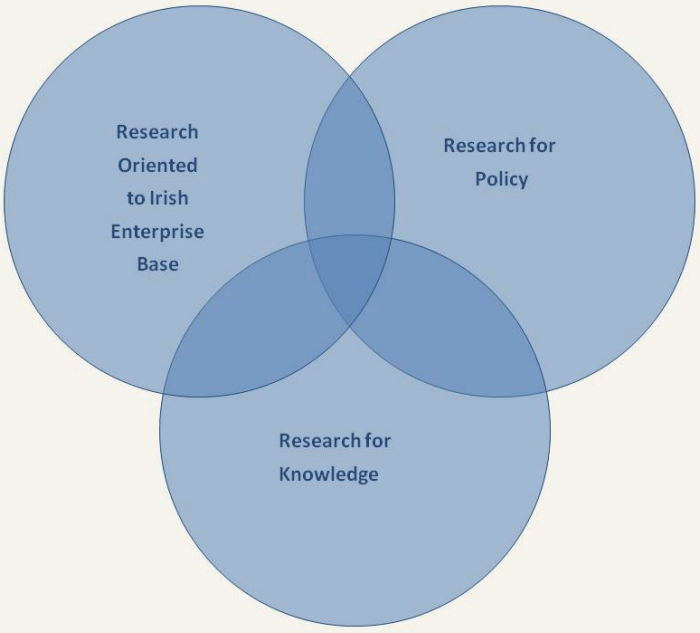
Our interaction with Government Departments, agencies and other research funders has highlighted the important role that research plays in helping the Government to deliver on policy and associated service and system objectives. These policy objectives include those set out in government programmes and, in addition, those policy targets linked to EU and other international obligations. This type of research is determined in the first instance by policy and associated service and system needs rather than by the likely commercial impact of the research.

Research for Knowledge

While most public investment in research in Ireland is driven by an economic motive, a proportion of investment should be available to support research driven by a knowledge creation motive rather than by a direct connection to a sectoral opportunity or a specific, identified enterprise need. This type of (typically) basic research should continue to be funded in Ireland as part of a sustainable, well functioning STI system. Together with the other broad categories of research we identify (research oriented towards the Irish enterprise base and research for policy), it helps to develop the human capital that is required for a sustainable system including postgraduate and post-doctoral training of researchers and the recruitment and retention of world class senior researchers.

The three high level objectives as shown above in Figure 1 below reinforce the point that these are not mutually exclusive categories of investment. All public investment in research is ultimately aimed at improving the economic and societal wellbeing of the country and the health and wellbeing of its citizens. In terms of interpreting the Terms of Reference, however, the key point to clarify is that we are deliberately focusing on the portion of investment that is concerned with research oriented to the Irish enterprise base while fully recognising the critical importance of research for policy and research for knowledge.

Figure 1: Key Objectives of Government's Research Investment



Source: Forfás *Illustratitive only - does not represent scale of funding*

Timeframe for Economic Impact

Reference is made to "the medium term (5 years) and beyond" in the terms of reference. We have interpreted the five year time horizon in two ways:

- Firstly, we believe that the priority areas that we recommend should set the agenda for the coming five years. While a process for regular review of the priority areas must be put in place, we believe that the areas we propose should have relevance for at least a five year timeframe. The areas we identify will be areas where a meaningful multiannual research agenda can and should be put in place.

- Secondly, we believe that it is imperative that specific outcomes and impacts can be reported for each of the areas we recommend within a five year timeframe of implementation. This is not to say that the full commercial impact of research has to be realised within five years in order for us to recommend an area. We recognise that the lead time to commercialisation can vary considerably across areas. However, given that we are charged with building on research strengths that have emerged based on at least ten years of sustained investment, it is reasonable to expect that there will be demonstrable economic impacts from each of the recommended areas within a five year period.

Mobilising the Full Community of Researchers

The Steering Group debated at length the degree of specificity and precision that should characterise the priority areas we are to recommend. Proponents of specificity argued that resources are limited and, therefore, what is available must be concentrated where the payoff is likely to be greatest. Others cautioned against being highly specific based on the limitations of any group, no matter how expert, to make predictions regarding economic outcomes. Our approach has been to identify areas that are sufficiently narrow to provide focus, but sufficiently broad to avoid "picking winner" challenges in terms of individual researchers and/or the research programmes of individual institutions. Furthermore, we recognise that world class research in a number of key platforms are an essential pre-requisite across a range of areas. We identify these platforms and where they fit across our recommended priority areas.

Researchers across all disciplines should demonstrate the contribution of their research to the priority areas recommended. A healthy, balanced, sustainable research system supports all aspects of the research continuum and this cannot be achieved by focusing investment on only the applied part of the research spectrum.

European and International STI Linkages

The SSTI and the mandate for this exercise provide us with a reminder that Ireland cannot pursue any research agenda in isolation. We account in absolute terms for a very small fraction of global research output even in the areas where we have developed some level of critical mass or "strength". As with all countries, we need to both compete and to collaborate when it comes to research and innovation.

None of the areas that we recommend in this process will involve purely national agendas. Our national funding programmes should continue to take into account the international dimension in order to facilitate international networking and mobility. More importantly, we should ensure that we position ourselves to connect appropriately into European research and innovation programmes in order to contribute to pan-European agendas and to avail of non-exchequer funding where appropriate. This will help us to access international expertise and networks, share the costs and risks of performing research and leverage funding where it is appropriate to do so.

We have tried to reflect the international dimension in our work with particular reference to the Seventh EU Framework Programme (FP7) and its successor, Horizon 2020, and the EU 2020 Strategy which highlights the importance of responsible innovation. The overall aim of EU strategy is to make Europe a smart, sustainable and inclusive economy, repositioning itself towards a low carbon, resource efficient future. The Government Departments, funding agencies and other stakeholders that have been central to our process are already fully engaged in the appropriate networks and have brought to bear their knowledge of developments at EU level so that they could be taken into account in our deliberations.

3. Process Overview

The Steering Group, supported by Forfás, designed its own process to deliver on the mandate that was given to the group within the one year timeframe set down by Government. The key elements of the process are summarised briefly below. A more detailed account of our process is set out in Annex 4.

To inform our deliberations, Forfás undertook a number of information gathering work strands that bring together a wide array of baseline information, each element of which is linked to the Steering Group's mandate. These include:

- Work Strand 1 - Study on Global Market Opportunities, Growth Markets and the Positioning of the Irish Enterprise Base;
- Work Strand 2 - Review of Drivers, Trends and Societal Issues from a National Perspective in a Global Context;
- Work Strand 3 - Review of Current Strengths and Areas of Emerging Critical Mass in Irish Research; and
- Work Strand 4 - Views of Research Funding Government Departments and Agencies.

Based on the large amount of information gathered, the Steering Group agreed four high-level criteria that would be used to evaluate potential "priority areas". The group also agreed that four Thematic Working Groups (TWGs) would be established to assess potential priority areas against the agreed criteria. The high-level criteria are set out in Table 3 below.

Table 3: The Four High Level Criteria for Assessment of Priority Areas

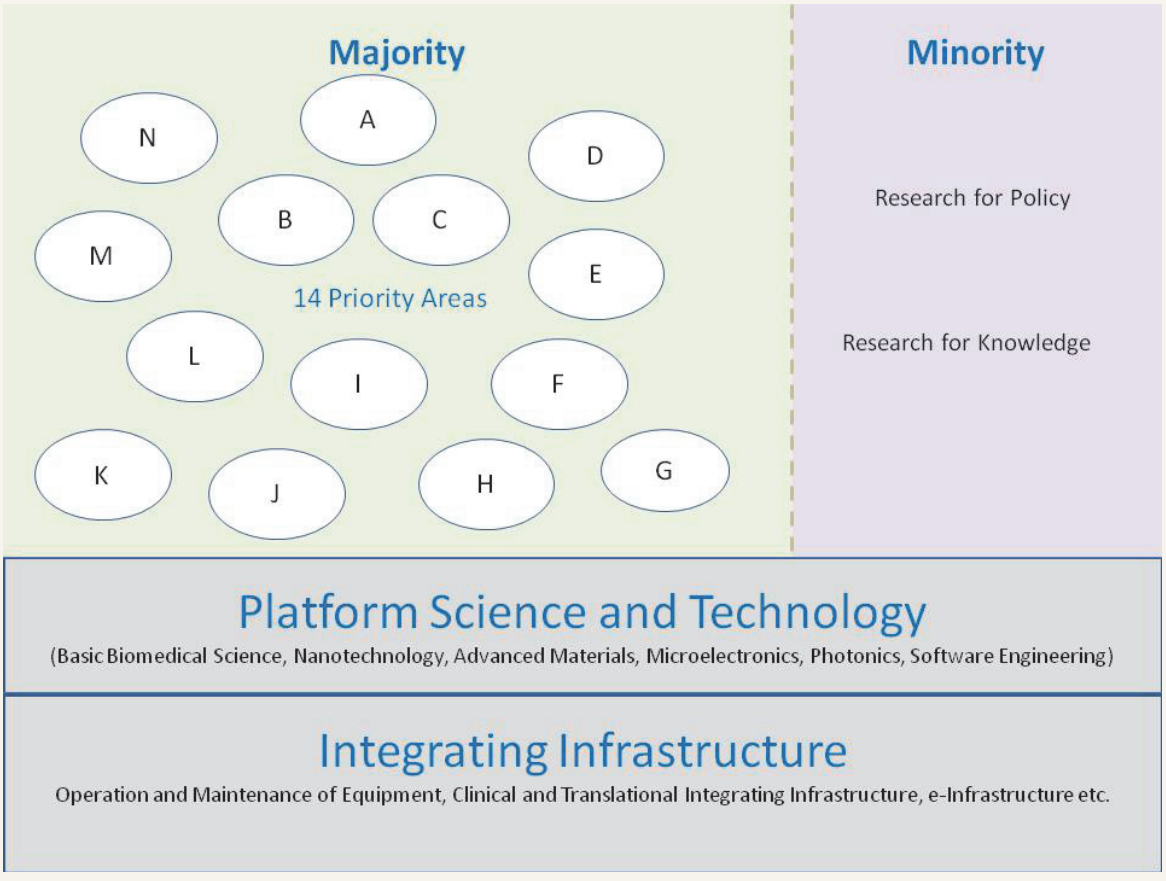
1. The priority area is associated with a large global market or markets in which Irish-based enterprises already compete or can realistically compete
2. Publicly performed R&D in Ireland is required to exploit the priority area and will complement private sector research and innovation in Ireland
3. 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

The TWGs recommended priority areas to the Steering Group in August 2011. The Steering Group validated the proposed priority areas against the four criteria and oversaw an additional round of stakeholder engagement on the emerging recommendations. The Steering Group held its final meeting at the end of September 2011 at which it signed-off on the recommendations contained in this report.

4. The Priority Areas and the Wider STI System

This section identifies the 14 priority areas and 6 platform science and technology areas that we are recommending to Government should become the focus of future research investment that is oriented towards the Irish enterprise base. Figure 2 below positions the 14 areas and the platform science and technology areas in a wider context. Figure 2 represents the total funding within the scope of this exercise (i.e. total Government investment in research less the research component of the "block grant" to HEIs and the funding administered by the enterprise development agencies for in-company performed R&D).

Figure 2: Priority Areas and the Wider STI System



Source: Forfás

Figure 2 aims to bring out a number of points:

The majority of the available funding should be allocated to: the priority areas; the platform science and technology that is undertaken in direct support of the priority areas and certain integrating infrastructure that is required to support the priority areas.

In addition to the maintenance and support of existing infrastructure and some allowance for new physical infrastructure, examples of integrating infrastructure we identified as being required to support the priority areas include:

- An integrated national system of clinical and translational research capacity that can help Ireland capture the local and global benefits of investment in health related research;

- Data repositories serviced by experts to capture and enable the exploitation of publicly available data from research and administrative sources to benefit future research; and

- On-going investment in the ICT/"e-infrastructure" that underpins all research endeavours in the country.

Further information on integrating infrastructure is provided in Annex 3.

The minority share of available funding should be allocated to:

- Research for policy - research that Government Departments and their agencies undertake or commission in pursuit of specific policy objectives and mandates; and

- Research for knowledge – as set out in our mandate, a share of future investment will remain untargeted in order to support excellent basic research in new and unanticipated research areas.

The remainder of this section provides: a summary overviews of the 14 priority areas (A-N) being recommended by the Steering Group (with greater detail in Annex 1); together with a non-exhaustive list of key science and technology platforms that will require support. A short description of policy research is also included with further elaboration in Annex 2.

A number of the priority areas (e.g. Food for Health, Sustainable Food Production and Processing, Marine Renewable Energy, Smart Grids and Smart Cities) will serve simultaneously to generate enterprise, improve quality of life and help meet legally binding obligations. This will help sustain and promote our reputation as a 'green economy' ensuring the economy is competitive, inclusive and provides a high standard of living with lower environmental impacts.

Priority Areas:

Priority Area A - Future Networks and Communications

This priority area will address the challenges of scalability, capacity, throughput, mobility and trust of the internet, including:

- Network and Service Management – how to best manage and serve the network given new demands from devices and applications;
- Internet Technologies – the software and protocols to support the network; and
- Fixed, Mobile and Wireless Communications – enabling connection and collaboration.

"Future Networks and Communications" includes fixed, mobile and wireless communications, internet technologies and network and service management tools that will need to be developed to meet the huge increase in demand for services over the internet (it is predicted that global online traffic will quadruple by 2015 as the number of devices linked to the internet climbs to 15 billion). "Future Networks and Communications" will need to address the challenges of scalability, capacity, throughput, mobility and trust by learning how to best manage and serve the network given new demands from devices and applications and by enabling connection and collaboration.

This priority area will underpin the development of smart systems and cloud computing and will provide the underlying hardware and software infrastructure that is required for the realisation of many of the other priority areas identified in this project such as Connected Health and Smart Grids and Smart Cities. There are over 400 enterprises in Ireland within the telecommunications sector employing around 15,000 people and generating revenues of over €6 billion. Ireland could seek to differentiate itself by becoming a test bed for trial and validation of "Future Networks and Communications" technologies.

Priority Area B - Data Analytics, Management, Security and Privacy

This priority area is focused on turning data into information and ultimately knowledge that can be exploited for both economic and social benefit ("Smart Data"). It has two major components:

- Data Analytics and Data Management – managing data as a resource and converting it into useful information; and
- Security and Privacy – protection of information and regulation of data.

The “Data Analytics, Management, Security and Privacy” priority area is seeking to address the market opportunity of turning the huge increase in data that is being generated into information and ultimately knowledge that can be exploited for economic, environmental and social benefit by citizens, enterprises, government and public sector organisations. The focus of this priority area is on data analytics, data management, security (including information security, biometrics, and cryptography) and privacy. Research in this area can offer systems modelling to provide ‘smarter intelligence’ around which to base decisions. Realising some of the technology actions to support the smart economy will require expertise in the handling and development of data. Development of expertise in this area has the scope to be applied to several markets including healthcare, tourism, smart cities, smart environment etc. Ireland has a number of market leaders within its enterprise base associated with this priority area. There is potential for Ireland to reinforce its strong position in this area and to establish itself as a test bed for trial and validation of new technologies.

Priority Area C - Digital Platforms, Content and Applications

This priority area is focused on the development of platforms that enable the commercial exploitation of ICT research and the development of ICT based public services. It includes:

- Digital Content and Applications – content development and the development of applications in areas such as eGaming, eLearning, eEnvironment and eTourism; and
- Human-Machine Interface, multi-media, multi-modal service creation environment.

Priority Areas A and B provide the underlying capacity and infrastructure that enables the digital products, applications and services to be provided to end users. This priority area provides direct engagement with customers and users of public services and monetises the developments from all three priority areas. “Digital Platforms, Content & Applications” has the potential to include most if not all developments in the digital economy space, focusing on content development and the development of applications and services such as eGaming, eLearning, eEnvironment and eTourism. Key research fields include digital media, human machine interface (physical and software components), social sciences, digital humanities, behavioural psychology, localisation (including language technologies) and personalisation. Implicit within the priority area are the subject areas of advertising and design, both of which have significant potential to impact on the development of digital products, applications and services and their exploitation. Ireland has a good representation of leading players from both the eGames and eLearning sectors. A solid indigenous base is also being built up in these areas.

Priority Area D - Connected Health and Independent Living

This priority area is focused on technologies that facilitate remote delivery of healthcare and assisted living, moving the emphasis of care to the patient in their own home. Connected health and independent living technologies have the potential to transform healthcare and services delivery, thereby reducing burdens on health systems and improving quality of life and independence of our ageing populations. This is an emerging area and there is an opportunity to position Ireland as a 'proving ground' for connected health solutions.

Connected Health and Independent Living are terms given to technologies and models for healthcare delivery that allow people greater independence and the opportunity to live in their own homes for longer. Products are typically derived from combinations of technologies such as medical devices, sensors, alert systems and communication and data management systems. Development of Connected Health and Independent Living technologies requires a cross disciplinary approach involving many research disciplines and sectors and Ireland has the research and enterprise capacity to develop solutions in this area.

There is a real opportunity for Ireland to become a 'proving ground' for connected health solutions. However, this will require an enterprise imperative within the national healthcare system to support development, trial, validation and implementation of connected health technologies and products. This would not only position Ireland as a unique environment for the development of connected health solutions with associated economic benefits, but also provide solutions to challenges faced by the healthcare system presented by changing demographics and requirements for increased efficiencies and cost reductions.

Priority Area E - Medical Devices

This priority area is focused on further strengthening Ireland's position as a hub for medical devices, through integrating existing enterprise and research strengths to drive development and manufacture of next generation medical devices here.

Medical devices can be defined as products used in healthcare and applied to the body for diagnosis, treatment or therapy. Their effects are usually physical, as opposed to the chemical effects of pharmaceuticals, although trends within the sector are increasingly towards devices with combinations of biochemical, electronic and biologically active components.

Ireland is one of the leading manufacturing hubs for the medical devices industry, generating €6.7 billion in exports in 2009 and employing more than 22,700 people. Ireland is now the second largest exporter of medical products in Europe, behind Germany. Eight of the world's ten largest medical device companies are located in Ireland. Most of the Irish sector is focused on the manufacture of medical and surgical instruments, and on surgical appliances and supplies. There is a strong reliance on interventional cardiology, with 80 per cent of global stent products manufactured in Ireland. Medical devices based on electronics and information technology form a major part of the device sector globally, but only a small part of the sector in Ireland. There is an opportunity to further strengthen Ireland's position as a global hub for medical devices and help position the industry for the future, through integrating the research and enterprise capabilities. An important enabler of innovation in this sector is engagement by the national healthcare system in clinical and translational research to facilitate testing, validation and adoption of new medical devices.

Priority Area F – Diagnostics

This priority area is focused on ensuring that research strengths developed over the last decade of investment are fully exploited. Ireland has developed significant research capacity in a range of areas that underpin development of diagnostics including biomedical research, nanotechnology, materials and photonics. There are opportunities for commercialisation in emerging growth areas such as personalised medicine/companion diagnostics, nutrition related diagnostics, veterinary diagnostics and point-of-care devices. Applications in connected health can also be promoted through focussed investment and/or coordination.

One of the key application areas for discoveries arising from biomedical research is in the development of diagnostics, which are products designed to provide information on health status, disease propensity and progression, or therapeutic impact. Diagnostics form a critical part of healthcare delivery, enabling the early and accurate detection that is vital in ensuring successful treatment, and reducing health costs. In this regard, population health research identifies needs and opportunities for diagnostic products while health services research enables their adoption in the health system. Diagnostic products are based on diverse technologies (biological, physical and engineering) and require a broad spectrum of research expertise and enterprise capacity.

The major enterprise capacity in Ireland is in molecular and *in-vitro* diagnostics - products used to test patient samples e.g. blood, urine and tissue. These include clinical chemistry assays; Immuno-assays; and DNA or Molecular Diagnostics. The *in-vitro* diagnostics market is attractive in that there are relatively low entry barriers for new products and companies. Some enterprise capacity in imaging exists in Ireland, but it is relatively small and is spread across diverse fields.

Ireland has built significant research strengths and capacity in diagnostics and other research fields of relevance to diagnostics development, and investment in these areas should be maintained. There is now an opportunity to harness these existing strengths and identify and exploit commercialisation opportunities in emerging growth areas such as personalised medicine/companion diagnostics; nutrition related diagnostics; veterinary diagnostics, point-of-care devices and applications in connected health, through focussed investment and/or coordination.

Priority Area G – Therapeutics: Synthesis, Formulation, Processing and Drug Delivery

This priority area is focused on developing competence and activity in pre-manufacturing research, technology and development areas responding to industry needs in Ireland in therapeutics/pharmaceuticals (for example, the manufacture and formulation of small molecules and bioprocessing research). Drug delivery is also an opportunity for further enterprise development based on innovative drug delivery systems.

Therapeutics are chemical and biological products used to treat diseases. Ireland is a major manufacturer of pharmaceuticals and some biologics, with 25,000 employed within 81 foreign companies based in Ireland and exports of €38.2 billion (2008). There are also small but growing indigenous pharma and drug delivery sectors.

The main priority for Ireland within the field of therapeutics is to develop competence and activity in pre-manufacturing research, technology and development areas. In addition to the industry need for support, a further justification for investment in research in this area is the training of skilled graduates who will become employed in in-company development operations. Involvement in relevant RTD enhances the value of graduates to the industry and thereby Ireland's appeal as a manufacturing location.

Drug delivery is also an opportunity for further enterprise development based on innovative drug delivery systems, and Ireland has significant enterprise and research capacity. The sector can benefit from the same underpinning technologies as medical devices/diagnostics.

Excellent research that may lead to drug discovery may be funded as part of basic biomedical research with clinical, translational and other integrating infrastructure being available to support compelling opportunities where appropriate.

Priority Area H - Food for Health

This priority area is focused on building the capacity to develop and produce functional foods or ingredients in Ireland. The challenge is to ensure full integration of the research base and enterprise to enable product development and validation of product claims to meet regulatory requirements.

Food for Health products or functional foods are foods or ingredients that provide health benefits in addition to providing basic nutrition. They are developed through identification, analysis and optimisation of the health promoting properties of particular foods or food ingredients, including micro-organisms, though clinical and population based validation. The increasing world population, the changing demographics of that population (particularly the increase in the ageing population), the increase in diet related diseases and the growing consumer demand for health and wellness food products are key drivers for growth in the food industry and are enabled by population-level surveys of consumption behaviour and health status across the life-course.

The food sector is the largest indigenous sector in Ireland. It accounts for more than 6 per cent of Gross Domestic Product (GDP) and employs 48,500 people. Development of novel high-value nutrition and wellness products and functional ingredients is an exciting new opportunity for the sector.

Ireland is uniquely positioned in this area with the natural resources, research strengths, enterprise base and reputation to develop foods for health. The challenge is to ensure full integration of the research base and enterprise to enable discovery, development and delivery of new functional ingredients and foods. Robust scientific data is required to underpin health claims; therefore access to a functional clinical research infrastructure is essential to trial new products.

Priority Area I - Sustainable Food Production and Processing

This priority area is focused on sustainable, competitive and efficient:

- Agri-food production;
- Marine fisheries and seafood; and
- Food processing including manufacture of safe, value added and innovative foods.

Ireland has a very favourable agricultural situation. It is one of Europe's largest dairy and beef exporters and home to several indigenous multinational enterprises. Growth in the global population and changing diets in emerging countries are projected to bring about a 70 per cent increase in the global demand for food over the next 40 years. Alongside the need to increase food production is the challenge of doing so in a manner that does not impact on greenhouse gas emissions, water quality, biodiversity or fish stocks. The focus of this priority area is on sustainable, competitive and efficient agri-food and marine food production and processing which includes land-use optimisation, forestry and non-food crops; wild fish harvesting and aquaculture and the manufacture of safe, value added and innovative foods. The agriculture and fisheries industry is one of Ireland's most important indigenous manufacturing sectors, employing over 150,000 people and contributing approximately €24 billion to the economy.

Priority Area J - Marine Renewable Energy

The focus of this priority area is to position Ireland as a research, development and innovation hub for the deployment of marine renewable energy technologies and services. This would facilitate the creation of an early stage industry and research cluster and open up the possibility of becoming a significant exporter of electricity. The development and testing of ICT applications in a marine environment (based on the Smart Ocean concept) could be supported to enable this priority area.

Ireland's ocean territory, at approximately 10 times the size of our land area, is an excellent potential source of energy. Our marine environment can provide a vast amount of energy through offshore wind, wave and tidal energy technologies. The use of the sea as a renewable energy source is growing in importance considering the Government's ambitious targets of generating 40 per cent of electricity from renewables by 2020, including 500 MW from ocean energy, which will be vital to ensuring that we meet our greenhouse gas emissions targets by 2020. Ireland could, along with other European Atlantic seaboard countries, become a very important future energy/electricity source for Europe. The focus of this priority area is to promote the green economy through positioning Ireland as a research, development and innovation hub for the deployment of marine renewable energy technologies and services and to create an early stage industry and research cluster, allowing the sustainable commercialisation of our natural resources including the possibility of exporting electricity from these sources.

Priority Area K - Smart Grids and Smart Cities

This priority area is focused on the development of Smart Grids and Smart Cities using a layer of technologies (including software, sensor hardware and control and interface systems) and design solutions to more effectively and efficiently manage complex infrastructure systems, enable greater resource efficiency and help move to a low carbon society.

Smart Grids and Smart Cities involve the application of energy and advanced ICT technology solutions to more effectively and efficiently manage complex infrastructure systems. They typically use a layer of technology, including software, sensor hardware and control and interface systems, which can be embedded in the design of new infrastructure or applied to existing infrastructure.

Smart Grids comprise a broad and evolving range of energy and ICT technologies that can be applied along different elements of the electricity supply chain – from generator, through transmission and distribution, to end users (e.g. commercial & domestic buildings). They are particularly valuable in the context of increasing use of intermittent sources of energy. Together, these technologies (which include advanced sensors, two-way communications and distributed computing) can increase the deployment of variable renewable energy generation, enable demand response and energy storage and improve the efficiency, reliability and safety of power delivery and use. The end-user element of Smart Grids is also a component of Smart Cities.

Smart Cities is the application of sensor, communication and analytical technologies and design solutions to urban infrastructure such as energy, water, wastewater, waste and transport systems. For example, sensors can be used to monitor traffic and sequence traffic lights accordingly in urban areas.

Smart Grids and Smart Cities can significantly improve the efficiency of complex systems, such as the electricity system and the urban transport system, thereby reducing their costs while contributing to the “green economy”.

Priority Area L - Manufacturing Competitiveness

This priority area is focused on the development and application of technology and knowledge management systems to reduce costs, eliminate waste, drive resource efficiency and improve product quality for increased competitiveness.

Manufacturing competitiveness is a key driver of export led growth and is the backbone of the economy. The manufacturing sector in Ireland employs 192,000 people and generated Gross Value Added (GVA) of over €31 billion (2008 figures).

The manufacturing industry is continually responding to intense global competition and technological change. The focus of this priority area is on the development and application of technology and knowledge management systems to reduce costs, eliminate or seek commercial opportunities for waste and to improve product quality for increased competitiveness. Research into quality control, product design, sustainable technologies and knowledge management are examples of the kind of research that can contribute to manufacturing competitiveness.

Priority Area M - Processing Technologies and Novel Materials

This priority area is focused on enabling the Irish manufacturing base to transition into one with enhanced capabilities in processing technologies and materials science and engineering.

This priority area is focused on enabling the Irish manufacturing base, in collaboration with Irish researchers, to transition into one with enhanced capabilities in processing technologies and materials in order to remain competitive and future focused. Examples of innovation aligned to this priority area include milk dehydration technologies for the food industry; moving from batch to continuous processing in the pharma industry; and the development of novel materials with increased functionality. Examples of advances taking place in materials for manufacturing include the use of nano-coatings, polymers, composites and biomaterials. This priority area will be of importance to key manufacturing sectors in Ireland such as ICT, Life Sciences, Food and Drink, Clean Tech and Renewable Energy.

Priority Area N - Innovation in Services and Business Processes

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

This priority area is focused on enabling both the manufacturing and service sectors to respond and evolve with the new realities of doing business in a global market i.e. to be able

to respond to the growing importance of services and to innovate in service offering and delivery and in business processes. Examples of areas that require innovation underpinned by R&D include management of complex supply chains, new business model development, personalisation of products/services, sales and marketing, risk governance and sustainability.

The Wider STI System:

Platform Science and Technology

I. Basic Biomedical Science

Basic biomedical research is defined (for the purpose of this exercise) as the scientific investigation required to understand the underlying life processes which affect human well-being and disease, encompassing such areas as cellular and molecular bases of diseases, genetics, immunology etc. Basic biomedical research produces knowledge that underpins the design of methods, drugs and devices used to promote wellness, prevent, diagnose and treat disease. This platform is of particular relevance to the following priority areas:

Therapeutics	Food for Health
Diagnostics	Medical Devices
Connected Health	Food Production and Processing

II. Nanotechnology

Nanotechnology is a general purpose technology which involves the purposeful engineering of matter at scales less than 100 nanometers to achieve size dependent properties and functions. Nanotechnology acts as an enabling toolkit which has a broad impact across multiple sectors. The main markets enabled by nanotechnology include the aerospace, automotive, construction, electronics, energy and environment, manufacturing, medical and pharmaceutical and oil and gas markets. Examples of the application of nanotechnology across these markets include: sensor development and anti-wear coating for the manufacturing sector; and in the pharmaceutical sector the development of new coatings and methods for drug delivery. This platform is of particular relevance to the following priority areas:

Medical Devices	Diagnostics
Future Networks and Communications	Processing Technologies and Novel Materials
Food Production and Processing	Smart Grids and Smart Cities
Manufacturing Competitiveness	

III. Advanced Materials

Advanced materials refers to new materials with novel properties such as strength to weight ratios, cost effectiveness and reduced environmental impact. Advanced materials underpin numerous markets including electronics, energy and environment, manufacturing, medical and pharmaceutical. Globally, major advances are taking place in areas such as coatings, polymers, composites, advanced functional materials and biomaterials. Advanced materials facilitate recycling, lowering the carbon footprint and energy demand as well as limiting the need for raw materials that are scarce in Europe. This platform is of particular relevance to the following priority areas:

Processing Technologies and Novel Materials	Medical Devices
Diagnostics	Food Production and Processing
Smart Grids and Smart Cities	Manufacturing Competitiveness

IV. Microelectronics

Microelectronics (including semiconductors) is essential for all goods and services that need intelligent control in sectors as diverse as automotive and transportation, aeronautics and space. Smart industrial control systems permit more efficient management of electricity generation, storage, transport and consumption through intelligent electrical grids and devices.

This platform is of particular relevance to the following priority areas:

Future Networks and Communications	Data Analytics, Management, Security and Privacy
Digital Platforms, Content and Applications	Medical Devices
Diagnostics	Connected Health
Marine Renewable Energy	Smart Grids and Smart Cities
Manufacturing Competitiveness	Processing Technologies and Novel Materials

V. Photonics

Photonics is a multidisciplinary domain dealing with light, encompassing its generation, detection and management. Among other things, it provides the technological basis for the economical conversion of sunlight to electricity which is important for the production of renewable energy, and a variety of electronic components and equipment such as photodiodes, light-emitting diodes (LEDs) and lasers.

This platform is of particular relevance to the following priority areas:

Future Networks and Communications	Connected Health
Diagnostics	Smart Grids and Smart Cities
Marine Renewable Energy	Processing Technologies and Novel Materials

VI. Software Engineering

Software Engineering is the application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of computer software, and the study of these approaches; that is, the application of engineering to software.

This platform is of particular relevance to the following priority areas:

Future Networks and Communications	Data Analytics, Management, Security & Privacy
Digital Platforms, Content and Applications	Connected Health
Diagnostics	Smart Grids and Smart Cities
Medical Devices	Innovation in Services and Business Processes
Processing Technologies and Novel Materials	Manufacturing Competitiveness

Research for Policy

Research plays an important role in helping Government to achieve its policy objectives and to design the associated systems and services needed to realise these policy goals. It facilitates us in meeting our objectives at minimum cost, encourages innovation, and supports productivity and fiscal integrity by minimising the resources we have to spend on achieving objectives by actively encouraging new and better ways of doing things. Research programmes designed to inform the policy process play a vital role in agenda setting and increase the likelihood of translating important findings in relation to health, education, environment and other research domains into feasible and implementable services and systems.

In a number of areas, policy is negotiated with the European Union, out of which emerge obligations, regulations and income transfers. The quality of our negotiating effort is directly shaped by the quality of the evidence-based research that we bring to the negotiating table. High quality research, informing both our negotiating position and then the implementation of decisions, is required if we are to succeed.

Government funded research programmes and projects should be identified and justified by the relevant Government Departments and agencies, and should be evaluated using appropriate peer review systems. Ultimately, the value of such funding should be judged in terms of the extent to which the research helps improve the quality of decisions around policy, services and systems and the benefits, outcomes and impacts that flow from them. The present process of commissioning and evaluation is *ad hoc*; there is no overt and systematic linkage between what is needed by the policy process, and what the research system delivers.

Some important policy issues came to our attention during the course of our deliberations. As they are not driven principally by a commercial motive, they did not fall within the direct scope of our prioritisation exercise. These included:

- Improving the health of the population across the life-course;
- Minimising and mitigating climate change;
- The contribution of bioenergy to the achievement of renewable energy targets;
- Building a safe and sustainable environment; and
- Delivering new and cost-effective models of health care.

Further details on these areas are set out in Annex 2.

There are many other needs-driven issues that require research to underpin social progress and economic growth, such as child development, dealing with unemployment, enterprise policy, education, training and re-training, social integration, etc. We realise the importance of research in all of these policy areas but recognise that they lie outside our terms of reference. Consequently we see a need for separate funding to support needs-driven sectoral research and we recommend that similar standards be set to evaluate research proposals along similar lines as those highlighted for the 14 priority areas.

5. Implementing the Priority Areas into the STI System

The identification of priority areas will not, in itself, be enough to transform the STI system to one that is focused more on outcomes and impacts. Throughout the process, the Steering Group has captured good practice on how to accelerate the economic impact of the priority areas in order to bring about a step change in the efficiency and effectiveness of the current STI system. We believe that this good practice must now be firmly embedded, or further embedded, in the STI system and in this section we set out recommendations to achieve this.

1. In the first instance, we believe that the Government should re-state its objectives for science, technology and innovation policy with clear goals and metrics for each element of this policy. While goals are contained in the SSTI and re-iterated more recently in the *Programme for Government*, we believe that there is a need to re-articulate the high-level goals and objectives and, in that context, to set a new over-riding national objective to accelerate the delivery of specific economic outcomes from our investment in research.
2. The policy goals and objectives that are set should be underpinned by a set of national indicators that reflect the goals and objectives (e.g. R&D intensity of enterprise; number of research personnel per 1000 employees) and this should include indicators of economic impact. These indicators should help to clarify programme level objectives and targets and the allocation of resources. There should also be clarity in the allocation of roles and responsibilities to achieve the high level targets.
3. The Department of Jobs, Enterprise and Innovation should annually monitor performance, with independent oversight, on behalf of the Government. These regular reviews should report timely and consistent data that will determine the allocation of resources at a system level and inform and underpin future priority setting exercises. Difficulties in monitoring performance at the system level can be addressed by introducing standard measurement and reporting systems across funding programmes.
4. Implementation is the responsibility of the Government departments and agencies. Ireland, like many other European countries, has a decentralised model of STI policy with individual departments responsible for sectoral or mission-based areas. The high level goals and indicators provide the necessary framework for funding agencies to design and manage funding programmes. Many of the funding programmes have evolved over the last ten years of investment and in response to different priorities and missions. However, with the introduction of priority areas, it is important that all funding mechanisms that will be used to give effect to the priority areas should be assessed to ensure that they are fit-for-purpose in terms of delivering economic impact. The Government's intention to extend the remit of Science Foundation Ireland to enable it support research that is "closer to market" is welcome in this regard. Given the nature of the priority areas, joint calls by multiple agencies are likely to be required to fund the breadth of research activity involved. The funding that has been available for research with a primary goal of publication and citation has given Ireland credibility in the international community. However, to exploit this research capacity, needs-driven research and innovation with the goal of innovating

new or improved products and services are required which will deliver economic and social impact in the next five to ten years. The Irish BioInnovate Programme which builds on the success of the BioDesign fellowship at Stanford University has been identified as a model that focuses on commercialisation and innovation leading to economic outputs. The first phase of the programme involves identifying needs by spending time with a medical team and then carrying out a full technical and market analysis of those needs. The second phase involves concept generation around the identified needs, leading to prototyping. The final phase involves developing and implementing the business strategy. This model of needs driven innovation could be adapted for different research areas or sectors and integrated into programmes that support the commercialisation of research. Therefore, we recommend that programmes that focus on commercialisation and innovation leading to economic outputs should integrate the core principles of programmes that identify needs, invent solutions and commercialise products or services.

5. It is clear that many research funding programmes and schemes will need to be adapted to reflect the new priority areas. Where competitive calls are linked to the priority areas, applications will need to demonstrate both excellence/originality and direct relevance to the priority areas. Applications for funding under the priority areas will require at least a two-stage process. The applications should be screened based on demonstrated relevance to the priority areas, clarity of deliverables and, where appropriate, end-user engagement. Applications that pass the test of relevance to the priority area should be reviewed against criteria of excellence and originality based on established peer review processes.

6. While it is legitimate for research funders to develop multiple programmes to reflect the different outcomes that are required, there should be an ongoing review of all funding programmes to ensure continued relevance and clarity of purpose, that programmes have sufficient scale and that unnecessary duplication is avoided. The review should ensure that the costs of the programme are commensurate with the benefits achieved. New programmes should be avoided if the objectives can be achieved through adaptation of existing programmes. A positive outcome of this review will be greater clarity for research performers, both public and private, on the funding supports available.

7. Programme application and administration can be a significant overhead within the research institutions as well as the funding agencies. Internationally, a number of research funding organisations are looking at innovative ways of reducing the amount of time that researchers spend on grant applications e.g. the Howard Hughes Medical Institute and the Wellcome Trust have shifted towards a system that funds people rather than projects. There should be coherence and a consistency of approach between funding programmes to reduce the administration burden on both agencies and applicants and also to allow for system level evaluations.

8. Following a sustained period of capacity building over 10 years, funding programmes for physical infrastructure should adapt to recognise the current priority to maintain and support operation of existing infrastructure while also incentivising sharing of resources thereby utilising their full capacity. A key requirement of achieving this will be a national inventory of all significant publicly funded infrastructure and equipment.

9. Policies and procedures for the commercialisation of intellectual property (IP) arising from publicly funded research should be fast, predictable and consistent. The Steering Group acknowledges the work that the IP Policy Group and the IP Implementation Group (established by DJEI) are undertaking to ensure IP policies and procedures support innovation and urges speedy implementation of their proposals.

10. Research centres with a mandate to engage with industry, including CSETs, SRCs and public research organisations, must develop a distinctive industry focused culture. They should have the breadth of multidisciplinary research activity and the range of expertise (including business development skills) to partner with industry. A key performance indicator for such centres will be the proportion of funding leveraged from enterprise. Developing such centres will require a reorganisation around the priority areas and sufficient autonomy for HEI based centres to prioritise an industry oriented mission.

11. In general terms, innovation activity should also be accommodated by the system for career progression for academic staff within HEIs and public research organisations.

12. The ability to translate research into economic and societal benefits ultimately comes down to the quality of people working in the research system and the quality of the trained researchers emerging from that system at all levels (Masters level, PhD level and post-doctoral level). With multiple funding streams, responsibility for the quality of postgraduate training and education and the quality of the postgraduate experience, including the development of the structured PhD model in Ireland, needs clarity. A consistent quality framework should be developed for postgraduate education and training incorporating the Structured PhD model. Responsibility for monitoring of the output and quality of masters and PhD training and education should rest with the Department of Education and Skills (DES). Indicators of the quality of postgraduate education and training should be developed by DES and integrated into the Government's overall framework for monitoring science, technology and innovation in Ireland.

13. Initiatives to improve further and keep under continuous review the alignment between the supply of trained researchers from academia and the demand for such skills from the enterprise sector are imperative. The Steering Group has reviewed recommendations in this regard made by the Advisory Council for Science, Technology and Innovation (ACSTI) in recent reports[4] and we endorse these recommendations. In particular, we agree that:

    - Models that allow researchers based in industry to study for a PhD qualification are to be encouraged. They help to upskill researchers working in enterprise; build know-how within the enterprise; build closer links between HEIs and enterprise and help to ensure commercialisation of know-how. Such models build on the Danish industrial PhD model and are already starting to be supported in Ireland through national and EU funding[5]. A proportion of PhD

[4] "*Towards a Framework for Researcher Careers*" ACSTI, 2008; "*The Role of PhDs in the Smart Economy*" ACSTI, 2009; "*Maximising the Environment for Company R&D*" ACSTI, 2010

[5] In Denmark, the industrial PhD programme accounts for 7 per cent of all PhD graduates and this could inform an appropriate target for Ireland.

funding should be earmarked to support the development and rollout of the industrial PhD model in Ireland.

- From an enterprise perspective, researchers qualified to Masters level can bring relevant and practical skills that contribute to the research and innovation agendas of the enterprise sector. The Steering Group supports the ACSTI recommendation that a proportion of PhD funding should be redirected towards the development of industry driven Masters programmes.

- PhD and early stage post-doctoral researchers should be able to contribute directly to enterprise creation and job creation through the commercialisation of their research. Technology Transfer Offices within the HEIs should develop a coherent and integrated programme of support for PhD students and early stage post-doctoral researchers that enables them to identify and exploit commercial opportunities arising from their research.

Annex 1: Descriptions of the Priority Areas

This annex provides descriptions of the 14 recommended priority areas to highlight their fit with the criteria employed in the prioritisation process and to draw attention to details that should be taken into account in translating these areas into research agendas around which future calls can be based.

As part of their deliberations, the Thematic Working Groups identified a number of actions required for each area to help realise the economic impact from research investment. Most of the actions have a strong R&D dimension. However, in some cases, actions which are less specific to R&D have been included where these could help to complement the R&D agenda. The actions required are guidance to the implementation of these priority areas and further work, involving engagement with all stakeholders, will be required to develop full, detailed action plans with timelines and metrics.

Priority Area A - Future Networks & Communications

The internet has become a critical infrastructure that forms a key element of our social and economic fabric. As more and more services for business, government and citizens move online, global online traffic is increasing. Cisco predicts that global online traffic will quadruple by 2015 as the number of devices linked to the internet climbs to 15 billion. The increase in demand for new services over the internet is of such a scale that the current internet as we know it will shortly reach the limits of its performance. This increased demand brings challenges of scalability, capacity, throughput, mobility and trust, all of which need to be addressed by "Future Networks & Communications".

"Future Networks & Communications", which includes fixed, mobile and wireless communications, internet technologies and network & service management, needs to be developed in a holistic way taking into account all building blocks from users, services, applications and networks. The pervasive nature of ICT technologies includes ubiquitous communications, computing and networking facilities that facilitate the collection of data from connected sensors and actuators, and new models of user interaction. These technologies are forming part of the development of new smart systems and cloud computing infrastructures and systems, the continued development of which will be underpinned by "Future Networks and Communications".

"Future Networks & Communications" research will provide the underlying hardware and software infrastructure that is required for the realisation of the "Data Analytics, Management, Security & Privacy" and "Digital Platforms, Content & Applications" priority areas. This is also true of a number of other priority areas covered by the other three thematic working groups. The realisation of priority areas such as Connected Health and Smart Grids and Smart Cities will all also rely on the presence of a robust "Future Networks & Communications" hardware and software infrastructure.

"Future Networks & Communications" can contribute to addressing a number of key global and national drivers by facilitating the delivery of services for health, education, business & financial services, transport, environment, energy, security and entertainment. It will also provide the necessary infrastructure and capacity for monitoring, data gathering and modelling to support climate change research and resource efficiency initiatives such as the deployment of Smart Grids and Smart Cities management tools.

The *Programme for Government* sets out the Government commitment to ICT. A key aspect of the exploitation of ICT to address global and national challenges is Ireland's role in the development of the Future Internet. The realisation of initiatives such as the Exemplar Smart Communications Network, the positioning of Ireland as a Green Data Centre location, the establishment of an International Digital Services Centre, the creation of a Smart Electricity Network and Ireland becoming an early mover in the 'internet-of-things' all rely on Ireland having the wherewithal to deliver and implement an appropriate "Future Networks & Communications" infrastructure.

There are a number of high profile EU initiatives underway which are of relevance to Ireland's involvement in "Future Networks & Communications" such as the e-Infrastructures initiative, the European Future Internet Assembly (EFIA), the Future Internet Forum (FIF) and the Future Internet public-private partnership. Ireland is involved in projects relevant to all the initiatives including in the latter the areas of environmental observations and service applications (ENVIROFI) and in smart energy (FINSENY). The HEA is co-ordinating a project called e-InfraNet focused on the integration of regional policies in eInfrastructures. Ireland is also an active member of the EFIA and FIF.

The value of the global ICT market was estimated at €4.6 trillion in 2009 with an annual growth rate of 5.5 per cent up to 2013 anticipated. The constituent elements of the market of relevance to Future Internet include communications, which was estimated at $1,406 billion in 2009 with a CAGR of 5.22 per cent. Cloud computing is expected to grow from $37.8 billion in 2010 at a CAGR of 26.2 per cent to $121.1 billion in 2015. The European sensor market was worth €10.1 billion in 2007 with an expected CAGR of 6 per cent between 2007 and 2011. The global sensor market was estimated at €36 billion; significant growth in the market is anticipated as sensor technologies are implemented in cities, water infrastructures etc.

There are over 400 enterprises in Ireland within the telecommunications sector employing *c*15,000 people and generating revenues of over €6 billion. In the cloud area there is a wide range of multinational companies in Ireland engaged in the three service areas of Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). SaaS is the largest segment of the cloud computing market accounting for 73 per cent of the market's revenues for 2010. Ireland has a number of key global players in the sensor market as well as playing host to a number of large scale data centre facilities focused on cloud and green approaches. Key multinational companies engaged in the communications area include Ericsson and Alcatel Lucent. IBM and Oracle are also engaged in the network & service management area.

Ireland has a number of research centres engaged in research activity which underpins the "Future Networks & Communications" area, such as semantic web, analysis and visualisation of network data, optical and wireless networks, microelectronics, network modelling and

analysis, adaptive sensing and embedded systems. Between 2005 and 2009 Ireland scored above the global average for research impact in the computer science (high performance computing, hardware and architecture and software engineering) and electrical and electronic engineering fields.

There is a strong case for publicly supported research in this field. There is significant public good in the development of "Future Networks & Communications" . It is an area that will underpin several markets such as healthcare, tourism, eGovernment, smart cities, smart environments, commerce and marketing. This area also has significant potential to support Ireland in achieving its carbon emissions targets by supporting the development and exploitation of smart grid and intelligent transport systems. A particular challenge that could be addressed is the reduction of energy intensity of data transmission and storage. Interoperability and integration across developments in "Future Networks & Communications" could also be a focus of publicly funded research.

Ireland needs to be able to develop a competitive position and carve out niche areas where it can lead in the Future Internet to be able to compete with other significant global initiatives in this area such as Asia FIF, Korea FIF and the US GENI (Global Environment for Network Innovations) programme. Ireland could seek to differentiate itself by becoming a test bed of test beds for trial and validation of "Future Networks & Communications" technologies. Building on existing test beds such as SmartBay, Exemplar, Comreg Test & Trial and the IMS Carrier Grade test bed would make Ireland an even more attractive location for potential FDI clients. This would present an opportunity to develop an integrated national sensor test bed.

Key Actions Required

- There is a need for funding resources to facilitate collaboration between academia and industry bringing together the necessary disciplines to work collectively on future network & communications developments.

- Ireland already has a number of test-beds in place (Smart Bay, Exemplar, Comreg Test and Trial etc.). There is an opportunity to integrate the test-beds to create a national differentiator.

Priority Area B - Data Analytics, Management, Security and Privacy

Data is growing at an exponential rate; information on the web alone was doubling every 18 months in 2009, it is estimated that it is now doubling every 11 months. Data generated by consumers through social media sites: by enterprise through eCommerce, by governments through eGovernment online services and by machines through sensor networks are all adding to the deluge of data being stored and transmitted over the internet and cloud computing infrastructure. The "Data Analytics, Management, Security & Privacy" priority area is seeking to address the market opportunity of turning such data into information and ultimately knowledge that can be exploited for both economic and social benefit by citizens, enterprises, government and public sector organisations. McKinsey Global Institute estimates that European government administrations could save more than €250 billion in operational efficiency improvements alone by using 'big' data. This priority area is focusing on data

analytics, data management, security (including information security, biometrics, cryptography) and privacy.

"Data Analytics, Management, Security & Privacy" has a role to play in addressing some key global and national drivers for example in relation to the drivers associated with complexity and uncertainty. Research underpinning this priority area can offer systems modelling and enhanced systems thinking to provide 'smarter' intelligence around which to base decision making. 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. In the education area, it can provide new tools and techniques and eLearning products and services.

The development of "Data Analytics, Management, Security & Privacy" solutions fits with the Government's commitment to ICT as set out in the *Programme for Government*. Realising some of the technology actions to support the smart economy will also require expertise in the handling and development of data; particularly in relation to the ambitions of Ireland as a centre for Green Data Centres and cloud computing and the establishment of an International Digital Services Centre.

As outlined above, there are potential savings to be made in operational efficiencies through the management of 'big' data. The establishment of Green Data Centres and cloud computing also bring with them significant job creation and revenue generating opportunities.

An EU high level expert group on Scientific Data sets out a vision of a scientific e-Infrastructure that supports seamless access, use, re-use and trust of data which entails the physical and technical infrastructure becoming invisible and the data themselves becoming the infrastructure. This EU infrastructure would be a valuable asset on which science, technology, the economy and society can advance. The development of an international collaborative data infrastructure as proposed by the EU group would set out how different companies, institutes, governments and individuals would interact with the system. A further example is the proposed Scientific Cloud Computing Infrastructure for Europe initiative led by CERN and ESA.

"Data Analytics, Management, Security & Privacy" can potentially create value in five application areas: i) by creating transparency, ii) by enabling experimentation to discover needs, expose variability and improve performance, iii) segmenting populations to customise actions and iv) replacing/supporting human decision making with automated algorithms and v) innovating new business models, products and services.

Ireland has a good representation of market leaders within its enterprise base for each of the sub-markets associated with Data Analytics, Management, Security & Privacy. Companies such as Oracle, SAP, IBM, SAS and Microsoft are all market leaders in the data analytics market area and are all present in Ireland. Companies such as Accenture, Aon, and Paypal are also present in Ireland and seeking skilled data analytics people. Four of the market leaders in the cyber-security market: Symantec, McAfee, Trend Micro and Computer Associations all have a presence in Ireland. Ireland is also fast becoming a leader in the cloud computing market with a strong multinational and indigenous base of companies engaged in the market.

There is a range of research activities underway covering topics such as semantic web, semantic sensors, capture, storage, retrieval and analysis of data, constraints programming, optimisation research, trend analysis, decision support and data visualisation tools, data security, secure systems, digital humanities, digital repositories and data preservation.

There is a strong case for publicly funded research in the "Data Analytics, Management, Security & Privacy" field. There is significant public good in the development of expertise in the area which has the scope to be applied to several markets including healthcare, tourism, eGovernment, smart environment, eScience, commerce and marketing. The value of converting data into useful and digestible knowledge for governments, enterprises and citizens is immense. To maximise the benefit from Ireland's cultural heritage, the priority area provides a window of opportunity to accelerate availability and access to Ireland's digital libraries and data repositories.

In relation to data security and privacy, government has a role to play in protecting Ireland's data assets from both a cyber-security and eGovernance perspective. As we move towards the 'internet-of-things', investment in research in "Data Analytics, Management, Security & Privacy" therefore will be required to ensure Ireland is well positioned to reap the rewards of existing research and the presence of key market players. There is an opportunity for Ireland to position itself as a safe place to do business; tackling the challenge of data security in the cloud computing space could present a potential niche for Ireland. Privacy and ethics in meta data is another area that could be focused on.

There is potential for Ireland to reinforce its strong position in the field of "Data Analytics, Management, Security & Privacy" and to establish itself as a "test bed of test beds" for trial and validation of new technologies in the area.

Key Actions Required

- Structured training at postgraduate level would position Ireland well to take advantage of the global skills gap in the data analytics field.
- Development of a national knowledge management strategy for Ireland. Availability of data is critical to this priority area; there is a policy gap in terms of open, accessible data, particularly in the public sector that needs to be addressed.
- Cyber security is critical. The government has a role to play in creating an environment that promotes cyber security. Ireland should aim to take a leading position to leverage opportunities in this dynamic area.
- An agile and adaptive governance framework is needed to be able to offer guidance in instances of shifting points of authority and ownership in relation to data.

Priority Area C - Digital Platforms, Content and Applications

The previous two priority areas outlined; “Future Networks & Communications” and “Data Analytics, Management, Security & Privacy” provide the underlying capacity and infrastructure that enable the digital products, applications, services and content that can be delivered to end users. “Digital Platforms, Content & Applications” is the priority area that provides direct engagement with end users across society and monetises the developments from all three priority areas. “Digital Platforms, Content & Applications” offers significant potential to transform the economic, social and environmental fabric of Ireland by:

- Developing and delivering products and services that will improve the productivity of enterprise and the public sector;
- Offering improvements in quality of life for citizens through products targeted at independent living and healthcare;
- Progressing the ‘smart economy’ by realising developments in smart grid, smart cities, smart homes, smart environment, smart oceans etc.;
- Boosting Ireland’s image and reputation through the global exposure of Ireland’s culture and heritage through digital means;
- Becoming a global leader in the research, development, exploitation and export of digital technologies.

The focus of this priority area is on content development and the development of applications and services in areas such as eGaming, eLearning, eEnvironment and eTourism. Key research fields include digital media, human machine interface (physical and software components), social sciences, digital humanities, behavioural psychology, localisation (including language technologies) and personalisation. Implicit within the priority area are the subject areas of advertising and design, both of which have significant potential to impact on the development of digital products, applications and services and their exploitation. Ireland's internationally recognised contribution to cultural creativity is a key driver and strength.

“Digital Platforms, Content & Applications” can contribute to addressing key global and national drivers by improving eLiteracy, increasing quality of life through for example eHealth, eTransport, eEnvironment and eLearning applications and services. It can also provide a framework for converting data into knowledge. In the national context, it has a key role to play in delivering on the technology actions for the establishment of an International Digital Services Centre and the facilitation of Ireland becoming an early mover in the commercialisation of the ‘internet-of-things’.

The potential economic benefit to be derived from cloud computing and data analytics have already been outlined in other priority areas. These benefits can only be realised if relevant digital content and services are accessible over and through the cloud. Digital Platform, Content & Applications will provide the mechanism for identifying and productising such content and services. Building partnerships particularly with cultural institutions will serve to enhance this area.

There are a number of EU initiatives relevant to Digital Platforms, Content & Applications, such as eInfrastructures which proposes the development of appropriate scientific e-Infrastructures to facilitate researchers collaborating on the same data set. "Digital Platforms, Content & Applications" could offer access to such eScience repositories. The HEA is co-ordinating an EU project eInfraNet which is seeking to integrate regional policies in the field of eInfrastructures. A related initiative is the Future Internet public private partnership. The CULTURA project is building systems to facilitate access to digital culture materials. The DARIAH project is supporting digitally enabled research across the humanities and arts. Ireland is a partner in both of these projects.

The digital media global market which includes education, entertainment, consumer information and infrastructure was estimated at $258 billion in 2010. Between 2005 and 2010, the sector experienced a CAGR of 11.7 per cent. Within the overall sector sub-markets, such as eGames, have experienced rapid growth (currently worth $52.5 billion with an expected CAGR of 10.6 per cent between 2009 and 2014). It is estimated that the eLearning market will be worth $107.3 billion in 2015. Creative Industries have been in decline in their traditional forms (film and music) over the last 5 years; the digital markets for such products however are on the increase. The development of cloud computing is expected to have a positive impact on these markets going forward.

Ireland has good representation of leading players from both the eGames and eLearning sectors. A solid indigenous base is being built up also in these areas. In tourism, the digitising of content, development of linked data and e-readiness of tourism companies is critically important to the Irish economy. Indigenous firms have been particularly successful in elearning, animation and in the enabling wireless infrastructures and middleware (Jam Media, Nooked, Skillsoft Ireland). There is a strong dynamic emerging in eGames development (Open Emotion, Digital Sideburns). Ireland has a strong reputation in the production of cultural and creative products.

Software Technology and the Digital Arts have key underpinning roles in the "Digital Platform, Content & Applications" area. Research in this area is being undertaken in topics such as internet technologies, digital content and localisation, sensor technologies, embedded systems, computer vision, computational science and informatics, digital humanities, digital repositories, eLearning systems, animation, cultural heritage, cultural tourism and cyber-psychology.

Ireland has a number of key research centres in this space which include centres focused on web science, software and evolving critical systems, localisation of digital content and sensor web. Technology Centres in the digital platform, content and applications area are focused on developing practical tools and approaches to maximise ICT investments, helping to establish Ireland as a leader in green computing and support research and innovation in technology enhanced learning products and methods.

There is a strong case for publicly supported research in the "Digital Platforms, Content & Applications" field given its wide range of application across eHealth, eGovernment, eTourism, eLearning, eEnvironment, eBusiness and other sectors. "Future Networks and Communications" and "Data Analytics, Management, Security & Privacy" provide the underlying hardware and software infrastructure for a smart economy. The "Digital Platform, Content & Applications" priority area can provide the content and services that interface

directly with end user citizens, businesses or government. Potential niche areas for Ireland to focus on include the development of tools for content authoring and creation and interdisciplinary fields between technology, social science and humanities e.g. in social media applications and in making the human-machine interface more intuitive.

Key Actions Required

- Development of a comprehensive and coherent digital strategy and vision for Ireland.
- Development of large scale flagship project(s) and/or research themes that combine industry, government and academia, for example linking cloud computing to the public service in a way that can demonstrate the ability to deliver projects of scale in Ireland.
- Development of an Intellectual Property Strategy to address intellectual property issues particularly in more complex areas such as art and culture (e.g. copyright).
- Continued Government support for libraries and universal access to electronic journals for higher education institutes.
- Flexible funding instruments are required to facilitate inter-disciplinary research across technology, humanities and social science disciplines.

Priority Area D - Connected Health and Independent Living

Connected health involves use of ICT to improve healthcare quality and outcomes. It encompasses eHealth, digital health, health informatics, telemedicine, and mHealth. Related to the concept of Connected Health is that of 'Silver technologies'. This term has been adopted to encapsulate the broad range of technologies and services that can positively influence the ageing experience of older people and that enable older people to remain active in society as well as staying socially connected and independent for longer. Connected health technologies can improve quality of life for all, but particularly the elderly and the disabled, and can also reduce healthcare costs by facilitating home delivery of services. The products are typically derived from combinations of technologies such as medical devices, sensors, alert systems, vital sign monitoring devices; and health informatics and data management systems. Their uptake and implementation will require buy-in from patients, health service providers, insurers and policy makers (regulatory and legal). Connected Health initiatives will require changes in clinical work practices as they allow novel forms of interactions with patients. Implementation must be seen as part of a transformation process of healthcare delivery.

Major societal issues and trends impacting Connected Health include: Demographics – the increase in population, particularly the increase in the ageing population and the accompanying increase in the prevalence of chronic illness will put pressure on provision of healthcare services; technology innovation and convergence will drive new product and process development and wider solutions to societal issues and challenges; the ageing

population (In Ireland, 1.5 million will be aged 60+ by 2020) will create a market demand for silver technologies and connected health technologies and solutions. At Government level, there is recognition of the importance of Connected Health in the provision of healthcare services in the future (in the *National Development Plan* (2007-2013), *Action Plan for Health Research* (2009-2013) and the *Programme for Government*). In Ireland, a number of telemedicine services have been in operation since 2006. The applications available include teleconferencing, teleradiology and teleconsultation. Typically telemedicine in Ireland involves local solutions to local problems rather than a national approach, although there have been some national initiatives.

The EU e-Health sector includes large companies, but is particularly characterised by a very large number of SMEs. Recent market estimates in segments of the Connected Health market include the following: the global Hospital Information Systems (HIS) market was valued at $7.8 billion in 2009 and is forecast to reach $18 billion in 2016 (CAGR, 13 per cent); the global telemedicine market will be worth some $23 billion in 2015 compared to $9.8 billion in 2010 (CAGR, 18.6 per cent over 5 years); the mobile healthcare market has huge potential and opportunities in 2010 were estimated as being worth $50 billion.

There are approximately 50 Irish Connected Health companies in very diverse markets but particularly in Personal health records (12 companies, 3 MNC); Medical Devices/Sensors (14 companies, 3 MNC); Information and Communications Technology / System Integration (16 companies, 11 MNC); Alarms, Telecare, Ambient Assisted Living, and Telemedicine (11 companies); and Mobile Healthcare (9 companies). Some companies span several of the segments. The presence of global players (MNC) is important for the development of a Connected Health / Assisted Living sector in Ireland as their scale and reach can be instrumental in attracting other international players to Ireland for technology platform purposes or as a location for the provision of services internationally. Indigenous companies appear to be proliferating in every segment except ICT/system integration (though there are a few companies) – this segment has higher barriers to entry.

Ireland has a growing R&D expertise in areas that are central to remote healthcare and diagnostics. In addition, Ireland has proven expertise in R&D and advanced manufacturing in medical technologies, embedded software systems and wireless communications. The larger research centres to date have not had specific focus on connected health and much of what is conducted is at the periphery. Many applications have been developed that are relevant to the sector including sensor development, communications, middleware systems, data mining, telemedicine, and assistive and remote technologies. There is a lot of activity in the ambient assisted living area across the country but this is only one of the thematic areas being investigated.

Among the justifications for public intervention in this sector is the major potential for public health cost-savings, and the enterprise development opportunities. Maintenance of patients in their own home is both the preferred option for the patient, and also less expensive for the public purse. Ireland also has research expertise and enterprise capacity in the sector. Products which emerge are likely to be the result of convergence of medical devices and IT technologies, guided by clinicians, patients and home-care specialists. Uptake of Connected Health initiatives requires buy-in by the HSE, including changes in clinical work practices and procedures for interaction with patients. However, the HSE at present is not a test-bed; it is a

service provider that is under pressure. Other non-market barriers include telecommunication and broadband infrastructure and the regulatory environment.

Development of connected health and independent living technologies (including silver technology), requires a cross disciplinary approach involving many research disciplines and sectors, and Ireland has the research and enterprise capability to develop solutions in this area. Consumer-driven innovation is also expected to be a major factor in technology development. There is a real opportunity for Ireland to become a 'proving ground' for connected health solutions. However, this will require an enterprise imperative within the national healthcare system to support development, trial, validation and implementation of connected health technologies and products. Development of such conditions would position Ireland as a unique environment for the development of connected health solutions.

Key Actions Required

- In conjunction with key stakeholders, including the healthcare system, identify actions required to position Ireland as a test bed for trial, validation and implementation of new connected health technologies and silver technologies, identifying barriers and enabling infrastructure improvements.
- Identify discrete areas of need within this sector where Ireland can develop technology and enterprise capability and focus research on supporting these opportunities.
- Fund public health research in areas of patient behaviour, product usability and benefits and barriers to the uptake of new technology in healthcare.
- Identify and promote convergence opportunities in connected health and silver technologies.
- Investigate business models and channels to market for connected health technology, products and services where Ireland could become a world leader.

Priority Area E - Medical Devices

Medical devices can be defined as products used in healthcare and applied to the body for diagnosis, treatment, or therapy.[6] Their effects are usually physical, as opposed to the chemical effects of pharmaceuticals, although trends within the sector are increasingly towards combination devices with combinations of biomechanical, electronic and biologically active components. The sector produces over 500,000 individual products, in 10,000 generic groups ranging from simple tongue depressors to highly complex artificial hearts. The medical device sector is constantly driven by research and development and Ireland has built strength

[6] In some case *in vitro* diagnostics, imaging and drug delivery devices are included in the medical device sector, and this wider sector is called 'medical technology'. However, for the purpose of the exercise, diagnostics, imaging and drug delivery have been considered separately.

and critical mass in a number of research areas that underpin the sector including materials, nanotechnology, biomedical research etc.

Major drivers of growth in the medical device sector are demographics (the ageing population) and technology innovation and convergence, particularly between medical devices and therapeutics, where devices are becoming an integral part of therapeutic treatments in ever more sophisticated ways. In an era of ageing populations and growing health expenditures, medical innovations can improve the quality of people's lives and increase the efficiency of health care systems and contribute to significant cost savings and economic growth. Innovation in medical devices should contribute to the continued improvement of patient safety and outcomes. As a major sector of employment and export in Ireland, support for new product development within the medical device sector has clear societal benefits.

Globally, the medical device market is fragmented with the top 10 companies having less than 50 per cent market share[7] and the industry is facing a high degree of consolidation. In the EU, 80 per cent of the 22,500 medical technology companies are SMEs. The global medical device market was reported as $296 billion in 2010. Growth varies from 3-9 per cent per annum depending on sub-segment, with higher growth forecast for technology intensive segments. Structural factors within the medical device industry create a pivotal role for the sub-supply and contract manufacturing segment, with outsourcing in the region of 40 per cent.

Ireland is one of the leading global hubs for the medical devices industry, generating €6.7 billion (2009) in exports and employing more than 22,700 people (90 per cent in foreign multinational companies). Ireland is now the second largest exporter of medical products in Europe, behind Germany. Eight of the world's 10 largest medical device companies are located in Ireland. Of the 120 companies in the sector, 50 are foreign owned (mainly US) MNCs, 40 are Irish companies engaged in sub-supply and contract manufacturing and there are approximately 30 indigenous companies involved in developing and marketing finished products (some innovative). While the R&D base is small, most foreign MNC do carry out R&D in Ireland; mainly process, but some product R&D. Of the key FDI companies in the sector, Abbott, Boston Scientific, Medtronic, Stryker, De Puy, Vistakon, Covidien and Nypro are engaged in significant product development. Creganna –Tactx Medical also has a significant product development activity. Most of the Irish sector is focused on the development and manufacture of medical and surgical instruments, and on surgical appliances and supplies. There is a strong reliance on interventional cardiology, with 80 per cent of global stent products manufactured in Ireland. Medical devices based on electronics and information technology form a major part of the device sector globally, but only a small part of the sector in Ireland.

There has been a significant Irish investment in medical device research in the last 10 years; from 2003 to 2010, SFI has invested approximately €160 million in Bio-engineering, Diagnostics, Devices and Imaging. In addition, over €150 million has been invested in applied and industry partnered research. Key areas of research include: Minimally-Invasive Surgical

[7] Frost and Sullivan, 2011. *European Medical Device Industry Assessment – A Symptomatic Evaluation*

innovations; Cardiovascular and vascular disease, particularly stents; Biomaterials and scaffolds, particularly in orthopaedics.

Building on basic research capacity, a number of clusters and centres (including SFI funded CSETs and several SFI-funded Strategic Research Clusters) are currently engaging with and supporting the activities of the medical device industry. These centres play a critically important role in linking clinicians with innovation.

The medical device sector continues to demonstrate strong growth prospects. An important enabler of innovation is engagement by the healthcare sector with industry, and with academic and clinical researchers, to facilitate testing, validation and adoption of new medical devices and to support clinician-led innovation and the generation of start up companies. Clinical and translation medicine, population health and health services research will be vital in facilitating such engagement and ensuring that innovations are adapted and adopted by the health system.

There is an opportunity to further develop Ireland's position as a global hub for medical devices, through integrating existing enterprise and research strengths to drive development and manufacture of next generation medical devices here.

Key Actions Required

- Build preclinical, clinical and translational research capability; investigate mechanisms / models to allow industry engagement with HSE resources and access to public research expertise; engage industry in the process.
- Incentivise clinicians to engage in medical device innovation in collaboration with industry.
- Develop mechanisms to identify and take advantage of opportunities for convergent technologies in the medical device sector (shift from hospital to patient centric care through use of ehealth and mhealth, and technologies for independent living etc.).
- Promote innovation in research areas to underpin next generation medical devices. Carry out mapping and gap analysis exercise in conjunction with industry, develop road map and identify collaborative models.
- Define education and training programmes required to produce skilled "industry ready" graduates for current and next generation human capital needs.
- Promote entrepreneurial activity and models aimed at increasing the number of start up companies.

Priority Area F – Diagnostics

Diagnostic products are designed to provide information on health status, disease propensity and progression or therapeutic impact. They form a critical part of healthcare delivery, enabling the early and accurate detection that is vital in ensuring successful treatment, and reducing health costs. Diagnostic products are based on diverse technologies (biological, physical and engineering) and require widely different research expertise and enterprise capacity. The major product types can be divided into two primary categories:

- Imaging & *In-Vivo* Diagnostics: products used to conduct tests directly on a patient: e.g. X-rays, MRI and associated contrast agents and newer biological targeting techniques.

- *In-Vitro* Diagnostics: products used to test patient samples e.g. blood, urine and tissue. These include clinical chemistry assays; immuno-assays; and DNA or molecular diagnostics.

Enterprise capacity in Ireland is currently stronger in the *in-vitro* and molecular diagnostics segment. Major drivers of growth in the medical diagnostics sector include demographics (the ageing population) and technology innovation and convergence. Diagnostics are clearly a critical part of healthcare maintenance and of disease management and early detection of disease may be the critical factor in ensuring successful treatment.

The global market for *in-vitro* diagnostics was valued at $44b in 2010 (anticipated CAGR of 5 per cent) and imaging market was valued at $5.7b. The diagnostics market is continually expanding, and also dramatically changing. Priority areas include: new markers of disease or health status arising from basic biomedical research; new formats of diagnostic products e.g. point of care testing; companion diagnostics; and home diagnostics.

The major enterprise capacity in Ireland is in *in-vitro* and molecular diagnostics (25 companies approx.). Of these, 9 are based on technologies from Irish HE institutions and 10 are units of MNCs (e.g. Abbott, & Beckman Coulter). There is adequate management and technical capacity to commercialise research outputs, but industry has yet to effectively leverage the research base in this area. Some enterprise capacity in imaging exists in Ireland, but it is relatively small and is spread across diverse fields. New technology uptake is important, but product development is mainly conducted within companies as many have a specific platform (sometimes proprietary) on which their products are delivered. Most of R&D activity in imaging in Ireland is in developing applications rather than novel technologies.

There is significant national capacity in diagnostics R&D, but it is widely spread and there are few investigators exclusively involved in diagnostic development. Relevant technologies may emerge from general medical research (e.g. new biomarkers); from chemistry/biochemistry (new reagents and signal detection systems); from materials and physical/engineering research (analytical equipment). A growth area is companion diagnostics, which may provide a basis for pharma-diagnostic collaborations.

There are at least three major dedicated nationally funded research centres operating in the area of diagnostics. There are also 15 other centres with relevant activities which contribute to Ireland's capacity in this area. Diagnostics represents a growing area for

commercialisation activity with companion diagnostics as an emerging yet increasingly important area. 17 projects, representing €2.4m investment, have been supported by EI in the diagnostics area and it is anticipated that this will grow considerably.

Basic biomedical research underpins and acts as a critical driver in the diagnostic space particularly in biomarker identification and development. Therefore, continued investment in research leading to both therapeutics and diagnostics development is needed in Ireland. Focusing research capacity in cellular and molecular pathways and fundamental mechanisms of disease to maximise exploitation of diagnostics development is a logical step.

Medical imaging represents a further major area of growth globally and advances in imaging technology and in image analysis software are driving this sector. Nevertheless, R&D activity in Ireland is limited to a few centres. Importantly, the speed of results and generally non-invasive nature of these modes of diagnostics have major cost advantages for public health systems.

One of the key application areas for discoveries arising from biomedical research is in the development of diagnostics. The *in-vitro* diagnostics market is attractive in that there are relatively low entry barriers for new products and companies. Ireland has built significant research strengths and capacity in diagnostics and other research fields of relevance to diagnostics and should maintain its current level of investment in this area. There is now an opportunity to harness these existing strengths and identify and exploit commercialisation opportunities in emerging growth areas such as personalised medicine/companion diagnostics; nutrition related diagnostics; veterinary diagnostics, point-of-care devices and applications in connected health. This will require focussed investment, enabled by clinical, translational and health services research to translate these developments from the bench to the clinic and community.

Key Actions Required

- Undertake a mapping exercise to identify areas of strength and opportunity (e.g. personalised medicine/companion diagnostics, biomarkers, nutrition related diagnostics, point of care, veterinary diagnostics) in conjunction with industry, where focussed investment or coordination could lead to increased collaboration and commercialisation.

- Develop mechanisms to identify and take advantage of opportunities for smart and convergent technologies in the medical diagnostics sector for point of care or connected health applications.

Priority Area G – Therapeutics: Synthesis, Formulation, Processing and Drug Delivery

Therapeutics are chemical and biological products used to treat diseases. The process of their development is long and complex involving a highly diverse range of research expertise and often with origins within basic biomedical research projects. The early phases, usually

termed 'discovery', aim to identify a 'target', i.e. a step in the disease mechanism which may be impacted by a drug, and also to identify lead compounds which may have the desired impact. When potential drug leads have been identified, there are intermediate phases which involve safety and efficacy trials in animals and man, and later phases which will define the final chemical formulation, manufacturing process and the dosage and delivery method. These decisions will be dependent on, for example, regulatory issues, ease of manufacture, clinical efficacy, ease of compliance and cost.

The global market for pharmaceuticals is $850 billion in 2010 and is expected to reach $1.1 trillion in 2014. A 5-8 per cent compound annual growth rate during this period reflects the impact of leading products losing patent protection in developed markets, as well as strong overall growth in the world's emerging countries. The drug delivery market, while smaller, is faster growing and is expected to grow to $199 billion in 2016 from $101 billion in 2009. Major drivers of growth in the pharmaceutical sector are demographics (the ageing population) and technology innovation and convergence.

Ireland is a major manufacturer of pharmaceuticals and some biologics, and 25,000 people are employed in more than 80 foreign companies based in Ireland. A further 24,000 people are employed in support services. Exports of €38.2 billion make Ireland one of the world's largest exporters of pharmaceuticals. There is also a small but growing indigenous pharma sector, notably including Opsona and Genable.

Development of competence in technologies or services to support this sector can yield national benefits through development collaborative linkages with companies, which may serve to embed them in Ireland. However, Irish based MNCs have virtually no involvement in the early drug discovery stages, while this is the area of greatest Irish RTD activity. Irish research capacity in disease mechanisms is substantial (approximately 18 RTD centres focus on this area) and of high quality. The major fields of disease research investment are: Oncology & Cancer; Neuroscience; Immunology & Infection; Genetics & Genomics.

While this research is attracting attention from the discovery units of MNCs, the link with the Irish activities of these same companies is distant. Nevertheless, multiple research collaborations between Irish researchers and MNCs and SMEs on projects involving the development of therapeutics do exist, particularly in the areas of neurosciences, cancer and inflammation.

On the other hand, there is interest among Irish MNCs in obtaining support for RTD in the pre-manufacturing phases of therapeutics development. Some MNC companies have process development R&D in Ireland, and it is estimated that 43 per cent of Irish MNCs are R&D active to some extent. Research in areas such as formulation and process development is of direct relevance to the operations of these companies, and is seen as a mechanism by which these companies can be encouraged to increase their RTD activity. As evidence of this, the Irish research centres which specialise in these areas have attracted strong MNC collaboration.

The opportunity for research to support the Irish pharmaceutical industry focuses on: manufacture and formulation of small molecules, e.g. organic and analytical chemistry, solid state pharmaceuticals, crystallisation processes; bioprocessing research e.g. cell line development, media optimisation; drug delivery including advanced materials (including polymers) and nanotechnology. Ireland has a number of major research centres and research

networks directly involved in these areas. In addition, there are many other centres which conduct research of some relevance to the sector and several PIs (Principal Investigators) with international reputations and strong partnerships with industry.

Future Irish investment in therapeutics RTD therefore requires a strategic choice. The major areas of current activity and quality are in drug discovery and in the basic research which underpins this activity. However, this research has little immediate relevance for Irish-based MNC enterprises (although it is generating interest from pharma discovery units of MNCs in other countries). On the other hand, the RTD of interest to Irish enterprise (e.g. formulation and processing) is pursued only by a small number of Irish research centres.

The establishment of a large-scale therapeutics discovery endeavour in Ireland as a priority is considered to represent a relatively high-risk strategy due to the scale of required investment and the existing structure of the industry. However, maintenance of activity among some of the excellent groups in this field may create valuable opportunities, some of which it will be possible to exploit in a focused and strategic manner, with partnership of industry and effective clinical and translational pipelines. Investment in such cutting-edge biomedical research also underpins the medical diagnostics, devices and food sectors which have been defined as priorities. Basic research not only feeds the pipeline for early drug development, but also has an impact in other opportunity areas.

The main priority within the field of Therapeutics is to develop competence and activity in pre-manufacturing RTD areas, and in drug delivery. In addition to the industry need for support, a further justification lies in the need for training graduates who will become employed in in-company development operations. Involvement in relevant RTD enhances the value of graduates to the industry and thereby Ireland's appeal as a manufacturing location. Drug delivery is also an opportunity for enterprise development based on innovative drug delivery systems, and Ireland has significant enterprise and research capacity. The sector can benefit from some of the same underpinning technologies as medical devices and diagnostics.

Key Actions Required

- Ensure appropriate capability and incentives to meet industry need for research support in pre-manufacturing technologies and services, e.g. Biocatalysis/ Biopharma/Chemistry, Continuous processing with modelling, Process Analytical Technology, Solid State Pharmaceuticals, Analysis, formulation science expertise.
- Assess feasibility of a process and technology centre for small molecules.
- Continue to build strengths in advanced drug delivery systems and drug delivery devices.
- Develop mechanisms to take advantage of opportunities for convergent technologies in formulation, drug delivery and drug delivery devices.

- Continue to build excellence in basic biomedical research in areas where we have acknowledged competence and critical mass. Highly selective, integrated basic research support to core biomedical researchers.
- Promote uptake of EU and International research funds.
- Recognising that serendipitous discoveries in therapeutics will arise from basic biomedical research, support compelling translational research opportunities to develop IP to a stage where it is ready to attract VC investment or license.

Priority Area H - Food for Health

Food for Health products or functional foods are foods or ingredients that provide health benefits in addition to providing basic nutrition. They are developed through identification, characterisation and evaluation of the health promoting properties of food. New high-value nutrition and wellness products, produced by re-formulation of existing products or through development of new functional foods, are an exciting new opportunity for Ireland's food sector. The discovery of new bioactive components from natural resources, functional ingredients and nutraceuticals is the key to the development of foods for health. There is a requirement for robust scientific research to underpin health claims, therefore access to a functional clinical and translational research system is essential to trial new products with added health and wellness benefit thus enabling a full understanding of the contribution of such products in promoting wellness and addressing the grand societal challenge of increasing levels of diet related diseases such as obesity and Type II diabetes. Also, the identification and understanding of individual and population differences in gene expression in response to diet, through population health research, will lead to food products customised for an individual's nutritional needs.

The increasing world population, the changing demographics of that population (particularly the increase in the ageing population), the increase in diet related diseases and the demand for health and wellness food products across the lifecourse from childhood to old age are key drivers for growth of the food industry. Additional drivers are technology innovation and technology convergence. A societal benefit of food for health related research is that it can support public awareness of the relationship between food and health. Consumers are willing to pay a premium price for food products with credible claims for health benefit. Research will inform dietary habits and advance national health goals by reducing public spending on diseases with a dietary link (e.g. Type II diabetes and CVD). It will also inform policy-makers, health practitioners, and the food industry.

The global market for nutraceuticals was reported to be $117.3 billion in 2007 and is expected to reach $176.7 billion in 2013 (CAGR 7.4 per cent). The main areas of focus are dairy products, soft drinks, baby food and cereals with applications directed at improving digestive health, weight control, and bone and brain health. Demand for functional foods drives demand for bioactive ingredients with clinically validated health benefits. The ingredients sector, rather than the consumer foods sector, is mainly responsible for innovative functional food products. Food and beverage conglomerates are reshaping to reflect the demand trends for functional foods e.g. companies with an agrifood business (e.g.

Nestle) are moving to an R&D-driven nutrition, health and wellness business. In turn, major pharma companies are looking towards the functional foods sector (e.g. Abbott).

The food industry is the largest indigenous industry in Ireland and accounts for > 6 per cent of GDP and employs 45,800 people, which is approximately 7 per cent of national employment. It sources 71 per cent of its raw materials in Ireland, compared to 41 per cent for total manufacturing industry. Ireland has dynamic dairy and food ingredients sectors and these companies are very aware of functional food opportunities. Current Irish manufacturing capability in functional foods is mainly linked to dairy companies (e.g. Glanbia) and SMEs in the ingredients and beverages supply side. Ireland accounts for approximately 15 per cent of the world market in infant formula production.

'*Food Harvest 2020*' a strategy developed in collaboration with the food industry in 2010, sets out clear and achievable export targets for the sector. Research in this general field is underpinned by a wide range of skills in nutrition/dietetics, microbiology (where probiotics are involved; gut health) and clinical medicine related to the particular area of intended health impact. A major focus of Irish research activity in the food for health area is in nutrition, probiotics and generation of novel bioactives / functional ingredients. In addition, there are four Irish universities in the Irish Universities Nutrition Alliance - they carry out national nutrition surveys and develop databases which address both nutrition and food safety issues of relevance to development and implementation of public health policy as well as the needs of the food industry.

Public funding of Food for Health is in the region of €50 million. The major R&D funders are DAFF, SFI, HRB, EI, Marine Institute and industry. DAFF is currently finalising the National Food Research & Innovation Plan, based on a robust stakeholder consultation, which defines six key research areas, of which one is Food & Health. Publically funded research may provide the basis for new enterprises, or the technological enhancement of existing Irish enterprise. Background medical, population and nutrition research will enable functional food research activities. It is also an opportunity to apply some of the expertise developed within the Pharmaceutical sector to a new area of Irish enterprise.

Development of novel high-value nutrition and wellness products and functional ingredients is an exciting new opportunity for Ireland's food sector. Ireland is uniquely positioned in this area with the natural resources, reputation, research strengths and enterprise base and to develop foods for health. The challenge is to ensure full integration of the research base and enterprise. Robust scientific data is required to underpin health claims; therefore access to a functional clinical research infrastructure is essential to trial new products.

Key Actions Required

- Develop capacity for screening bioactives for potential nutraceutical compounds.
- Develop model framework for development of new nutraceutical products to ensure Ireland realises its potential to be a leader in this area:
    - Process for translating food health research into commercial outcomes and products (including validation of food health claims);

  - Lead development of clinical trial framework for functional ingredients and functional foods;
  - Lead development of regulatory framework for functional ingredients and functional foods, given pharma expertise in Ireland.
- Develop and maintain population health databases (e.g. related to interaction between nutrition and lifestyle); manage and facilitate access to data.
- Identify industry research needs and develop new mechanisms to promote industry academic collaboration.
- Exploit synergies with diagnostics research, e.g. to develop biomarkers for nutrition and for assessing personalised nutrition.
- Ensure strategic, synergistic Irish participation in the relevant European and other trans-national initiatives such as the EU Joint Programming Initiative (JPI) - *A Healthy Diet for a Healthy Life*.

Priority Area I - Sustainable Food Production and Processing

Ireland has a very favourable agricultural situation. It is one of Europe's largest dairy and beef exporters, and home to several global enterprises. Global demand for food is projected to increase by 70 per cent over the next 40 years.[8] Alongside the need to increase food production is the challenge of doing so in a manner that does not impact on greenhouse gas emissions, water quality, biodiversity or fish stocks. The focus of this priority area is on sustainable, competitive and efficient agri- & marine food production and processing which includes: land-use optimisation, forestry and non-food crops; wild fish harvesting and aquaculture; and the manufacture of safe, value added and innovative foods.

Growth in global population and changing diets in emerging countries are projected to bring about a 70 per cent increase in food demand to feed 9 billion people by 2050. The greatest challenge faced by agriculture is to meet development and sustainability goals, while increasing production. Over the coming decades, there will be increased global competition for land use. This is the 'food, energy and environment trilemma', where increased demand for food and energy combine, pressure on land conversion is increased, leading to further climate change, which in turn may affect productivity and availability of land.

The reform of the Common Agricultural Policy (CAP) will drive further change in farming, with EU agriculture needing to meet the challenge of increasing competitiveness. Challenges at processor and manufacturing level in Ireland include scale, international competition, international retail consolidation, and lack of consumer orientation in addition to the issues around energy security and reliance on carbon fuel imports.

[8] *Pathways for Growth: Building Ireland's largest indigenous industry*. Bord Bia 2011

In a national context, agriculture and fisheries combined are one of Ireland's most important indigenous sectors, employing over 150,000 people and contributing approximately €24 billion to the economy. The agri-food sector, with 7.4 per cent of national employment, accounts for around 8 per cent of GDP. Most of the enterprises in the agri sector are the 128,200 Irish family farms, of which, 63 per cent are less than 30 hectares in size. There are a number of indigenous multinational food, agri-chemical, animal health and nutrition companies, and equipment/machinery companies some of whom are global players with substantial investments around the world. The UK at 44 per cent of exports remains the principal market (sales over €3.4 billion in 2010), and continental EU markets account for 34 per cent of food and drink exports. Irish agriculture is primarily a grass-based industry with 4.2 million hectares used for agriculture (about 64 per cent of total land area). Approximately 80 per cent of agricultural area is devoted to grass. Beef and milk production currently account for about 60 per cent of agricultural output. Ireland exports some 90 per cent of its net beef output, making it the largest beef exporter in the EU. Exports of dairy products and ingredients account for 29 per cent of agri-food exports. Strongest growth potential for Ireland exists in dairy, beef, prepared foods, and alcoholic beverages. The grass-based nature of Ireland's dairy, beef and sheepmeat industries gives a strong competitive advantage and the sector has a global reputation due to a clean environment and high animal welfare standards.

The seafood trade is one of the world's largest and fastest growing international commodity industries. Global demand for seafood is increasing; it is estimated that an extra 40 million tonnes of seafood will be required annually by 2030. However, declining stock and increased regulation to protect the remaining seafood stock has meant that supply cannot meet demand. Aquaculture can bridge this gap. In Ireland (2010), the seafood sector contributed up to €713 million to the national economy (domestic €333m, export €379m) supporting 11,000 jobs, mostly in rural coastal areas. The Irish seafood sector is comprised of numerous small producers, with only a handful of companies performing at an international level. Ireland's ocean territory extends to 220m acres (10 times Ireland's land area) however the Irish fishing industry operates under a strict EU quota regime. The aquaculture sector consists of 850 licensed operations, on 2,000 sites, directly employing about 2,000 people, with an output of €104m in 2009. The seafood processing sector is comprised of about 200 firms, mainly SMEs, engaged in handling, distribution and processing of fish, employing 2,800 people (full & part-time).

The food supply chain connects three important sectors of the economy: agriculture & aquaculture; the food processing industry; and the distribution sectors. The food sector is critically important to the Irish economy and is our biggest indigenous industry accounting for 58 per cent of exports by indigenous firms and employing 46,000 people. There is a significant enterprise base in Ireland in the food and drink sector, with some 700 food companies of which over 90 per cent are SMEs. The sector has a greater regional spread than any other manufacturing sector. The gross output value of the Irish food and drink sector is expected to double from €20bn to €40bn by 2030.

Forestry is an important part of a sustainable agricultural and food production system. As well as its direct economic contribution, it is key to meeting international climate change targets through carbon sequestration. The output of the Irish forestry and forest products sector is currently €1.89 billion, or just less than 1 per cent of GDP.

In addition to Teagasc, Ireland has a number of HEI based research centres involved in sustainable food production and processing. There is considerable capacity and a number of state of the art research infrastructures supporting internationally renowned researchers across all of the disciplines relevant to food production. Publicly funded R&D is essential to support the primary agriculture and the marine sector. A recent US report[9] concluded that the private sector faces weak incentives to undertake research in numerous areas relevant to agriculture and marine.

Research areas relevant to the future of Irish agriculture include: animal breeding and genetics; animal nutrition; animal fertility, health and welfare; animal product quality and safety; grass breeding, management and utilisation; soils and nutrient use efficiency; crop production; and sustainability and environmental impact of farming. Fragmentation of the primary production industries, farm level competitiveness, increased productivity and sustainability are key issues for the sector.

Areas requiring research in the Irish seafood sector have been identified as: added value processed seafood; sustainable management of high value inshore stocks; improving the quality of marine science related to water quality and wild fish stocks; environmentally sustainable fishing and aquaculture production methods to secure a sustainable resource base.

There has been substantial public investment in food research in Ireland over many years. Research areas that are of particular relevance to the food and drink market include: food safety; food processing technologies; food products; food business and consumer services; and nutrition and dietetics (including food and health and diabetes). Research is needed to support food sectors highly relevant to Ireland, including dairy, beef, poultry, pork, sheepmeat, organic food, seafood, processed or convenience foods, alcoholic and non-alcoholic beverage sectors, the fruit and vegetable sector; and in innovative processing or packaging technologies.

Key Actions Required

- Ensure collaboration and co-operation across all the relevant funding and development agencies to facilitate streamlined, joined-up implementation of the actions required to realise this priority area.
- Maximise the collaboration and resource sharing between all the agri, food & fisheries research active organisations and institutes.
- Implement the recommendations of the *Food Harvest 2020* strategy for the development of the agri-food & fisheries sectors, with due regard to environmental considerations such as the Strategic Environmental Assessment directive requirements.

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[9] Centre for Council for Agricultural Science and Technology (CAST). 2011. *Investing in a Better Future through Public Agricultural Research*. CAST Commentary QTA2011-1. CAST, Ames, Iowa.

- Promote sustainable economic development through ensuring that our natural capital is protected and that binding environmental requirements for greenhouse gas emissions, water and wastewater management and resource efficiency are achieved.

- Implement the F*ood Research Ireland* Strategic Agenda for Food Research developed by DAFM's industry-led Food Research Expert Advisory (FREA) Group.

- Implement the Primary Agricultural Research Agenda as outlined in the document *Stimulating Sustainable Agricultural Production through Research & Innovation* produced by DAFM's industry-led Agri Research Expert Advisory (AREA) Group.

- Continue to implement *Sea Change* (A Marine Knowledge, Research and Innovation Strategy for Ireland 2007-13) research objectives in order to facilitate the delivery of the seafood sector targets in *Food Harvest 2020*.

- Introduce measures to ensure that (a) private industry investment in agri-food & fisheries research is leveraged and (b) Irish drawdown under EU & international research funding mechanisms is maximised.

- Ensure strategic, synergistic Irish participation in European initiatives such as the relevant EU Joint Programming Initiatives (JPIs) and other trans-national initiatives such as the Global Research Alliance on Agricultural Greenhouse Gases.

Priority Area J – Marine Renewable Energy

The focus of this priority area is to position Ireland as a research, development and innovation hub for the deployment of marine renewable energy technologies and services. This would facilitate the creation of an early stage industry and research cluster and open up the possibility of becoming a significant exporter of electricity. The development and testing of ICT applications in a marine environment (based on the Smart Ocean concept) could be supported to enable this priority area.

The development of renewable energy is central to overall energy policy in Ireland as it reduces dependence on fossil fuels, improves security of supply and reduces greenhouse gas emissions while creating environmental benefits, delivering green jobs to the economy and contributing to national competitiveness.

Many of Ireland's Renewable Energy (RE) commitments are derived from those set out in European Directive 2009/28/EC. The EU has a European-wide target of 20 per cent for all energy to come from renewable energy sources by 2020. Ireland's legally binding national target is for 16 per cent of total final energy consumption to come from renewable energy in 2020. Our ocean energy target is for 500 MW of ocean energy capacity by 2020. While no targets are currently set for beyond 2020, the Government needs to take a longer term view to avail of the significant opportunities to sustainably develop Ireland's rich potential from offshore wind, wave and tidal energy over the coming decades.

The use of the sea as a renewable energy source is growing in importance considering the government's ambitious targets of generating 40 per cent of electricity from renewables by 2020. Ireland could, along with other European Atlantic seaboard countries, become a very important future energy/electricity source for Europe.

The Ocean Energy Development Unit (OEDU) in the Sustainable Energy Authority of Ireland[10] (SEAI) was established to take forward the Government's *Ocean Energy Strategy*. In 2008, SFI's remit was extended to include the funding of energy research while Smart Ocean seeks to develop a marine ICT innovation cluster that can provide products and services to the marine energy sector.

In its review in 2008, Indecon suggested that delivering 500MW via offshore wind energy would add €4.3 billion to the Irish economy. According to SEAI wave and tidal energy production and ancillary activities could add between €1.3 - €9 billion to the Irish economy by 2030. The key supply chain elements required to exploit these markets are: the structure and the core wind/wave/tidal converter technology; the power take-off; foundations & moorings; electrical connection; installation process; and O&M (Operation & Management) process.

The core energy conversion technologies for off-shore wind, wave and tidal energy differ in terms of both design concept and product maturity, however there are significant synergies between all three markets such as: grid connection & integration (Smart Grids); installation; and O&M. Offshore wind is the most developed of the three technologies with wave and tidal energy technology still at research, development and pilot deployment stages. The commercial and technical feasibility of the technology is therefore not proven and will require R&D investment. On a global basis, there are currently only a small number of pilot-scale tidal stream and wave devices that have developed to the level of generating electricity output. While these devices are all at pre-commercial stages, there is a rapid acceleration of effort taking place internationally. Despite being overshadowed by the offshore wind sector, wave & tidal energy offer much long-term potential and the next five years could see a number of technologies reach commercial application and be installed. In this respect these developing industries can be seen as being at a similar stage to offshore wind a little over a decade ago.

Ireland's target of 500MW of ocean energy capacity by 2020 represents a very significant challenge to which industry will be looking to academic researchers for innovative solutions. One of the major challenges faced by offshore renewable energy is in reducing its costs to be comparable with 'conventional' power generation from gas and coal.

Ireland has considerable third-level expertise in areas including: sea current turbine design; wave tank model testing; and wave energy modelling. Offshore wind, platforms, modelling, and ecosystems are other key areas of research.

The integration ICT in the marine environment will become strategically more important with the growth of the marine energy market. This is a key element of the Smart Ocean concept developed by the Marine Institute. The global market for marine IT and ocean surveying is estimated to be worth €6.7bn, which includes a €200m sub-market for marine monitoring

[10] www.seai.ie/renewables/ocean_energy/

applications served by integrated and real time systems. The Marine IT market includes digital design and simulation tools; subsea and wireless communication systems; web enabled sensor networks; satellite to seafloor sensing; data management systems; seabed mapping; and forecast models. Ireland has a strong enterprise and expertise base in the development of such "Smart Ocean" technologies. In addition to marine renewable energy applications these products, services and expertise can also target significant opportunities in related sectors such as maritime transport, security and surveillance, aquaculture and environmental monitoring.

There are a number of collaborative initiatives, most notably *Smart Bay* and the ¼ scale OE test facility in Galway Bay, which provide testing infrastructure and involve significant FDI ICT players, SMEs and the HEI sector. The Atlantic Marine Energy Test Site, Belmullet is being developed as a grid-connected test facility for wave and possibly floating offshore wind devices, at the final stage of test and demonstration of arrays of candidate technologies for full commercial deployment. The underlying strategy is to retain existing and attract additional device and project developers, create a unique pre-operational facility, and support the build-up of the cluster of industrial technology and operational expertise that will contribute to maximising a value-added supply chain in Ireland.

The HEI sector collaborates extensively with national and international device developers and has been successful in securing significant FP7 funding. Between 2004 and 2010, marine energy received 10 per cent of all Irish public R&D funding in the energy field. The total current funding for marine energy is €27.2m and for marine ICT is €13.2m.

Key Actions Required

- Draft a clear national policy statement on marine renewable energy.
- Introduce clear licensing and permitting procedures.
- Ensure environmental requirements, e.g. Environmental Impact Assessment and Strategic Environmental Assessment are satisfied.
- Provide test & demonstration infrastructure.
- Develop and implement effective inter-departmental and inter-agency co-ordination mechanisms.
- Ensure a sufficient pipeline of electrical engineers.

Priority Area K - Smart Grids and Smart Cities

Smart Grids and Smart Cities involve the application of energy and advanced ICT technology and solutions to more effectively and efficiently manage complex infrastructure systems. They typically use a layer of technology, including software, sensor hardware and control and

interface systems, which can be embedded in the design of new infrastructure or applied to existing infrastructure.

Smart Grids

Smart Grids comprise a broad and evolving range of energy and ICT technologies that can be applied along different elements of the electricity supply chain – from generator, through transmission and distribution, to end users (e.g. commercial & domestic buildings). Together, these technologies, which include advanced sensors, two-way communications and distributed computing, can increase the deployment of variable renewable energy generation, enable demand response and energy storage and improve the overall efficiency, reliability and safety of power delivery and use.

Electricity is the fastest-growing element of total global energy demand. The requirement to meet this demand in a cost effective, secure and sustainable way is driving the development of a high growth market for smart grids. One estimate puts global investment in smart grids at US$200bn between 2008-2015. The annual market for smart grid technology infrastructure (including smart meters, sensor networks, fibre optic & wireless networks, data analytics) will grow to nearly US$16bn by 2020. The market for energy storage technologies is also growing rapidly, albeit from a low base.

Ireland has a strong FDI ICT enterprise base with significant R&D interest in smart grids such as IBM's Smarter Cities Technology Centre, Intel, Bell Labs, UTRC (United Technologies Research Centre) and the IERC (International Energy Research Centre) as well as some indigenous firms. In addition, there are several electrical engineering oriented FDI companies with interests in smart grids. Most of the electricity generators in the Irish market also have smart grid initiatives and there is significant expertise in ESB Networks and Eirgrid. There is also a growing number of indigenous companies that have invested in R&D to develop smart grid and smart building technologies.

Smart Grids is one of seven European Technology Platforms (ETPs) in the energy sector. Several of the nine ETPs in the ICT sector are also relevant to smart grids and smart cities. Smart grids, energy efficiency in buildings and smart cities are all elements in the strategic energy technologies identified by the EU Commission in the 2009 EC Technology Roadmap to 2020 – altogether the EC has identified a >€10bn research requirement in these technologies by 2020 (private & public funds). Research in this priority area is funded through two FP7 themes: energy (€2.3bn) and ICT (€9.1bn).

Ireland has a potential competitive advantage with respect to attracting future FDI and stimulating indigenous enterprise in this sector. The imperative to facilitate renewable energy on Ireland's grid, the existence of a strong research capability in this area, the opportunity presented by the characteristics of Ireland's transmission system, and the presence of several large FDI ICT enterprises with global smart grid ambitions positions Ireland as a potential test bed for smart grid technologies.

The end-user element of Smart Grids is also a component of Smart Cities.

Smart Cities

Smart Cities is the application of sensor, communication and analytical technologies and design solutions to urban infrastructure such as energy, water, waste and transport systems. The Smart Cities concept is about:

- Deploying ICT technologies (often embedding them within the architecture) to exchange information and monitor and control various building systems; and
- Ensuring that the requirements with regard to the design of buildings, the materials used, and the way space is planned allows the desired outcomes to be achieved.

Relevant technologies include a variety of both hardware and software systems, e.g. wireless sensors, embedded software, middleware, databases, data mining, data analytics, building management systems, energy management systems, data security systems, building performance diagnostics, maintenance management systems, smart meters, smart appliances and advanced control systems.

Smart transport is about the development of infrastructure, technologies and systems which have a low impact on the environment, is energy efficient and provides the mobility required by society in an economic and competitive manner.

Smart transport is one of the strategic energy technologies identified by the European Commission in its 2009 EC Technology Roadmap. Many of the leaders in telecommunications and software R&D are investing in research on intelligent transport systems (e.g. Nokia, Alcatel-Lucent & Ericsson), as are several of the vehicle manufacturers (e.g. Fiat). Ireland has a small cohort of highly innovative enterprises developing intelligent transport system technologies.

Ireland's waters are one of its major natural resources and availability of clean water is a global challenge. It is a resource that must be carefully managed. The technologies involved in achieving this include: water and wastewater treatment systems; monitoring and testing equipment for water quality (e.g. environmental sensing and monitoring); remediation systems; and the use of ICT to reduce consumption and manage water networks (e.g. data management, forecasting).

Sustainable waste management addresses the need to reduce resource consumption by reducing waste generation and increasing reuse and recycling of waste streams. It is closely linked to renewable energy - bioenergy (e.g. waste to energy) and water management (e.g. wastewater treatment).

The EPA's waste & resource management research programme aims to provide research that supports the more effective management of waste, resources and chemicals and is aligned to the EU 2020 Resource Efficient Initiative. This work is complemented by SFI-funded research in the area of waste to energy.

In summary, Smart Grids and Smart Cities can significantly improve the efficiency of complex systems, such as the electricity system and the urban transport system, thereby reducing their costs while contributing to the "green economy".

Key Actions Required

- Ensure collaboration and co-operation across all the relevant funding agencies to facilitate streamlined, joined-up implementation of the actions required to realise this priority area.
- Develop a range of innovation test-bed opportunities to deliver a single national test platform brand for conversion of R&D outputs into new products and services.
- Engage in active industry-academic collaborations in convergent technology arenas in order to capitalise on significant public investments to date and integrate the SME and MNC research base.
- Build strategic international alliances to enhance competitive positioning and to develop new market niches focusing on key partnerships in Europe, US and Asia.
- Ensure that binding environmental requirements in the areas of water, waste water, and waste management and emissions levels are satisfied.
- Ensure strategic, synergistic Irish participation in the relevant European and other trans-national initiatives such as the *Smart Cities & Communities Initiative* within the EU Strategic Energy Technology (SET) Plan and the JPI on *Water Challenges for a Changing World* and the EU 2020 *Resource Efficient Europe Initiative*.

Priority Area L - Manufacturing Competitiveness

The focus of this priority area is on the application and development of technology and knowledge management systems to reduce costs, eliminate waste and to increase product quality. Irrespective of size, sector or ownership, manufacturing companies must constantly adapt to economic conditions and technological advances to improve their competitiveness by focusing their innovation management strategies across the four modes of innovation (product, process, marketing and organisational innovation). Success is illustrated by turning a potential disruptive factor, such as increasing energy costs, into a competitive advantage by, for example, increasing energy efficiency. The areas of research described below illustrate in more detail the type of research within this priority area:

- Ensuring quality across the value chain: this refers to activity across a firm's value chain to ensure compliance with quality and regulatory standards and also to ensure that the final product meets consumers' expectations. The production of food products to meet pharma standards is one need that technologies in this area could address. Understanding of the toxicology of nanoparticles employed in manufacturing processing and which are embedded in a product is another key area;
- Product design: this refers to the translation of an idea into a product that adds value for the customer and enhances sustainability and represents one of the key components of manufacturing;

- Green sustainable technologies: this refers to the production of goods that are designed to reduce a product's environmental footprint. Examples include minimising dissipated energy during manufacturing processing and reducing waste; and

- Tacit knowledge management: this refers to the effective management of knowledge relating to processes and procedures which can reduce cost, increase productivity and improve manufacturing performance.

The key drivers of innovation in this space include: increased pace of technological change combined with a move to technological convergence; increased energy costs; increased cost of waste disposal; and the requirement for increased product quality from a cosmetic, functional and regulation /standard perspective.

According to the Forfás report "*Research and Development Activity of Irish Based Enterprises* (2010)", manufacturing sectors accounted for 38 percent of GDP and 10.5 percent of national employment in 2007. The Census of Industrial Production 2008 reported that in 2008 there were over 4,500 Irish owned firms engaged in manufacturing. These firms employed over 100,000 people and generated Gross Value Added (GVA) of €6.3 billion. During the same period there were approximately 450 foreign owned companies carrying out manufacturing in Ireland, employing 92,000 people and generating a GVA of €25.5 billion. Irrespective of ownership, the fundamental issues around using technology and knowledge management for increased competitiveness are common across the whole manufacturing sector. Key national manufacturing sectors include: ICT; Life Sciences; Food and Drink; coupled with newer industries developing in the Clean Tech and Renewable Energy Sector.

The manufacturing sector in Ireland is a knowledge creator and is therefore one of the leading sectors engaging in innovative activities, as evidenced by:

- The *Community Innovation Survey* 2008: of the seven categories in this survey, the manufacturing category was second in terms of reported process and product innovations carried out by companies.

- The *Business Expenditure on Research and Development* (BERD) Report 2009/10, published by the Central Statistics Office (CSO): manufacturing accounted for almost forty percent (€743 million) of total BERD expenditure.

- BERD: manufacturing accounted for 39 percent (6,088) of the total number of researcher personnel (15,773) employed.

Significant public research funding is invested in research areas of potential relevance to this priority area. This investment has resulted in above world average impact in terms of citations in key relevant research areas such as materials; physics; maths; electrical and electronic engineering; and automation and control systems. However, it is important to highlight that the majority of research is currently not focused on this priority area. Small and medium sized manufacturing firms often lack the necessary absorptive capacity to benefit from technological developments arising from research and development. While large enterprises may have the absorptive capacity to meet their own needs, small and medium sized companies tend not to have the same capability.

Over the last number of years a research agenda focused on the application of technologies and knowledge management systems to manage manufacturing costs for improved competitiveness has emerged in Ireland. Ireland has two Technology Centres focused on manufacturing. Both of these centres host open innovation networks comprising academic researchers and industry (both Irish and foreign owned) who jointly work to seek technological and knowledge management solutions for increased manufacturing competitiveness.

Government intervention is required to support an R&D agenda for manufacturing as Ireland cannot compete on the basis of low cost for investment in manufacturing. To address current market failures, Government should act as a network facilitator between knowledge providers across the higher education sector and industry so that research can be focused on addressing the needs of industry. Government intervention can stimulate networks that specifically target companies with low absorptive capacity. In addition, the knowledge providers across the higher education sector may not obtain the required input from industry to make their research programmes relevant to industry. An intervention of this nature would also assist in the cross fertilisation of knowledge between the traditional and modern manufacturing companies based in Ireland.

Success in relation to this priority area will result in the technological upgrade of the traditional manufacturing base, the attraction and retention of foreign owned manufacturing companies, and the development of high level skills for manufacturing.

Key Actions Required

In order to support and enhance the competitiveness of the Irish based manufacturing sector, the following key actions are required to realise this opportunity:

- A statement from Government is required to communicate the importance of the manufacturing sector to Ireland in terms of economic prosperity.
- The R&D agenda for manufacturing competitiveness is required to be industry led and will require a refocusing of current R&D activity towards applied research. To achieve this, manufacturing companies need to proactively engage in the programmes offered and provide continuous feedback of their needs as they evolve over time. It is vital that this process of engagement is open to both the small traditional and the large advanced manufacturing firms.
- A successful R&D agenda for manufacturing requires participation by industry and the knowledge providers from across the higher education sector. To bring these actors together in a focused and coordinated manner, Government can act as the network facilitator.
- Manufacturing firms should engage in benchmarking (supported by the development agencies) at a sectoral level in order to gain a more in-depth understanding of areas for improvement across production, business and workplace processes. Due to a lack of national research capabilities in this area, identified knowledge gaps should be

addressed via strategic collaboration with international research institutions such as Fraunhofer in Germany.

- Given the applied nature of the R&D agenda for manufacturing competitiveness, the appropriate performance metrics need to be clearly defined. The metrics should address both the "*hard*" (technology focused) and "*soft*" *(*business practices*)* sides of manufacturing.

- A highly trained and adaptable workforce is required for a successful manufacturing sector. Action must be taken to develop and up-skill the current and future talent required for the manufacturing sector. This will require a multidisciplinary approach to education.

- Regulation and standards play a pivotal role in how a product is manufactured. Those responsible for regulation and standards should play a role in research in order to provide an evidence base for the establishment of regulatory standards for manufacturing.

Priority Area M - Processing Technologies and Novel Materials

This priority area is focused on enabling the Irish manufacturing base to transition into one with enhanced capabilities in processing technologies, and material science and engineering. The research agenda for this priority area includes the following:

- Processing technologies: This refers to the collection of technologies and methods used to manufacture a product. Processing technologies can range in complexity from simple manual activities to very complex automated technology. Examples of current research in processing technologies include: process analytical technology; milk dehydration technologies for the food industry; and moving from batch to continuous processing in the pharma industry.

- Material science and engineering: Manufacturing companies rely on materials and the ability to use them within the manufacturing industry in novel ways. Key to delivering on this is material science (exploring the design and properties of novel materials) and also materials engineering (development of existing materials for commercial application, environmental impact, etc.). Globally, this is an area with significant research activity and currently major advances are taking place in areas such as coatings, polymers, composites, advanced functional materials and biomaterials.

Societal issues and global trends driving the need for new innovations across the manufacturing industry include the following:

- Depletion of mineral and resources. This has placed increased focus on product life cycle management. Product life cycle management refers to the process of managing the entire lifecycle of a product from its conception through to the recycling and subsequent integration of used materials back into the production cycle once the buyer is ready to dispose of them. Successful implementation of

product life cycle management: yields improved product quality; reduces prototyping costs; reduces wastes; and increases the operational profit for a company.

- Movement away from mass production to semi-customisation (e.g. blockbuster drugs for the mass markets to niche market orphan drugs).
- Increased pace of technological change combined with a move to technological convergence.

As indicated under Priority Area L, manufacturing accounts for approximately 38 percent of GDP in Ireland, 40 percent of business expenditure on research, 39 percent of business research personnel and 10.5 percent of national employment. Key national manufacturing sectors include: ICT; Life Sciences; Food and Drink; coupled with newer industries developing in the Clean Tech and Renewable Energy Sector.

A number of key research centres have been established to support materials research and processing technologies. These research centres all host open innovation networks comprising academic and industrial researchers (both Irish and foreign owned companies) who jointly work on research focused on the issues identified in this priority area.

The nanotechnology, materials and processing (NMP) Framework Programme 7 (FP7) thematic area aligns most closely with this priority area. Ireland had drawn down approximately €27 million to date in NMP. An analysis of Ireland's performance within FP7 shows that Ireland is above EU average in terms of the success rate of applications and also in relation to the funding granted to successful applicants. According to the FP7 National Support Office in Enterprise Ireland, there is strong interest from both Irish and foreign owned companies in participating in NMP. Building on the success of Irish based researchers in NMP, the research base will be able to leverage European funding under the Factories of the Future public private partnership initiative.

Sustaining the manufacturing sector into the future in Ireland is fundamental for economic prosperity. The next generation of manufacturing industries require continual and radical innovation focused on processing technologies and utilisation of novel materials. There is currently a low absorptive capacity for new technology in many of the small and medium sized manufacturing firms based in Ireland. Government intervention can act as a network facilitator between industry and the knowledge providers across the higher education sector. Engagement with industry on these issues will help researchers in the higher education sector to give their research programmes the appropriate focus. An intervention of this nature will assist in the cross fertilisation of knowledge between the traditional and modern manufacturing companies based in Ireland.

Successful implementation of this opportunity will result in the technological upgrade of the traditional manufacturing base, assist in attracting and retaining foreign owned manufacturing companies and upskill the workforce. There is also a need to fund research to understand the environmental and health impacts of novel materials to ensure their public acceptance.

Key Actions Required

In order to assist the Irish based manufacturing sector make the required transition to next generation manufacturing, the following key actions are required to realise this opportunity:

- A statement from Government is required to communicate that the future sustainability of the manufacturing sector in Ireland is important for economic prosperity.
- The R&D agenda for processing technologies and novel materials should be established with proactive engagement from both industry and the knowledge providers across the higher education sector. It is vital that this process of engagement is open to both small traditional manufacturing firms and large advanced manufacturing firms.
- Once the R&D agenda is defined for this priority area, identified knowledge gaps should be addressed via strategic collaboration with international research institutions such as IMEC in Belgium or Fraunhofer in Germany.
- A programme of research is needed to understand the properties and environmental fate of new materials through their lifecycle will also help to ensure consumer confidence in emerging areas such as nanomaterials.
- A highly trained and adaptable workforce is required for a successful manufacturing sector. Action must be taken to develop and upskill the current and future talent required for this sector. Academic/industry exchange programmes is one means of achieving this.

Priority Area N - Innovation in Services and Business Processes

This priority area is focused on enabling both the manufacturing and service sectors to innovate their service offering, service delivery and business processes. Examples of areas that require innovation underpinned by research and development include management of complex supply chains, new business model development, personalisation of products/services, sales and marketing, risk governance, and sustainability. The areas presented below illustrate in more detail the type of business process innovation that requires research activity:

- Servitisation of manufacturing: The boundaries between manufacturing and services are increasingly becoming blurred with services now a core part of business for many manufacturing companies. This has led to the introduction of the term servitisation of manufacturing as companies embrace strategies around product related services to capture supplementary value.
- Smarter commerce (includes customer service optimisation): Smarter commerce recognises that the sale is just one aspect of the buying process and seeks to turn customer insight into action, enabling new business processes that help companies: buy; market; sell; and service their offering while managing their resources and assets to meet their business needs. It is important to note that both the private and

public sector can integrate smarter commerce into the delivery of their products and services. An illustration of a research agenda in this area includes the new ways to action targeted marketing across multiple channels and the integration of sales and marketing functioning to deliver increased customer service optimisation.

- Business model innovation: New technology is allowing companies to explore new business models due to an increasing pool of information on their existing and target markets. The need for innovation around new business models is illustrated by the potential use of social networking as a communication channel.

- Risk governance, risk management and compliance refers to the systemic approach to decision making processes that reduce risk exposure and vulnerability by filling gaps in risk policy in order to avoid or reduce human and economic costs caused by adverse events.

The service and manufacturing sector requires continual innovation across their business processes to respond to market forces. This is being driven by:

- The increasing power of customers who are in turn empowered by technology which allows them access to knowledge to compare product and service offerings; and

- As companies internationalise, they are required to localise their product / service offering and manage complex supply chains.

This priority area is relevant to manufacturing and services companies. The manufacturing sector has been profiled above in priority areas L and M. A review of services is presented here. Across the industrialised nations, services now accounts for over 70 percent of output and is increasingly seen as an engine for economic growth. The service sector in Ireland has grown in scale and represents an increasing proportion of jobs, value added and exports. According to the Forfás report *Research and Development Activity of Irish Based Enterprises* (2010), the service category (NACE 50-99 (Rev. 1.1) accounted for 46 percent of GDP and 65 percent of employment. The service sector nationally has undergone strong growth from both a foreign and Irish owned perspective. Data published by the Central Statistics Office on services reports that exports reached €73.3 billion in 2010, an increase of 10 percent compared to 2009.

According to the Forfás report, *Catching the Wave: A Service Strategy for Ireland* (2008) Ireland's export performance in services is largely based in two sectors – financial services (incl. insurance) and ICT (software and services). While it is of importance to support these companies and to foster their development and growth into the future, there are significant opportunities for growth in services in other sectors such as education services, healthcare services, tourism and creative services. Examples of foreign owned service companies based in Ireland include Accenture, Applied Communications Ireland, Facebook and Quintiles. CitiBank and Merrill Lynch both have also established RDI centres in areas aligned to this priority area. Examples of Irish owned companies include Parc Aviation, Zenith, ESBI and Aqua Fact.

According to the report *Towards a European Strategy in Support of Innovation in Services* (2007), the service sector has a high level of innovation and is often one of the leading edge

users of advanced technology developments. The service sector in Ireland is increasingly participating in innovative activities. Testament to this is the following:

- According to the BERD Report 2009 /10 published by the Central Statistics Office, services accounted for almost 60 percent (€1.1 billion) of total BERD expenditure.

- According to the same report, the service sector accounted for 65.8 percent (7,872) of the total number of researcher personnel (15,773) employed.

Ireland has a number of key research centres working in areas aligned to this priority area including centres undertaking research in financial services, IT for business value, innovation systems and internationally traded services. It is important to note that research aligned with this priority area is undertaken across the higher education sector at a small scale within business schools. An important gap currently in the research system for this priority area is the lack of multidisciplinary teams of researchers in the social and business sciences and technological and ICT sciences.

There is a significant presence of foreign owned companies and a growing indigenous base in these sectors and the capacity of these companies to innovative is fundamental to their sustainability. To enhance the innovative capability of industry in services and business processes, the Government should establish a focused and coordinated research capability in the higher education sector with the research agenda being informed by industry. This action will establish an increased knowledge base across the higher education sector that is aligned with the needs of industry and also will assist in producing the human capital for these sectors.

Key Actions Required

- The R&D agenda for innovative services and business processes is required to be industry led and will require the establishment of a national research capacity in the higher education sector. To achieve this, companies need to proactively engage in the programmes offered and provide continuous feedback of their current and future needs as they evolve over time. It is vital that this process of engagement is open to both the small and large companies.

- Companies should engage in benchmarking (supported by the development agencies) at a sectoral level in order to gain a more in-depth understanding of areas that need improvement in business processes. Due to a lack of national research capabilities in this area, identified knowledge gaps should be addressed via strategic collaboration with international research institutions.

- Action must be taken to develop and up-skill the current and future talent required for the service and manufacturing sector. In doing this, the importance of innovative thinking across the four modes of innovation (product, process, marketing and organisational innovation) should be emphasised. This will require a multidisciplinary approach to education.

- Innovation in services and business processes happens over a shorter timeframe; therefore, the R&D agenda is required to be underpinned by responsiveness and agility.

Annex 2: Examples of Policy Research

Climate Change and Related Environmental Research

Climate change is a massive global challenge. The nature of climate change means that even if global greenhouse gas emissions were reduced now, some climate change impacts are unavoidable. An improved understanding of climate change is imperative in order to implement the required emissions reductions and adaptation measures. Addressing climate change will require a major transition in technologies, systems and practices by key sectors.

Addressing climate change will pose significant challenges for Ireland in meeting the emissions limits established by the EU Directive 2009/28/EC (i.e., the 2020 Climate and Energy Package). Ireland needs to reduce its dependence on fossil fuels and at the same time ensure that significant increases are made both in energy efficiency and in the use of alternative energy sources such as wind, ocean and biomass. Achievement of the 2020 target and longer term goals to 2050 will require radical changes to current practices in all economic sectors, particularly those in agriculture, energy and transport.

Research is required to understand better how Ireland will enable this transition to a low emissions, sustainable and climate resilient economy and society. This will require engagement by enterprise and society generally. There is a requirement to develop innovative technologies and solutions to reduce greenhouse gas emissions and in particular, producing energy from low emission sources as well as devising climate-proofed planning and public policy measures.

Closely linked to the threat of climate change are the associated concerns about the sustainable use of resources. In considering opportunity areas for Ireland arising from its natural resources and utilising these to deliver economic growth and jobs, the climate change and sustainable environment drivers remain a constant theme. In identifying many of the key priority areas associated with our natural resources, (e.g. “Sustainable Food Production and Processing”, “Marine Renewable Energy” and “Smart Grids & Smart Cities”) it is acknowledged that all of these areas need to be developed in a sustainable manner that will minimise and ideally reduce our impact on our finite natural capital while also being realised in an economically competitive way.

Bioenergy

Bioenergy feedstocks include solid biomass, wood wastes, agricultural wastes, energy crops, landfill gases, biodegradable components of municipal solid waste and liquid biofuels. Ireland has a significant bioenergy potential in the form of agricultural land, forestry and recycled waste from municipal, agricultural and industrial sources. Although Ireland has good bioenergy resources, our use of them has been relatively limited.

Bioenergy offers several advantages over other sources of renewable energy, including: storability; scope for rural development; and a disposal route for wastes. Ireland’s targets for

bioenergy deployment are ambitious as they straddle transport (10 per cent biofuels), electricity (30 per cent co-firing in peat stations), CHP (significant biomass contribution to 800MW by 2020). However, care will be required to ensure no conflicts arise regarding food production and other environmental sustainability requirements.

Compared to other renewable energy technologies, the challenges with regard to the use of bioenergy in Ireland are less to do with technology development and more to do with resource development and supply chain coordination. However, the production of biomass for energy is a relatively new concept and significant payback can be obtained from research in optimising the yield of energy crops, the production of thinnings from forestry and the inclusion of waste in bioenergy streams.

Population Health Research

Research on population health generates significant net economic and social benefits in areas where there is little commercial incentive. It strives to keep people healthier for longer. Examples include disease prevention and control, nutrition surveillance, ascertaining which patient subgroup would not benefit from a standard treatment, understanding behavioural and lifestyle factors in disease or undertaking environmental remediation. These are situations where public funding for research is essential and merit priority. In some circumstances, there can be important enterprise benefits from the research outputs of these areas.

Population health research provides the evidence base that underpins healthcare planning, provision and policy, and ensures that delivery is cost effective and efficient. It covers the life-course from birth, child, adolescent, adult and ageing and is applied to communities and specific population groups. The Government faces major financial challenges in dealing with an ageing population, increases in chronic disease, spiralling costs of healthcare facilities and medication, and growing demands for higher quality and more personalised care. The analysis of data emerging from population-level surveys and surveillance helps to address these challenges by identifying the systemic and resource allocation decisions that are needed as well as future healthcare needs, products and services.

Environmental Health Research

Environmental health research deals with those aspects of population health that are determined or influenced by factors in the environment. The provision of a safe clean environment offers strong savings in avoidable healthcare costs. In addition, a good quality of life is fundamental to enterprise development. Environmental health research is driven by legislation and binding international agreements which require informed responses on key issues (e.g. air pollution, provision of clean water) and is, therefore, a vital component in delivering on wider economic and societal ambitions. Understanding the properties and environmental fate of new materials throughout their life cycle will also help to ensure consumer confidence in emerging areas such as nanomaterials.

Health Services Research

Health services research provides the evidence base that underpins healthcare policy, planning and provision and ensures that delivery is cost effective and efficient. The need for such an evidence-based approach to policy development will be brought more sharply into focus as work proceeds on the major programme of health reform set out in the *Programme for Government*. Within the overall context of the health sector reform programme, in itself a hugely complex and ambitious undertaking, the Government faces major financial challenges in dealing with demographic change and an ageing population, increases in chronic disease, spiralling costs of healthcare delivery, growing demands for higher quality and more personalised care with shifting focus from acute to primary, community and self-managed care.

Health services research informs the wider innovation value chain in the healthcare system by acting as the bridge between needs/priorities and the product/service design process. It does this by providing the data that underpin the development of new models of portfolio risk, deployment methods for healthcare products, reimbursement models, and the identification of new data services, platforms and partnerships. All of these outputs are of interest to the healthcare industry, both established and new entrants. There is also significant scope for the enterprise sector to engage in health service research through the development of eHealth, Connected Health and Assistive Living Technologies.

Annex 3: Examples of Integrating Infrastructure

On-going investment will be required to maintain and integrate research infrastructure as part of a sustainable system. Examples of the type of infrastructure and related investments referenced during the course of this exercise are set out below.

Clinical and translational research and infrastructure

Clinical and translational research is a critical enabler in the transfer of research findings from the laboratory to healthcare application. This occurs through refinement of discoveries, through their validation and clinical appraisal in patients; and finally through their commercialisation and delivery to the marketplace. It requires alignment of components to provide integrated processes, infrastructure and expertise. These include scientific excellence, a functioning clinical research system and a supporting regulatory and ethics system. Key investments in this area include:

- Clinical Research Facilities (CRFs) located on hospital campuses, which act as unique laboratories of human research and that cluster groups of investigators to facilitate clinical research. Over time, the CRFs will provide a research environment that is more nimble, conducive to, and responsive to, the demands of the healthcare industry;
- A national clinical research support framework, built on local strengths of the CRFs, offering a single point of contact and integrated services for academia, the health system and industry;
- Development of a pipeline of highly-skilled clinical investigators;
- Appropriate funding for research programmes in translational medicine; and
- Creation of collaborative research networks of clinicians in different disease disciplines in order to access large patient cohorts.

Developing clinical research capability within a primed health system will support innovation by Irish-based enterprises across many sectors, including pharma and biopharma, medical technologies and functional food. It also has the potential to improve the quality of patient care through access to clinicians who are active in leading-edge research. Without these interventions, it is not possible to fully benefit from the national investments in basic life sciences research. There has traditionally been under-investment in these parts of the healthcare continuum. As a result, key infrastructures in these areas are underdeveloped, engagement of clinicians and other health professionals in research is still limited and there remains a lack of capacity to undertake clinical trials in Ireland. Many Irish companies are carrying out clinical trials abroad whereas such activities, if done in Ireland, could provide significant revenue streams to the hospitals involved. These deficits in clinical trial capacity

limit indigenous enterprise development, foreign direct investment and the potential returns on the major investment by Ireland in biomedical and nutrition research over the last decade.

Ireland needs to build on progress to date in developing a fit for purpose national clinical and translational research capability to support the broad range of opportunities identified, with top down leadership and commitment by the Department of Health and active engagement by the health system in research and enterprise support.

E-Infrastructure

E-infrastructure refers to the use of ICT to enable researchers across a broad range of disciplines to gain access to facilities, resources and collaboration tools for accessing data, learning material, experimentation, connectivity, storage and instrumentation. In Ireland, e-infrastructure is provided through various entities and projects including HEAnet, ICHEC, e-Inis and Grid Ireland.

HEAnet is Ireland's National Education and Research Network, providing high quality internet services to Irish universities, institutes of technology and the research and educational community, including all Irish primary and secondary schools. HEAnet provides a high-speed national network with direct connectivity for its community to other networks in Ireland, Europe, the USA and the rest of the world. HEIs rely more and more on ICT for delivery of learning material and for enabling researcher collaboration. The increasing adoption of a cloud-based computing model places even greater dependency on the network as HEIs locate more and more resources off-campus.

A cutting edge and resilient network will be required to support and deliver on the national research priority areas including "Future Networks and Communications" and "Data Analytics, Management, Security and Privacy". Irish researchers are demanding solutions ahead of market provision (e.g. IPv6, bandwidth-on-demand, virtualised networking, etc.). A sustainable and forward looking network based on the provision of dark fibre which offers the necessary scalability is required. Network developments must recognise and enable the emergence of shared and cloud services (such as learning management systems, data repositories, and high quality videoconferencing).

The Irish Centre for High-End Computing (ICHEC) was established with SFI funding in late 2004 as a national High-Performance Computing (HPC) provider. It has since become jointly funded by the Higher Education Authority and Science Foundation Ireland. Its mission is to provide HPC resources principally for researchers in third-level institutions. A skilled team of system administrators and computational scientists now engage with these researchers to support the development of internationally competitive computational modelling and world-class research across all the main disciplines and institutions. ICHEC facilitates access to a number of programmes whereby Irish based researchers can gain access to very large scale HPC resources in the US and Europe. A joint HEA/SFI review of high end computing was completed in late 2010 and recommended the development of a coherent architecture to support research and innovation.

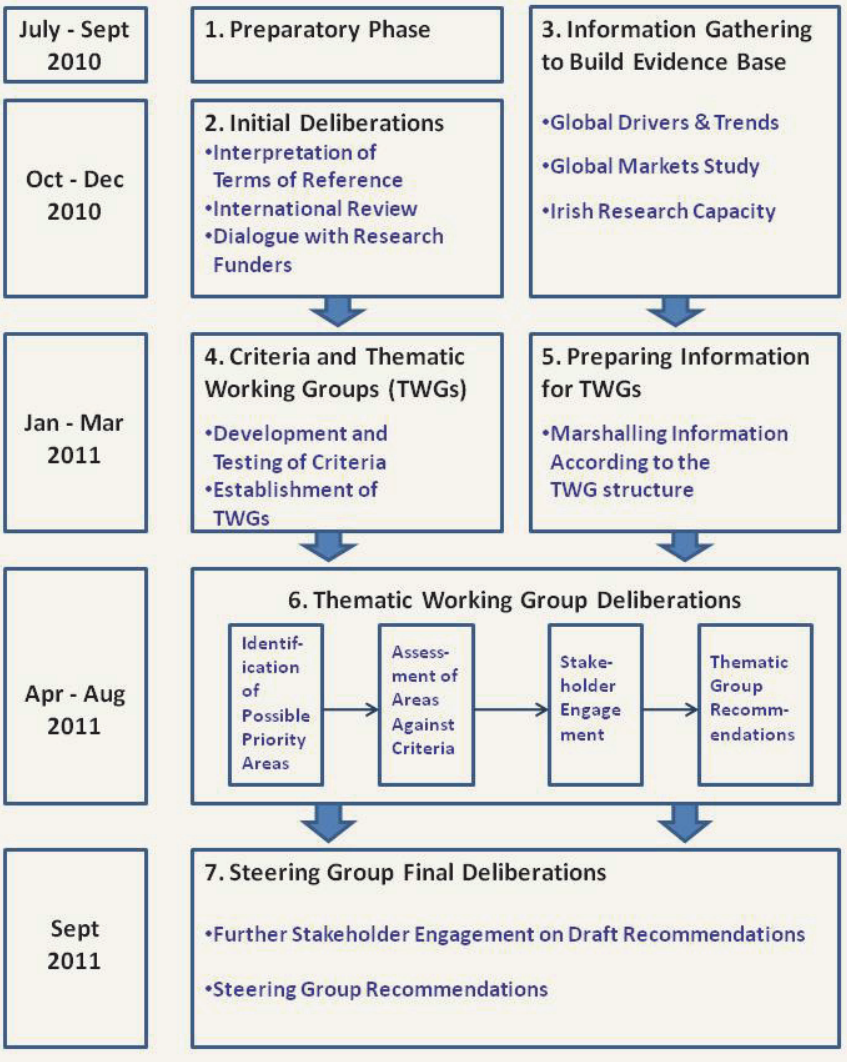
The e-INIS project funded under PRTLI Cycle 4 aims to provide a single access point to coordinate data, network and computing resources in Ireland as the foundation of a national e-Infrastructure. The project is focused on developing and providing a national facility for large scale data storage and management and currently maintains some 900 Tbytes.

Grid Ireland, funded mainly through several EU projects, provides support for virtual organisations using distributed grid resources.

Annex 4: Process and Methodology

The Steering Group, supported by Forfás, designed its own process to deliver on the mandate that was given to the group within the one year timeframe set down by Government. The key elements of the process are presented in Figure 3 below and can be summarised as follows:

Figure 3: Process Overview



Source: Forfás

1. Preparatory Phase

Based on the terms of reference agreed at Cabinet Committee level, DJEI and Forfás undertook preparatory work leading to the establishment of the Steering Group. The

preparatory phase included desk research on the approaches to research priority setting in five countries (UK, Sweden, Denmark, the Netherlands, Japan). A paper based on this desk research was prepared for the first meeting of the Steering Group identifying some of the key steps associated with consultative prioritisation exercises in other countries.

2. Initial Deliberations

The Steering Group's initial deliberations focused on different aspects of the STI system in Ireland and approaches to research prioritisation in other countries. During this phase, the precise methodology for delivering on the group's mandate was mapped out and agreed. This phase included:

- Deliberations within the Steering Group regarding the appropriate level at which priority areas should be identified;
- Discussions with invited experts from three of the countries reviewed (Denmark, Sweden and UK) and with an expert from the European Commission on the mechanisms by which priorities were identified and implemented in these countries/regions. Special workshops on approaches to research funding in New Zealand and Israel were also facilitated by Steering Group members during the process; and
- Presentations from six Government Departments and a total of twelve funding agencies/organisations that comprise the entire system for supporting research in Ireland. The dialogue with Government Departments and agencies provided the Steering Group with an overall picture of how the current system operates from a funding perspective and demonstrated that some level of prioritisation takes place on a continuous basis through the procedures already in place in these organisations.

3. Information Gathering to Build Evidence Base

A number of data gathering exercises were put in place from the start so that an evidence base would be available for Steering Group deliberations. The studies link to three key dimensions identified in the mandate of the group: the enterprise dimension, the societal dimension and Ireland's existing research base.

Study on Global Market Opportunities, Growth Markets and the Positioning of the Irish Enterprise Base

This study builds on, and integrates, a large number of sectoral studies that have been undertaken by Forfás and the enterprise development agencies. It provides profiles on more than 70 market areas of relevance to Ireland, drawing attention to research agendas associated with each market area and the current positioning of the Irish enterprise base, including its research and technological capacity. IDA Ireland, Enterprise Ireland and Science Foundation Ireland supported Forfás in the implementation of the study in addition to consultation with other government agencies and industry representative groups.

Review of Drivers, Trends and Societal Issues from a National Perspective in a Global Context

This study provides an assessment of key global issues and trends which are likely to have implications for research in areas such as climate change, energy supply, food security, health and ageing, environmental protection etc. The study has identified a total of 54 drivers and trends grouped into 8 thematic areas. A series of roundtable discussions took place in the context of this exercise with stakeholders from across all the government departments and the agencies involved in funding research. The purpose of the consultations was to explore the global trends, the challenges and opportunities they give rise to and the research and technology areas critical to addressing the challenges.

Review of Current Strengths and Areas of Emerging Critical Mass in Irish Research

This work strand brings together quantitative and qualitative information on current areas of focus in the public research system. The study provides a catalogue of research strengths in the public research system under a specially agreed classification of research areas. The study also identifies research areas of emerging critical mass. A large amount of information has been compiled by both research funding agencies and by HEIs and other research performers on the basis of agreed templates.

4. Criteria and Thematic Working Groups

Based on the large amount of information gathered and discussed up to Jan 2011, the Steering Group agreed the high-level criteria and the sub-questions under these criteria that would be used to evaluate potential "priority areas". The high-level criteria are set out in Table 4 below.

Table 4: The Four High Level Criteria for Assessment of Priority Areas

1.	The priority area is associated with a large global market or markets in which Irish-based enterprises already compete or can realistically compete
2.	Publicly performed R&D in Ireland is required to exploit the priority area and will 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

The group also agreed that four Thematic Working Groups (TWGs) would be established to assess potential priority areas against the agreed criteria. The four thematic working groups and their respective scopes are set out in Table 5.

Table 5: Thematic Working Groups

TWG Title	Scope of TWG
Health, Wellbeing and Ageing	All health, life sciences, pharmaceutical, medical devices and diagnostics research areas, health systems and delivery, population health, health policy research.
Natural Resources and Sustainable Environment	Agriculture, fisheries and food, marine research, energy, climate change, environment, including built environment, smart living spaces, smart cities, transport and related policy research.
Technology, Social Media; Creative and Cultural Enterprise	ICT including next generation internet and computing, information security, software, gaming, social networking, digital media, digital content, e-learning; Creative and cultural enterprise.
Innovative Processes for Enterprise (Advanced Manufacturing and Business Services)	Advanced manufacturing (including applications in ICT, pharmaceuticals, biopharmaceuticals, bio processing, medical technologies, food and drink etc.); Business and services innovation (e.g. financial services, educational services, etc.)

5 Preparing Information for Thematic Working Groups

To prepare for the first meetings of the TWGs, Forfás assembled relevant information from the three studies above and from other strategy documents and sectoral studies. These briefing documents were used as the basis for initial discussions within the thematic groups. During this phase, independent experts were recruited for each of the thematic working groups established by the Steering Group.

6. Thematic Working Group Deliberations

The TWGs were established purely for the purpose of bringing relevant actors together in order to have informed deliberations on possible priority areas within the thematic domains. The Steering Group proposed very tight membership of each group. Each group would be chaired by a member of the Steering Group and other members of the Steering Group were invited to participate. The rest of the membership comprised representatives from each of the relevant funding organisations active in the thematic area and a single representative each from the university sector, the institutes of technology sector and the enterprise sector.

For consistency, each TWG worked to an agreed process with the four high-level criteria (and a standard set of sub-questions) placed centre-stage throughout.

Each group met on four occasions between April and August 2011 in addition to hosting stakeholder events and other off-line activities. The process followed within each TWG is summarised below. The Steering Group oversaw the full process and received regular updates from the TWG chairs.

- Each of the funding organisations was asked to identify potential priority areas within the thematic domain based on their knowledge of existing and emerging research strengths and the potential fit with the other criteria;
- The TWG examined the areas proposed for overlap/duplication and agreed an initial list of areas for which detailed assessments would be undertaken;
- Forfás and the consultants prepared detailed assessments (including a SWOT analysis) on each of the proposed areas based on the four high-level criteria and associated sub-questions;
- The TWG reviewed the assessments and based on deliberations agreed a document to be used as the basis for consultation with targeted stakeholders. In some cases, areas were amalgamated at this point based on the deliberations within the TWG;
- Stakeholder engagement events were organised by each of the TWGs at which the TWG perspectives were shared with stakeholders in order to elicit feedback. In parallel, the Steering Group invited the main enterprise and higher education representative bodies to provide formal written responses to the stakeholder engagement documents compiled by each TWG; and
- TWGs met in late August 2011 to review the feedback from stakeholders and to agree the recommendations that would be made by the TWG to the Steering Group.

7. Steering Group Final Deliberations

A further large-scale stakeholder engagement event was organised in early September 2011 to inform stakeholders of the recommendations that each TWG would be making to the Steering Group.

The Steering Group received final presentations from each TWG in September 2011 and reviewed feedback from the stakeholder engagement event as part of its final deliberations on the priority areas to be recommended to Government.

Annex 5: Membership of Research Prioritisation Steering Group

Chair: Jim O'Hara, Former General Manager Intel Ireland, former Vice-President, TMG Intel Corporation and Member of Enterprise Ireland Board

Professor Nicholas Canny, Member of the Scientific Council of the European Research Council; was President of the Royal Irish Academy, 2008-11

Professor Frank Convery, Professor of Environmental Studies, University College Dublin

Marion Coy, Member of the Advisory Council on Science, Technology and Innovation (ACSTI)

Professor Patrick Cunningham, Chief Scientific Adviser to the Government

Seán Dorgan, Former CEO of IDA Ireland and Secretary General of Departments of Industry and Commerce and Tourism and Trade

Dr Alastair Glass, Former Deputy Minister of Research and Innovation, Ontario, Canada

Brian J Hayes, Managing Director, Head of Global Transaction Services Ireland and Citi Innovation Labs EMEA, Citibank Europe Plc

Professor Brian MacCraith, President, Dublin City University, Member of ACSTI

Kevin McCarthy, Asst. Secretary, DES, Deputy Chair of Inter-departmental Committee on STI

Dr Tom McCarthy, Chairman of ACSTI, CEO Irish Management Institute

Martin Naughton, Chairman, Glen Dimplex Group

Ian Quinn, Chairman, Creganna-Tactx Medical

Maurice Roche, General Partner, Delta Partners

Professor Frances Ruane, Director, Economic and Social Research Institute

Martin Shanagher, Asst. Secretary, DJEI, Chair of Inter-departmental Committee on STI

Martin D. Shanahan, Chief Executive, Forfás

Secretariat to Steering Group:

Marcus Breathnach, Forfás

Dr Lucy Cusack, Forfás

Maurice Dagg, Forfás

Sheena Duffy, Higher Education Authority

Catherine MacEnri, Forfás

Dr Paula Maguire, Forfás

Karen Hynes, Manager, Innovation Policy Department, Forfás

Annex 6: Membership of Thematic Working Groups

Health, Wellbeing and Ageing

Chair: Dr Tom McCarthy, Chairman of ACSTI, CEO Irish Management Institute

Dr Pamela Byrne, Research, Food & Codex Division, Department of Agriculture, Food and the Marine

Dr Shane Colgan, Environmental Protection Agency

Enda Connolly, Chief Executive, Health Research Board

Prof Brian Fitzgerald, Former Vice President Research, University of Limerick, (representing the Irish Universities Association, Meetings 1-3)

Dr Maura Hiney, Head of Policy, Evaluation and External Relations Unit, Health Research Board

Dr Dermot Hurst, Programme Manager, Marine Institute

Dr Chantelle Kiernan, Scientific & Technology Advisor, IDA Ireland

Dr Tim McCormac, Head of Research, Dundalk Institute of Technology (representing Institutes of Technology Ireland)

Dr Eucharia Meehan, Head of Research Programmes and Capital Programmes, Higher Education Authority

Dr Michael Napier, Director Chemical Technology, Janssen Pharmaceuticals (representing IBEC)

Dr Pat Nolan, Office of Science, Technology and Innovation, Department of Jobs, Enterprise and Innovation

Dr Keith O'Neill, Director of Life Sciences and Food Research, Enterprise Ireland

Dr Siobhan Roche, Scientific Programme Manager, Life Sciences Directorate, Science Foundation Ireland

Professor Frances Ruane, Director, Economic and Social Research Institute

David Shanahan, Global Head of Life Sciences, IDA Ireland

Dr Mary Shire, Vice President Research, University of Limerick (representing the Irish Universities Association, Meeting 4)

Dr Stephen Simpson, Director, Life Sciences, Science Foundation Ireland

Secretary: Dr Lucy Cusack, Forfás

Natural Resources and Sustainable Environment

Chair: Maurice Roche, Partner, Delta Partners

Dr Nuala Bannon, Senior Adviser, Department of the Environment, Community and Local Government

Ray Bowe, Clean Tech Division**,** IDA Ireland

Professor Frank Convery, Professor of Environmental Studies, University College Dublin

Professor Patrick Cunningham, Chief Scientific Adviser to the Government

Dr Brian Donlon, Senior Programme Officer, STRIVE Programme, Environmental Protection Agency

Richard Howell, Head of Research Division, Department of Agriculture, Food and the Marine

Martin Hynes, Executive Director of Irish Research Council for Science, Engineering & Technology

Neil Kerrigan, Head of Industrial Research Programmes, Enterprise Ireland

Paul Lynam, CEO, Siemens Ltd., Dublin, (representing IBEC)

Dr Eucharia Meehan, Head of Research Programmes and Capital Programmes, Higher Education Authority

Dr Frank McGovern, Senior Manager, Climate Change Research Programme, Environmental Protection Agency

Dr Wendy McLoone, Scientific Programme Manager, IC&ET Directorate, Science Foundation Ireland

Professor Fionn Murtagh, Director, Information, Communications & Emergent Technologies Directorate (IC&ET), Science Foundation Ireland

Dr Pat Nolan, Office of Science, Technology and Innovation; Department of Jobs, Enterprise and Innovation

Dr Frank O'Mara, Director of Research, Teagasc

Professor Ray O'Neill, VP for Research, National University of Ireland, Maynooth (representing the Irish Universities Association)

Aengus Parsons, Programme Manager, Research Funding, Marine Institute (Meetings 3-4)

Katrina Polaski, Head of Low Carbon Technologies, Sustainable Energy Authority of Ireland

Yvonne Shields, Director Strategic Planning and Development Services, Marine Institute (Meetings 1-3)

Dr Niall Smith, Head of Research, Cork Institute of Technology (representing Institutes of Technology Ireland)

Koen Verbruggen, Principal Geologist, Geological Survey of Ireland

Secretary: Catherine MacEnri, Forfás

Technology, Social Media; Creative and Cultural Enterprise

Chair: Brian J Hayes, Managing Director, Head of Global Transaction Services Ireland and Citi Innovation Labs EMEA, Citibank Europe Plc

Professor Nicholas Canny, Member of the Scientific Council of the European Research Council; was President of the Royal Irish Academy, 2008-11

Dr Sandra Collins, Scientific Programme Manager, IC&ET Directorate, Science Foundation Ireland

Tim Conlon, Acting Director, Irish Research Council for the Humanities and Social Sciences

Dr Willie Donnelly, Head of Research and Innovation, Waterford Institute of Technology (representing Institutes of Technology Ireland)

Emmanuel Dowdall, Manager of the Content Industrial & Consumer & Business Services Department, IDA Ireland

Dr Chris Enright, R&D Section Manager at Hewlett Packard Ireland

Dr Steve Flinter, Scientific Programme Manager, IC&ET Directorate, Science Foundation Ireland

Dr Ruth Freeman, Director of Enterprise and International Affairs, Science Foundation Ireland

Professor Ellen Hazelkorn, Director of Research and Enterprise, Dublin Institute of Technology

Pat Howlin, Manager, Information and Communication Technologies, IDA Ireland

Dr Gearóid Mooney, Director of ICT Research Commercialisation, Enterprise Ireland

Donal Murphy, Manager, Information and Communication Technologies, IDA Ireland

Dr Pat Nolan, Office of Science, Technology and Innovation, Department of Jobs, Enterprise and Innovation

Dr Roger O'Connor, Director of Business and Technology, Department of Communications, Energy and Natural Resources

Dr Jason Roche, Information and Communications Technology Specialist, IDA Ireland

Professor Terry Smith, VP for Research, National University of Ireland, Galway (representing the Irish Universities Association)

Secretary: Sheena Duffy, Higher Education Authority

Innovative Processes for Enterprise (Advanced Manufacturing and Business Services)

Chair: Marion Coy, Member of the Advisory Council on Science, Technology and Innovation (ACSTI)

Marion Byrne, Food Division, Department of Agriculture, Food and the Marine

Tim Conlon, Acting Director, Irish Research Council for the Humanities and Social Sciences

Dr Paul Dodd, Director of Industry Collaborative Programmes, Science Foundation Ireland

Tony Donohue, Head of Education Policy, IBEC

Seán Dorgan, Former CEO of IDA Ireland and Secretary General of Departments of Industry and Commerce and Tourism and Trade

Emmanuel Dowdall, Manager of the Content Industrial & Consumer & Business Services Department, IDA Ireland

Tommy Fanning, Manager of the Diversified Engineering Department, IDA Ireland

Jim Lawler, Manager of Industrial Technologies Commercialisation, Enterprise Ireland

Professor Anita Maguire, Vice President of Research, University College Cork (representing the Irish Universities Association)

Dr Eucharia Meehan, Head of Research Programmes and Capital Programmes, Higher Education Authority

Martin Naughton, Chairman of Glen Dimplex Group

Dr Pat Nolan, Office of Science, Technology and Innovation, Department of Jobs, Enterprise and Innovation

Dr David Tormey, Principal Investigator, Centre for Design Innovation, IT Sligo (representing Institutes of Technology Ireland)

Secretary: Dr Paula Maguire, Forfás

Annex 7: List of Acronyms

ACSTI	Advisory Council for Science, Technology and Innovation
BERD	Business Expenditure on Research and Development
CAGR	Compound Annual Growth Rate
CAP	Common Agricultural Policy
CSO	Central Statistics Office
CRFs	Clinical Research Facilities
CSETs	Centres for Science, Engineering and Technology
DES	Department of Education and Skills
DJEI	Department of Jobs, Enterprise and Innovation
FDI	Foreign Direct Investment
FP7	Seventh EU Framework Programme
GDP	Gross Domestic Product
GVA	Gross Value Added
HEA	Higher Education Authority
HEIs	Higher Education Institutions
HSE	Health Services Executive
IBEC	Irish Business Employers Confederation

ICT	Information and Communications Technology
IP	Intellectual Property
JPI	European Union Joint Programming Initiative
MNC	Multinational Corporation
PI	Principal Investigator
PROs	Public Research Organisations
PRTLI	Programme for Research in Third Level Institutions
R&D	Research and Development
RDI	Research, Development and Innovation
RTD	Research, Technology and Development
SEAI	Sustainable Energy Authority of Ireland
SFI	Science Foundation Ireland
SMEs	Small and Medium Sized Enterprises
S&T	Science and Technology
STI	Science, Technology and Innovation
SRCs	Strategic Research Clusters
SSTI	Strategy for Science Technology and Innovation
TWGs	Thematic Working Groups

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