TEAGASC TECHNOLOGY FORESIGHT 2035

TECHNOLOGY TRANSFORMING IRISH AGRI-FOOD AND BIOECONOMY

FINAL REPORT

Teagasc
Agriculture and Food Development Authority

Teagasc

Teagasc – the Agriculture and Food Development Authority – is the national body providing integrated research, advisory and training services to the agriculture and food industry and rural communities. It was established in September 1988 under the Agriculture (Research, Training and Advice) Act, 1988.

www.teagasc.ie

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Teagasc Technology Foresight 2035

Teagasc Technology Foresight 2035 focuses on the identification of key technologies that will drive the competitiveness and sustainable growth of the Irish agri-food sector over the next 20 years. Its goal is to identify new areas of technology in which Ireland should invest. It is aimed at the Teagasc Authority, its management and partners. It is also intended to feed into policy at national and EU level.

The full text of this report is available to download as a PDF file from **www.teagasc.ie**, along with all of the project's background papers.

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Preface

Dr. Noel Cawley
Chairman, Teagasc

Farms and processing companies are becoming smarter places. Scientific understanding is ever-increasing. Knowledge is growing. More data are emerging. These developments have propelled the agri-food sector over the last 20 years. But what will shape and influence the farms of 2035?

This Teagasc foresight exercise has canvassed the wisdom of experts and participants in the agriculture and food sectors in Ireland and internationally to report on the collective expectations of possible future developments. In particular, the foresight exercise has focused on the technologies that are likely to have the biggest influence.

Teagasc research has already revealed new information on Ireland's soils and on the genetic composition of the country's livestock. In addition, with our university partners, we are beginning to understand how the microbiota of the human gut can drive the development of new food products and enhance human health and nutrition. Working with public and private sector organisations, we are helping to develop digital technology solutions for Irish farmers and food companies that will enable them to be more competitive and sustainable. But much more needs to be done to enable Irish farmers and food processors deal with the opportunities and challenges of the next two decades.

More knowledge is emerging year-on-year, which if properly captured, anlaysed and interpreted, can be conveniently implemented and utilised by Ireland's farmers and food producers to enhance the quality of the produce. As more information emerges, the ICT tools to cope with "big data" are developing and will become increasingly sophisticated.

Innovative machine engineering has already removed some of the human toil from farming activities in developed countries. Robotic systems are common in processes outside the farm gate and are now making their way onto farms through, for example, robotic milking systems, sensor and GPS-guided machines, and precision agriculture tools. ICT-driven automation of remaining labour-intensive tasks is set to increase exponentially.

Growing knowledge-driven agriculture and food processing are key to economic prosperity in rural Ireland, which must deliver for all players in the chain for production systems to be sustainable. Teagasc has responsibility for the development of the agriculture and food sector and is focused on developing technologies that will assist its profitable and sustainable, growth.

This Foresight Report has identified the technology areas which Teagasc will prioritise in its research programmes to support Ireland's agriculture and food sectors in facing the challenges and opportunities that lie ahead. Connecting with both private and public organisations, Teagasc will work collaboratively to explore these sciences and to transfer the emerging knowledge onto farms through our advisors and educators.

Foreword

Professor Gerry Boyle
Director, Teagasc

Over the past century humanity has benefited from many profound technological transformations. In the developed world, the widespread diffusion of innovations such as electricity, telephones and automobiles has gone hand-in-hand with mass production and mass consumption. All of the evidence points, not alone to the continuation along the path of extensive technologically-driven change, but indeed to an acceleration of the pace of technology-driven change over the next twenty years.

A recent foresight report prepared by the US Atlantic Council[1] envisions more technological change impacting our lives in the next twenty years than in the past fifty. The rate of change in many new areas of technology and resulting innovation is exponential rather than linear. The pace of new technology adoption is also accelerating and progress is happening across a much broader spectrum of technologies.

The technical foundation for this on-going flow of innovation in large part derives from powerful developments in the fields of digital and genetic knowledge. The exploration and manipulation of these two building blocks are likely to open up great opportunities for both tool-builders and users. Indeed, there seems to be a strong virtuous circle between better information and higher performance tools, as each insight provided by digital computation or genetic mapping leads to new ideas about how to design and use technology.

Rapidly emerging new digital technologies, synthetic biology, nanotechnology, among others, will impact almost every sector of the global economy including the most important component of the Irish bioeconomy, our agri-food industry. New tools and techniques will help to better address the 'Grand Challenges' which confront mankind. In particular, new tools will enable the agricultural sector to better tackle the challenges of climate change and wider sustainability concerns while promising enhanced living standards and quality of life for sectoral players.

This is the main message of this Foresight Report. It presents a positive vision for Irish farming, food processing and the rural economy based on more productive, profitable and sustainable primary production; greater added value in the food processing sector built on innovative responses to rapidly changing consumer demands; and new economic opportunities in the rural economy based on the efficient use of waste and the extraction of biological raw materials in a circular bioeconomy.

While the Report identifies strongly with the promise of new science and technology, it also makes clear that there are several risks attendant on the anticipated technological innovations. As has been the case ever since technology was first employed, not only for survival but also for conflict, it is likely to have multifaceted implications, many unforeseen, for society. The technical feasibility of new techniques must be promoted in an overall context that assesses risks and benefits and that takes into account all relevant economic and social safeguards and is fully cognisant of the consumer, not as a passive recipient of all new technologies, but as an active participant in decision-making regarding processes and ingredients used to create food.

Teagasc, by virtue of its statutory mandate to "promote, encourage, assist, co-ordinate, facilitate and review agricultural research", is well-positioned to assume a leadership role in the management of the far-reaching technology-driven change in the agri-food and bioeconomy sector which is envisaged in this Report. Leadership in this case will involve a role of architect of the systems that will serve Teagasc clients of the food, forestry and other subsectors of the bioeconomy. As architect, Teagasc can ensure that services are designed to be affordable and easily adopted by the communities that will use them.

1 The Atlantic Council of the United States, 2013. Envisioning 2030: US Strategy for the Coming Technology Revolution. Washington, DC: The Atlantic Council.

Teagasc will also play the role of coordinator and facilitator, understanding who needs to sit around the table to discuss high-level issues of design, who needs to collaborate and who needs to be informed if the transition to a new technological era is to contribute to both job creation and wealth generation in 2035, especially for the smaller players in the system. Without coordination of the full complement of stakeholders, not just the researchers, it will be very difficult to arrive at a system which creates jobs and equitably distributes the gains realised by the new technologies discussed in this Report.

The Report is positive about the future. As a country, we are blessed with abundant resources for the production of food, bioenergy and other bio-products. We have a strong government commitment to investment in the generation of knowledge, in education and training and in implementing a coherent policy framework for the sector in the shape of the *Food Wise* 2025 strategy. We have an emerging generation of young farmers and rural entrepreneurs who are brimming with confidence to take on the challenges of the future. There is an exciting future to be had in farming and the wider bioeconomy, but that future cannot be taken for granted. Young people need the education, the knowledge and the mind-set to embrace the future. What they require from organisations like Teagasc is the support to enable them to attain, and hopefully to exceed, their ambitions.

This Report could not have been produced without the help of many people, both within and outside Teagasc. All of the individuals and organisations that assisted are listed in the annex, but I would like to mention the exceptional contribution of some individuals.

We were fortunate to have the wisdom, experience and commitment of Mr. Tom Moran, former Secretary General of the Department of Agriculture, Food and the Marine, as the Chairman of the International Foresight Steering Committee. We are particularly grateful to Dr. Lance O'Brien of Teagasc who, in his capacity as Foresight Project Manager, led the project from the outset with enormous energy and dedication, which is reflected in the high quality of the final Report. He was ably assisted by Ms. Jane Kavanagh, also of Teagasc, and by the other members of the Project Management Team who worked behind the scenes and ensured that the process was conducted with the utmost efficiency. A special word of thanks is due to the members of the Technology Cluster Working Groups. These experts were drawn from both within and outside of Teagasc and I am especially grateful to those external members who gave so generously of their time. A key part of the foresight process is stakeholder consultation and we benefited considerably from this interaction in the preparation of the Report. I wish to acknowledge the wholehearted engagement by Teagasc colleagues throughout the organisation and also the input made by the Teagasc Authority in the process that has led to this publication. Finally, I am grateful to our Foresight consultants, Dr. Patrick Crehan and Dr. Owen Carton of CKA.

This Foresight Report is merely the beginning of the engagement that will take place in the years ahead as we implement the strategic directions that are signalled. I look forward to that engagement and especially to the tangible benefits that I expect will accrue to farmers, food processors, rural dwellers and the wider economy and society.

Executive Summary

The agri-food and bioeconomy sector is a very significant part of the Irish economy in terms of jobs and exports. Its long-term competitiveness and sustainability are a priority concern for national policy. Agriculture in particular faces significant challenges in the coming decades, not only in Ireland but also in Europe and elsewhere around the world. On the one hand, it must produce more food for a growing, increasingly affluent global population that requires a more diverse, protein-rich diet. But it must also compete for lucrative new markets, while vying for access to increasingly scarce natural resources, preserving biodiversity, water and soil quality, restoring fragile ecosystems and mitigating the effects of climate change. Agriculture will have to adapt to direct consequences of climate change such as higher average temperatures, more extreme weather events and increased incidences of flooding and crop loss, as well as new plant and animal disease threats. The latter challenge is compounded by the increasing scarcity of appropriate control measures against consistently evolving pathogens and pests.

It is in this context that the long-term future of Irish agriculture and food must be considered. The new industry-led strategy launched in 2015, entitled *Food Wise 2025*, sets out ambitious growth targets while acknowledging the need to deal with many challenges. The continuous development and application of new technologies will be crucial to the realisation of these ambitions. Not only are new technologies needed to increase the productivity and competitiveness of Irish agri-food enterprises, they must also enable all actors of agri-food and bioeconomy value chains to play their part in protecting the environment and mitigating and adapting to climate change.

Teagasc Technology Foresight 2035 Project

Teagasc Technology Foresight 2035 focuses on the identification of emerging technologies that will drive the competitiveness and sustainable growth of the Irish agri-food industry and bioeconomy sector over the next 20 years. Its goal is to identify new areas of technology in which Ireland needs to invest.

Emerging Technologies

A key conclusion of the project is that the agri-food industry is on the verge of a revolution in the application of powerful new technologies. Increasingly rapid, recent advances in ICT and molecular biology, in particular, have the potential to transform the sector. It is essential for the success of the Irish agri-food and related industries that Ireland is a central player in this revolution. Investment in new and existing technologies will play a decisive role in enabling the sector to sustainably intensify production and to grow output, exports and jobs, while respecting the environment.

Technology will enable Ireland to demonstrate compliance with its legally binding obligations to protect the natural capital and reinforce its position as a clean-green producer. Harnessing this transformation will not only enable ambitious increases in the export of world-class agricultural produce, but will also drive the completion of a dynamic circular bioeconomy[2] creating new jobs and new opportunities. It will help to increase profitability throughout agri-food value chains. It will drive exports of smart knowledge-based data-driven services, developed by Irish service providers, to markets in Europe and across the globe.

The big challenge now is to identify which new areas of technology truly matter for the future productivity and sustainability of the sector. Our focus is on those, which when embedded in our existing research and knowledge transfer programmes, will have the greatest potential for economic impact and transformation by 2035 and for addressing key challenges such as the reduction of greenhouse gas (GHG) emissions from our livestock sector. With the aid of more than 200 experts who contributed to the foresight process, and in consultation with industry stakeholders, the following five technology themes have been identified as being the priorities for Irish research and innovation in the coming years:

1. Plant and Animal Genomics and Related Technologies
2. Human, Animal and Soil Microbiota
3. Digital Technologies
4. New Technologies for Food Processing
5. Transformation in the Food Value Chain System.

2 A circular economy is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life.

Plant and animal genomics and related technologies

Over the last ten years, the various fields of the life-sciences and molecular biology have developed a range of new techniques, which are potential game-changers for the agri-food sector. These include next-generation sequencing (NGS), whole-biome sequencing, gene editing and synthetic biology. Teagasc is already a key player with the Irish Cattle Breeding Federation (ICBF) in leading one of the most ambitious programmes in the world in the application of genomics to the dairy and beef sectors. Between now and 2035, these initial efforts will mature to the point that we will use detailed knowledge about the genotype of each animal as inputs to new and better farm management systems, allowing us to produce more and better livestock products at lower cost to the environment and climate. These new management models will also apply to the management of grassland and crops.

Combinations of these new and emerging technologies have the potential to transform the breeding of high-performance animals and crops with valued traits for producers, processors, consumers and the environment. Their full potential is only now coming into focus. Teagasc and its partners will build upon on-going initiatives to develop the services and capabilities needed to exploit the revolutionary new developments that are happening in this domain.

Human, animal and soil microbiota

It has long been recognized that natural environments ranging from soils and grasslands to human and animal digestive tracts contain complex communities of microorganisms. These communities have not only evolved to survive and proliferate in these environments, but they also perform complex higher-level functions in symbiosis with larger living systems. They play an important role in every aspect of agri-food value chains and we are now beginning to better understand their importance for food production, the health and nutrition of humans, animals and soils, as well as for the health of the environment.

Recent advances in computer processing and NGS allow us to study these microbiota at a much deeper level, to understand the bigger role that they play and develop strategies to manage interactions between these communities and the environments they inhabit. We are beginning to see how the microbiota of the human gastrointestinal tract (GIT) can drive the development of new products and services for human health and nutrition, targeting individuals for the management of allergies, intolerances, appetite and weight gain, as well as chronic lifestyle-related conditions such as obesity and diabetes. We are beginning to understand how the microbiota of the rumen in livestock has an impact on feed conversion and rate of emission of GHG. We are also beginning to understand how the microbiota of the soil has an impact on issues such as grassland productivity, nutrient cycling and carbon sequestration. These insights will help us improve the performance of the beef and dairy sectors based on better nutritional strategies for livestock and the grasslands they feed on.

Digital technologies

Digital technologies enable the data intensification of management systems and the automation of tasks such as milking, herd management, feeding, identification of oestrus, weed and plant disease management, as well as the simplification and automation of farm enterprise administration.

The adoption of technologies such as precision agriculture (PA) and robotic milking in Ireland has been slow until now. Arguably, cost and complexity have been prohibitory factors. Existing systems target the biggest producers employing technologically sophisticated personnel. But this will change. Between now and 2035 we will see the large-scale adoption of automation based on sensor-rich, data-intensive systems using nanotechnologies connected via the IoT (internet of things) and the IoFT (internet of farm things), as well as autonomous vehicles and drones, tractor-based sensing and micro-satellite deployments, as well as robotic systems for the handling of delicate produce such as fruit and vegetables. Farmers will do more and better with lower labour inputs. This will be facilitated both by the rollout of next generation network broadband and the growing impact of the digital economy in many other economic sectors.

New technologies for food processing

Between now and 2035, the food industry will continue to perfect advanced methods for fractioning, preserving and formulating innovative, safe and natural food products. These will increasingly exploit insights from our understanding of food chain microbiota. The biggest transformations, however, will be driven from the consumer end of the value chain, as data about needs and preferences for nutrition, convenience and lifestyle, flow from consumers to actors in retail, distribution and food service, to secondary and primary processors, all the way to growers and producers.

One of the challenges for the food industry is to offset potential losses of revenue associated with the elimination of food waste, which corresponds roughly to one third (approximately 1.3 billion tonnes) of global food production, with new sources of revenue based on value added services for convenience, lifestyle, health and nutrition. Individuals vary so much in terms of their lifestyle that there is considerable scope for improvement in terms of better nutrition and reduced waste. Technologies such as 3D printing and advanced robotics, combined with big data from smart wearables and data based on the personal gene type of consumers, will enable the food industry to augment the products they provide with value added services targeting the specific needs of individuals and micro-segment consumer groups.

Transformation in the food value chain system

The supply chains and value chains of the agri-food industry and bioeconomy in 2035 will be very different from those we know today. They will be much more knowledge-intensive involving the trading or exchange of vast quantities of data to drive more productive resource-efficient operations and services. They will reorganise based on principles of the circular economy, the dominant growth paradigm at EU level for sustainable industrial and economic development. They will employ economic and business models very different from those employed today. Enabled by low cost sensors connected via the IoFT, they will make more use of technology. They will avail of a larger range of knowledge-intensive services. Many will enjoy new sources of revenue. Practices such as collaborative farming and leasing might be more widespread and more sophisticated in approach. New actors will emerge focused on the processing of biomass and organic waste, not only from agri-food production and processing but also from forestry, paper, food retail, food service and domestic consumption. They will produce a wide range of products, biofuels and green chemicals, composts, animal feeds and food additives, as well as high-value molecules for food, pharma and cosmetics.

The Teagasc Vision for Technology-Driven Transformation

In 2035, the Irish agri-food and rural economy will have been transformed by a series of new systems and services enabled by the convergence of new technologies from the fields of ICT, biotechnology, nanotechnology and molecular biology. Teagasc, along with its partners, will play a key role in this transformation as architect of these new systems and as instigator of the partnerships and collaborations needed to make them happen. These new services will have boosted the prosperity of farmers, processors and other agri-food and bioeconomy entrepreneurs while respecting the most rigorous international standards around climate change and protection of the environment.

Implementing the vision

Teagasc is currently working with its partners and stakeholders to develop long-term research and knowledge transfer programmes which reflect the five priority areas of technology identified. The ‘smart farming ecosystem’ of the future will involve a complex range of players in the public and private sectors.

Partnering and collaboration are needed more than ever to understand and integrate the diverse new sources of knowledge and data that will drive new services, systems and management practices. These will enable growth based on sustainable intensification, while addressing the policy and regulatory issues that will arise, in addition to the concerns of consumers and citizens in Ireland and its export markets.

Teagasc is well-positioned to assume a national leadership role, establishing research and innovation platforms to act as vehicles to ensure the timely development of national roadmaps for each of these priority domains. Leadership in this case will involve a role of architect of the systems that will serve Teagasc clients and other stakeholders. As architect, it can ensure that services are designed to be affordable and easily adopted by the communities that will use them, while addressing the concerns of consumers and other potential barriers to adoption of these new agri-food and bioeconomy technologies.

As with all scientific and technological advances, end-user acceptance of new technologies cannot be assumed. Consumers have resisted such developments in the past for cognitive and emotive reasons, with enormous cost implications. The social sciences have an important role to play in integrating science and technology push with demand pull (e.g. through supporting on-going engagement with consumers and citizens as technologies progress through research commercialisation phases). Social science needs to be integrated into the design, development and implementation of new technologies to help find solutions to industry and societal needs. This will support informed consumer decision-making and help to ensure that technologies that offer significant benefits to society as well as the economy are not rejected out of hand.

01
Introduction

1. Introduction

Ireland's Agri-Food Industry and Bioeconomy[3]

Ireland's agri-food industry and broader rural economy are changing rapidly, driven by global trends and policy developments, combined with a range of non-monetary catalysts including concerns over food security and safety, health, natural capital, energy, climate change, demographic change, advances in science and technology and globalisation among others.

We have come to the end of the supply-driven market epoch to an era steered by wider market demands for competitively priced food products of required quality and safety and produced in a sustainable manner. This challenge is set against greater societal demands on land, not only for food production, but also for the provision of housing, roads, recreation and feedstock for a range of non-food products. Society also expects that all of these demands will be met simultaneously with the conservation of water, air, soil, and biodiversity resources.

The agri-food sector continues to play an integral part in Ireland's economic recovery and is our largest indigenous industry, contributing €26 billion in turnover and generating 12.3% of merchandise exports in 2013. The sector accounts for around 170,000 jobs, or 9% of total employment, and makes a particularly significant contribution to employment in rural areas. Food and beverage exports recorded an estimated increase of 3% in 2015 to exceed €10.8 billion for the first time. The sector recorded its sixth consecutive year of export growth in 2015 and has been a driving force in our economic recovery since 2009, delivering a cumulative export growth of 51% over that period.

In 2015, the Department of Agriculture, Food and the Marine launched a new industry-led national strategy- *Food Wise 2025*. This strategy outlines an ambitious vision for 2025 and highlights a range of actions needed to ensure that the industry realises the many opportunities in expanding global markets while also addressing difficult challenges, particularly that of sustainability.

Indeed, future prospects remain positive. The underlying trends in population growth, expansion of the middle-class in emerging markets and increasing urbanisation will continue to underpin the expansion in global food demand well into the future. At the same time, the abolition of dairy quotas and the continued widening of market access for our beef industry have dispelled some of the constraints that have restricted our industry's capacity to exploit the opportunities generated by expanding export markets.

3 While the term bioeconomy encompasses the agri-food sector, in an Irish context, the latter accounts for all of the bioeconomy, so we will use the terms interchangeably.

Dairy farming remains Ireland's most profitable farming system and notwithstanding the extreme price volatility witnessed in recent years, Irish dairy farmers are among the most economically competitive and carbon efficient farmers globally. While dairy farmers are well set to exploit the opportunities arising from quota removal, this is in stark contrast to the other farm sectors. The beef farm sector continues to be characterised by very large numbers of small producers, some part-time, with comparatively low farm incomes and a very high reliance on direct payments as a source of income. Innovation and technology adoption rates remain low on many small and part time farms, with little incentive to innovate given the high reliance on direct payments. Improving the productivity and profitability of these farms will be a persistent challenge for both research and knowledge transfer over the next ten to twenty years. Following a number of years of contracting sheep flock numbers across Europe and Ireland, the economic situation on sheep farms has improved recently. However, as with the beef sector, reliance on direct payments is still very high. While tillage farms in Ireland are large (in area) relative to beef and sheep farms, they are small by international standards. They have been particularly exposed to price volatility in recent years with a number of very difficult years of low-to-negative margins.

Science and Technology and the Role of Teagasc

The last decade has seen consistent and considerable public and private investment in science, technology and innovation in Ireland. As a result, the country has established a strong base of research expertise and research excellence in a number of strategic areas. The Government is committed to building on this investment under *Innovation 2020: Ireland's Strategy for Research and Development, Science and Technology*.

The agri-food and bioeconomy sector has benefited from the commitment to public science and innovation. The sector was identified as a priority area under the 2011 Report of the Research Prioritisation Group, which made recommendations to Government on areas of focus for the next phase of Ireland's science, technology and innovation strategy. Following this, the research and innovation agenda for the sector was identified in the *Sustainable Health Agri-Food Research Plan* (SHARP). The agri-food sector is identified in *Innovation 2020* as an area for investment in order to:

- Progress the economic development and enhance the competitiveness of the sector, focusing on efficiency and profitability
- Become a recognised world leader in sustainable, scientifically verified food production and capture new market opportunities
- Promote and enhance the already high standards of food safety, consumer protection, animal health and welfare, and plant health, and
- Become a consumer orientated industry, with incremental and significant innovations in food.

Innovation 2020 also supports the development of a national bioeconomy strategy.

Teagasc is expected to play a lead role in advancing these priorities as the independent government agency with a statutory role in the provision and coordination of research, education, training and advisory services for the Irish agri-food sector. Teagasc is committed to playing this role in support of *Innovation 2020* and all other relevant Government policies by working in partnership with other research and knowledge providers in Ireland and internationally.

Need for New Science and Technology to Transform the Agri-Food and Bioeconomy Sector

Continuing advances in science, technology and innovation will be central drivers of profitable and sustainable agri-food and bioeconomy industries into the future. However, the emergence of more competitive international commodity markets, the changing demands of consumers and priorities of policy makers and the development of a range of new market opportunities in the bioeconomy demand the introduction and more effective dissemination of existing and new science and technology solutions.

Agricultural and food research will be asked to address issues that require both multi- and inter-disciplinary responses and which focus more on enhancing the innovative capacity of the sector. This means supporting

the development of new ways to generate wealth, reduce input costs, add value, strengthen sustainability and resilience and develop new competitive and comparative advantages. This, in turn, will require new ways to optimise national science capacity, focusing on R&D collaboration across the supply chain and increasing the emphasis on technology transfer and commercialisation.

Emerging technologies that could transform the agri-food industry and bioeconomy

The world is on the cusp of the emergence of a set of new technologies which has the potential to transform economic activity and social relations and create new industries and services, including in the agri-food sector. Use of technologies like satellite imaging, digital sensors, advances in plant and animal genomics and advanced data analytics could lead to farming practices that are more productive, more precise in their deployment and thus more sustainable. Some of these technologies are already changing the agri-food sector, while others when scaled up, have the potential to truly revolutionise how our food is grown, processed, distributed and consumed.

Many game-changing 'Smart Agriculture' technologies are not yet available at commercial scale. According to research by Accenture[4], applications are currently only partly implemented, if at all, and mainly in developed countries on large farms. The vast majority of smallholders are yet to adopt these technologies. However, Accenture expect that in a decade's time, these and many other technologies will penetrate deeper into global food supply chains. What is needed to facilitate global Smart Agriculture is comprehensive access to high-speed internet and affordable smart devices. Although not available everywhere today, these technologies are expected to be near ubiquitous by 2035.

It is of the utmost importance that all of the stakeholders in the Irish agri-food and bioeconomy sector begin to prepare now for the widespread deployment of transformative technologies in the sector. Such techniques are capable of enabling

4 Vodafone and Accenture, 2011. Connected Agriculture: The Role of Mobile in Driving Efficiency and Sustainability in the Food and Agriculture Value Chain. London: Vodafone.

innovation and change at an exponential pace and of producing both benefits and risks. Surprising and abrupt changes will become more commonplace. Preparing for the disruptive and the surprising, and creating the future we want, will demand agility, resilience and an ability to anticipate alternative futures[5]. Foresight is a critical tool in helping us deal with these challenges.

Teagasc Technology Foresight Project

As the national organisation with the statutory remit for the development and dissemination of the agri-food industry and bioeconomy sector's technology needs, Teagasc in association with its partners, has a responsibility to invest not only in developing short-term solutions or technologies, but also in making strategic investments in ground-breaking research that has the potential to enhance the performance of Irish agriculture and food in the longer term. Foresight can help us to successfully undertake this task.

The Teagasc Technology Foresight Project 2035 is a follow – up to *Teagasc 2030,* the foresight project completed in 2008[6]. This new project focuses specifically on the identification of the key technologies that have the potential over the next 20 years or so to underpin competitiveness, innovation, market responsiveness, sustainability and growth in the Irish agri-food and bioeconomy sector.

The overall objective is to analyse the plethora of emerging technologies in order to provide a comprehensive and well-researched source of evidence for policy decisions relating to Teagasc's future science and technology programmes. It aims to assist Teagasc in identifying the new areas of technology which it should prioritise for the long-term and the resulting implications for investment in new programmes, skills, equipment and infrastructure.

The process also brought together a wide diversity of experts from different backgrounds to explore new ideas and to achieve consensus on the long-term challenges confronting the Irish agri-food and bioeconomy sector and its future technology needs. The primary user of the project outputs will be the Teagasc Authority. It is expected that the results will also feed into wider national and EU policy making.

Approach to the Study

The Project was initiated in December 2014 and was completed over the following fifteen months with the following Terms of Reference:

- Review, analyse and report on relevant existing and on-going foresight studies
- Analyse the main national and international drivers of change that will impact on the Irish agri-food sector up to 2035 and prepare a profile of the sector, including key trends, challenges, threats and opportunities that are expected to arise
- Prepare an initial technology scoping study which will identify, at a relatively high level, technologies that could be of long-term relevance to the Irish agri-food sector
- Using different foresight methods, conduct detailed analyses of the new technologies identified in the scoping study to identify the critical technologies to be prioritised in order to underpin the future competitiveness and sustainability of the Irish agri-food sector
- Present the results in a report and at a national foresight conference.

The project directly involved around 200 leading national and international experts drawn from a broad range of scientific disciplines and academic institutions. In addition, a large group of industry and policy stakeholders from within the Irish agri-food sector contributed.

A **Steering Committee (SC),** comprising national and international representatives from government institutions, industry and universities, was responsible for guiding the project. The SC was assisted by a number of **Technology Cluster Working Groups (TCWG),** which were responsible for undertaking the detailed technologies assessments. Each of these groups was chaired by a Teagasc staff member and all

5 Garrett, B. 2015. Technology will keep changing everything-and will do it faster. Washington, D.C.: The Atlantic Council.

6 Teagasc, 2008. Towards 2030: Teagasc's Role in Transforming Ireland's Agri-Food Sector and Wider Bioeconomy.

comprised a mix of Teagasc and external experts. A **Foresight Expert Panel,** comprising the chairs and *rapporteurs* of the individual Cluster Groups, was responsible for developing the foresight knowledge base and detailed guidelines for the work. The exercise was also supported by a Teagasc **Project Working Group,** which undertook the day-to-day management of the project. An external **Consultant** provided expert foresight input.

The main work of the project was completed by the TCWGs in six day-long workshops held between May and December 2015. These working groups were responsible for:

- Identifying breakthrough technologies
- Developing an inventory of new and emerging technologies
- Developing preliminary scenarios
- Agreeing a vision for the transformative role of technology in Irish agri-food and bioeconomy, and
- Identifying the actions needed to implement the vision.

Their work was complemented by written and verbal inputs from a wider network of experts from Ireland and abroad, by the outputs of two day-long stakeholder workshops and by invited public submissions. This final report represents a distillation of these various inputs.

02

Ireland's Agri-Food and Bioeconomy

Challenges and Opportunities to 2035

2. Ireland's Agri-Food and Bioeconomy: Challenges and Opportunities to 2035

Ireland's agri-food industry, while being firmly embedded in local rural economies right across the country, is now also highly integrated into the global food system through its success in meeting consumer needs in more than 170 markets around the world. Its continued growth and success will be heavily influenced by global demographic, economic and environmental drivers. The sustainable intensification of the farm sector will be both a key challenge and opportunity. Ireland's green credentials are already an important success factor on export markets and it will be imperative that any output growth in the sector will be achieved in a sustainable manner.

The global context for Irish agriculture and bioeconomy is changing rapidly, introducing both challenges and opportunities for an industry that seeks to strengthen its global reach and become a leader in sustainable food production and processing. This chapter will briefly explore some of the key drivers that are altering the landscape of food and non-food systems within which Irish land-based production and food processing are conducted. It also identifies the existing and new opportunities that will provide a platform for a vision of a technology-enhanced and sustainable sector by 2035.

Sustainability Challenges

Climate Change

Drawing on the most recent scientific evidence, the Intergovernmental Panel on Climate Change has concluded that global warming will continue to have severe, pervasive and irreversible consequences in most parts of the world[7]. In the absence of adaptation, some climate change scenarios project reductions of up to 30% in yields of rain-fed maize in developed countries to 2050, up to 18% in yields of irrigated rice in developing countries, and up to 34% in the yield of irrigated wheat[8]. Furthermore, yields will become more volatile with year-on-year variability growing by 50% by 2050[9]. Consensus is emerging that in the face of climate change significant mitigation and adaptation measures will be needed to maintain and enhance the natural capital needed to ensure the delivery of the productive capacity of global agriculture.

Agriculture, including land use change, is a significant contributor to global GHG emissions. Annual total emissions from agriculture in 2010 were estimated to have equated to 10-12% of global anthropogenic emissions. Deforestation, which is often associated with the expansion of the agricultural land use area, is accounting for 12% of emissions.

7 Fifth Assessment Report of the Intergovernmental Panel on Climate Change. See: http://www.ipcc.ch/report/ar5/wg3/.

8 FAO. 2011a. *The State of World's Land and Water Resources for Food and Agriculture (SOLAW) – Managing systems at risk*. Rome, FAO, and London, Earthscan.

9 Challinor, A. *et al.*, A meta-analysis of crop yield under climate change and adaptation. *Nature Clim. Change,* 4: 287-291 (2014).

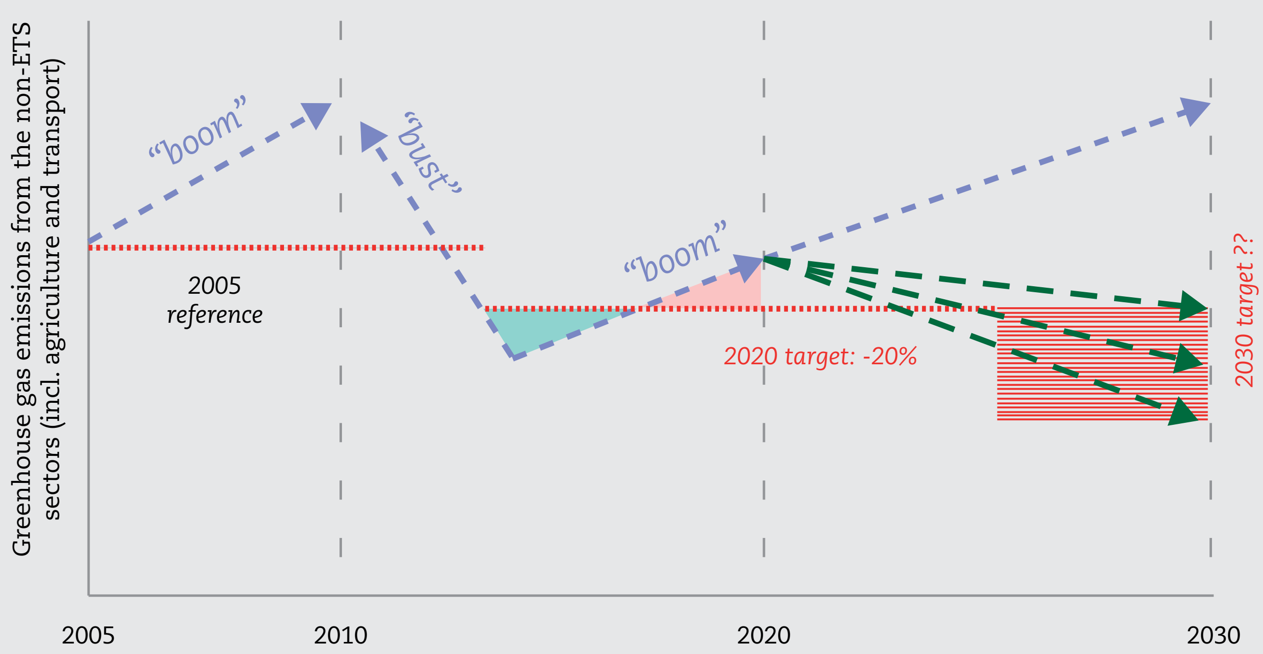
The national policy agenda on reducing GHG emissions from agriculture is shaped by the EU policy on climate and energy for 2020. The two main EU policy instruments are 1) the Emissions Trading Scheme (ETS), which applies mainly to large companies, and 2) the Effort Sharing Decision (ESD) for sectors that are not part of the Emissions Trading Scheme (known as the non-ETS), which includes agriculture.

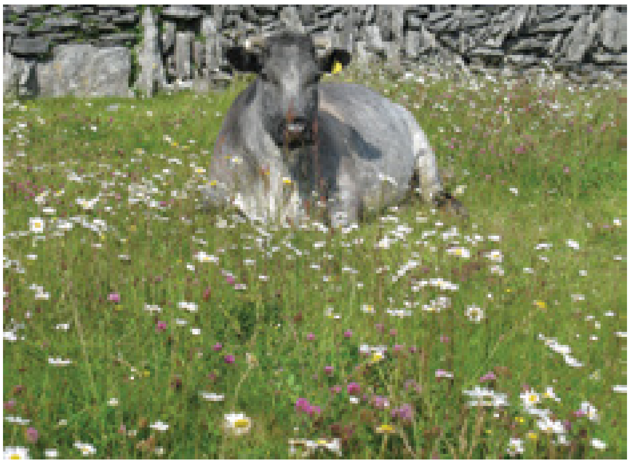
Under the EU Climate and Energy Policy for 2020, Ireland is required to reduce its GHG emissions from the non-ETS sector by 20% during the 2013-2020 commitment period, compared to the reference year of 2005. For the period post-2020, the EU is currently developing proposals for a Climate and Energy Framework for 2030. Whilst the national reduction target for 2030 for Ireland has yet to be agreed on, one thing is certain: this target will not be more lenient than the 2020 target.

Figure 2.1 shows that this will have significant implications for Ireland's non-ETS sectors. This figure shows the following:

- Ireland's non-ETS emissions grew rapidly between the reference year 2005 and 2010, but subsequently collapsed as a result of the recession.
- Aligned to the economic recovery, Ireland's non-ETS emissions are now growing again, albeit at a slower pace than during the "Celtic Tiger boom".
- As a result, emissions in 2020 are projected to be higher than the 20% reduction required under the ESD.

Figure 2.1: Free-style illustration of the '2020 cliff'





- However, the commitment period for the ESD applies to the period 2013-2020. During the earlier part of this 7-year period, emissions were below the 20% reduction. While this early 'undershoot' (green triangle) may not completely compensate for the later 'overshoot' (red triangle), the net difference is projected to be small.
- More significantly, non-ETS emissions are projected to continue to grow post-2020 under a business-as-usual scenario (blue dashed arrow)
- However, regardless of the *exact* reduction target that will be assigned to Ireland's non-ETS sector, emissions will need to be reduced significantly and on an on-going basis between 2020 and 2030.
- The difference between the most likely emission trajectory (blue dashed line) and the required trajectory (any of the green dashed lines) is known as the '2020 emissions cliff'.

In summary, the '2020 cliff' means that, whilst non-compliance with EU targets will be small up to 2020, the emissions from the non-ETS sector are on the wrong trajectory for 2030. Moving away from a business-as-usual scenario requires a decoupling of emissions from economic growth, which, in turn, will require a rethink of technologies.

Natural Capital and other Resources

Scarcities and declining quality of natural capital, such as water, air, soils and biodiversity, are a continuing cause of concern in the context of agricultural production. This arises from both the reliance of agricultural production systems on these resources and the effects they may have on fragile ecosystems. Expansion and intensification of agricultural land use have been major contributors to not only reductions in water, air and soil quality, but also to terrestrial biodiversity loss. With continuing growth in the demand for agricultural products, pressure will remain for further increases in land use for agriculture, thereby maintaining pressure on natural capital. Moreover, new challenges are emerging in terms of disease and pest controls in important agronomic crops and animal species, while the supply of energy and basic raw materials for fertiliser remains a concern.

Agriculture is the world's largest user of freshwater, accounting for 70% of global freshwater use[10], although there are large differences in water use between regions and farming systems. A large proportion of the projected increase in global agricultural production is likely to be derived through new irrigation initiatives, with potentially negative consequences for local groundwater or riverine water balances. In more temperate regions, the interface between agriculture and water is predominantly defined by the impact of farming on the quality of drinking water and surface waters. Here, the prevention of eutrophication, caused by excess nutrient losses to water, represents one of the main challenges to sustainability.

In relation to biodiversity, agriculture occupies 38% of the world's land surface[11] and competes for space with other land uses, most notably with ecological habitats, but also with urban and infrastructural land use. As a result, if increased food production were to be achieved through an expansion of the global agricultural area through a process of land use change, this would likely

10 Evans, A. 2009. The Feeding of the Nine Billion: Global Food Security for the 21st Century. A Chatham House Report. London: The Royal Institute of International Affairs.

11 FAO, 2013. Statistical Yearbook 2013. World Food and Agriculture. Rome: FAO.

pose challenges to the preservation of ecological habitats and their associated biodiversity.

A major emerging challenge to sustainable crop protection in the future will be the increasing scarcity of appropriate control measures (be they genetic or chemical based) against consistently evolving pathogens and pests. Crop diseases such as potato late blight and septoria blotch of wheat are constantly evolving against fungicidal chemistries and/or genetic resistance bred into commercial varieties. However, irrespective of what disease is targeted, the increased and/or repeated usage of a specific therapeutic will greatly increase the risk of resistant strains emerging. Indeed, the same scenario is occurring in regard to the emergence of herbicide tolerant weed biotypes.

A cursory examination of crop science literature clearly illustrates the point, highlighting the degree to which novel disease strains, insect pests and weed biotypes have emerged, with demonstrated resistance or insensitivity to crop protectant programmes. While growers bear witness to this phenomenon of evolution on a regular basis, it is clear that the current dependency on chemical protectants is becoming, or indeed has become unsustainable. This is all the more likely where legislative directives (Water Framework Directive 2000/60/EC and Drinking Water Directive 1998/83/EC) seek to reduce the availability of effective pesticide active substances. While seeking to reduce the potential occurrence of chemical residues in water systems-and ultimately in the food chain-is fundamentally logical, it has been predicted that this approach will have a negative impact on crop protection measures, because a reduction in the availability of active chemistries will lead to an overuse of the remaining compounds. Hence, this will drive the evolution of resistance in pest/pathogen/weed populations for the remaining active chemicals.[12] Such a scenario will seriously undermine the viability of several crop systems, if alternative measures of disease mitigation are not identified and integrated into crop rotations.

Accordingly, there is an increased need to develop integrated pest control measures that incorporate genetic resistance supported by chemical and/or agronomic interventions. Biotechnology has a crucial role to play in

this integrated approach through the use of new techniques of molecular biology and networks of sensors.

Antimicrobial resistance (AMR) in livestock production is also a major global public and animal health issue of increasing concern. If pathogens develop resistance, the antimicrobials will stop working, animals will not respond to treatment, performance will suffer and death or other losses may increase. Furthermore, antimicrobial resistant livestock pathogens may be able to pass their resistance on to human pathogens. This would result in antimicrobial drugs not being as effective in treating human infections as well. Similar issues are emerging in relation to animal parasites, particularly those inhabiting the gastrointestinal tract of animals. Accordingly, there is also a need in animal production to develop alternative strategies for parasite control to deal with both long-established and new/emerging parasitic diseases, in the context of changing husbandry systems, climate change and increasing resistance to anthelmintics.

Fossil fuel resources, a major input in agri-food production and processing, are considered uncertain in the longer-run future. The International Energy Agency notes growing fears regarding energy security in the medium and longer term, related to rapidly growing energy demand in emerging and developing countries and persistent uncertainties regarding Middle-East developments[13]. In light of the significance of energy in agricultural production costs (both related to energy as a direct input in agricultural production and as a driver for other input markets, such as fertilisers and chemicals), and the increased use of agricultural

12 Jess S, Kildea S, Moody A, Rennick G, Murchie AK and Cooke LR, European Union policy on pesticides: implications for agriculture in Ireland. *PestManag* Sci 70:1646–1654 (2014)

13 International Energy Agency, 2014. World Energy Outlook 2015. Paris: International Energy Agency.

biomass for fuel generation, such uncertainty is transmitted into the food and agriculture system.

Raw materials for basic fertilisers, such as phosphorus and potash, are concentrated in a limited number of countries. Production of potash is limited to 17 countries, with Canada, Russia and Belarus accounting for almost two-thirds of global supply in 2012[14]. Most countries completely rely on imports for this essential crop nutrient. To a lesser extent, this is also the case for phosphorus, for which the FAO reports 59 producing countries in 2012.

Food & Nutrition Security

Food and nutrition security is one of this century's key global challenges and has positioned the development of sustainable food production and processing systems at the top of the international agenda. The growing global population, increasing urbanisation and rising incomes will not only increase the overall global demand for food and agricultural products, but also lead to a greater demand for higher quality and processed food.

According to UN forecasts, the world population is increasing by over 80 million people per year. Most of this growth is occurring in emerging economies and developing countries, with Africa as the continent with the overall fastest growth. By contrast, population growth in most OECD countries today is low or even negative. While global food demand is growing, the opportunity for growth is switching towards the developing world. In addition, global GDP is increasing at the rate of 3.8% per year in real terms, with the OECD economies increasing at a much slower rate than non-OECD economies[15]. The UN projects that by 2050 the world will have to feed an additional 2.38 billion people, an extra billion of whom will be in the global middle – class income bracket of $10-$100 per day. All of these trends point towards a continued change in global consumption patterns towards diets that are richer in animal protein and sugar. The FAO, therefore, predicts a need for a 60% increase in agricultural production by 2050 compared to 2007, mainly driven by growing demand for livestock products[16].

It is estimated that as many as one–in-nine of the world's population is undernourished due to consumption of insufficient amounts of high quality protein. Global demand for protein will increase substantially between now and 2035, driven not only by basic nutritional needs of a growing population, but also by growth of a global middle-class population that will increase its intake of high quality proteins, in particular from consuming increased quantities of beef, poultry, fish and advanced dairy products.

Consumers in the developed world are increasingly concerned about living more sustainable lifestyles. The production, processing and distribution of food are but one part of this, convenience, health and nutrition being others. Aspects such as food safety, quality, traceability and health-promoting properties of food will all become more important as the sustainable lifestyles trend gains momentum. It is likely that there will be increasing policy interventions in relation to food production and consumption as governments seek to improve public health, promote healthy aging and address issues such as sustainability.

As well as increasing the quantity and quality of food required globally, these trends will also have an impact on supply chain dynamics and, by 2035, supply chains may depend as much on autonomous vehicles and drones as they do on generic white vans today. These trends will have an impact on agri-food value chains and producers and processors will need to be aware of requirements that filter back from consumers.

The reduction of food waste is another major challenge. Post-harvest losses are currently estimated at 33% worldwide, with waste and losses occurring in production, storage, transportation and processing, from the retail sector and by consumers. The

14 FAO, 2014. Statistical Yearbook 2015. World Food and Agriculture. Rome: FAO

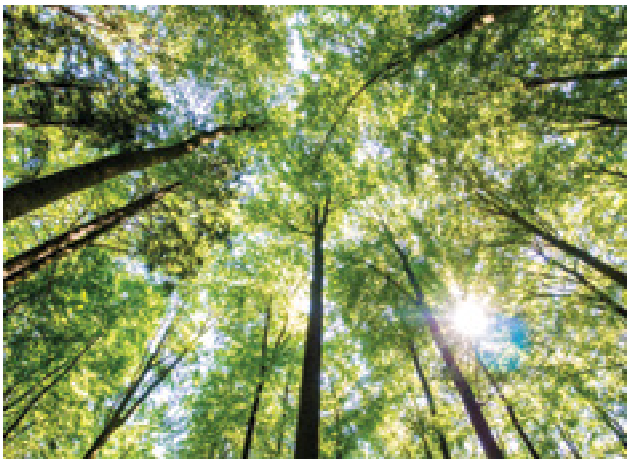
15 OECD, 2014a. OECD Economic Outlook, Vol. 2014, Issue 2, No. 96, November 2014. Paris: OECD.

16 FAO, 2012. World Agriculture towards 2030/2050, the 2012 Revision. Rome: FAO.

elimination or reduction of such losses has important implications for the environment and for resource efficiency of agri-food systems. In the meantime, there are opportunities for waste reduction using circular economy principles, but this may involve the development of a suitable bioreactor infrastructure by public sector authorities, perhaps on the basis of Public Private Partnerships. This represents a new area of research. Research on how to minimise food wastes during food processing, transport and retail is required, while options for recycling and reuse (e.g. composting and bioenergy) should also be further explored along with related health issues[17].

The Circular Economy

The Europe 2020 Strategy for smart, sustainable and inclusive growth identifies a resource efficient Europe as one of its flagship projects. The circular economy concept is viewed as the necessary response to achieving the resource efficiency goal of Europe 2020 and promoting long-term sustainable growth. This concept represents a departure from the current linear model of resource use (take-make-consume and dispose) which presupposes that resources are plentiful, accessible and easily disposed of. Switching to the circular economy model puts the emphasis firmly on reusing, repairing, refurbishing and recycling existing raw materials and finished products. The aim is to maintain the added value in products for as long as possible and eliminate waste.



The magnitude and complexities of these interrelated challenges is such that five of the 17 Sustainable Development Goals of the United Nations (http://sustainabledevelopment.un.org/) are devoted, either directly or indirectly, to the sustainable use management of land in delivering goods and services required by mankind. The five goals are:

- **Goal 2**: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
- **Goal 6:** Ensure availability and sustainable management of water and sanitation for all
- **Goal 7**: Ensure access to affordable, reliable, sustainable and modern energy for all
- **Goal 13**: Take urgent action to combat climate change and its impacts
- **Goal 15**: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

These multiple demands have given rise to a situation where land is becoming a constrained natural resource, which necessitates prudent management from the local scale (e.g. farm management) to global scale (e.g. governance).

17 Scientific Advisory Board, 2010. Agriculture, Food Security and Climate Change. Joint Programme Initiative (FACCE JPI). Scientific Research Agenda.

The Need for Transformation and Systemic Change

Policy makers and scientists are in broad agreement that the world cannot adopt a business-as-usual approach to producing the additional food needed by a growing and wealthier world population. Ireland has the capacity to contribute to reducing world food and nutrition insecurity. Major opportunities are being created for Irish agri-food businesses which are capable of expanding and innovating to service the demands of consumers who value quality, taste and origin of their food. The realisation of these opportunities requires the development of a knowledge-based, sustainable, and secure food system, embracing social, environmental, health and economic goals, as well as new policies, systems and procedures, and the evidence base to support marketing strategies.

The UK Foresight on the future of food and farming concludes that "***to address the unprecedented challenges that lie ahead, the food system needs to change more radically in the coming decades than ever before, including during the Industrial and Green Revolutions***"[18].

Ireland will have to focus on options for increasing the efficiency of farm-level output and use of our natural capital. Actors all along the agri-food and bioeconomy value chain will need to play their role in improving the efficiency of both the quantity and quality of outputs, enhancing the protection of natural capital and reducing waste. To achieve this, two things are essential:

- The development of new technologies to increase productivity, increase sustainability and enable superior management practices
- The widespread adoption of existing and new practices by the greatest number of producers and agri-food actors.

Sustainable Intensification

In response to these challenges, new high-level conceptual models of global food production have been developed, including that of 'sustainable intensification'[19]. Sustainable intensification refers to increasing total food production from the current global agricultural land area, thus preventing increased competition for land with ecological habitats. In the strictest sense of the term, sustainable intensification additionally implies increased production without increasing total inputs of resources such as nutrients, pesticides and energy. In a wider interpretation, it means increased production without increasing relative resource input rates, e.g. nutrients and pesticide quantities per unit food produced.

Food Wise 2025 advances a strategic plan for the sustainable development of the Irish agri-food and bioeconomy sector over the next decade. The Strategy sets a vision for Ireland's food industry as a leading exporter of quality food products, characterised by growing sales to an increasingly diverse range of markets and with a greater proportion of exports accounted for by high value-added products.

18 The Government Office for Science, 2011. Foresight. The Future of Food and Farming. Final Project Report. London: The Government Office for Science, p.176.

19 Godfray, C. *et al*. Food security: The challenge of feeding 9 billion people. *Science*. 2010 Feb 12; 327(5967):812-8. doi: 10.1126/science.1185383. Epub 2010 Jan 28.

Food Wise 2025 has set the following growth targets:

- Increasing the value of agri-food exports by 85% to €19 billion
- Increasing value added in the agri-food, fisheries and wood products sector by 70% to more than €13 billion
- Increasing the value of primary production by 65% to almost €10 billion
- Creating an additional 23,000 direct jobs in the agri-food sector all along the supply chain from primary production to high valued added product development.

Achieving these targets will require increased growth in the volume of primary output. This, in turn, will put pressure on Irish producers to demonstrate an increasingly high level of performance in terms of the impact of their activities on the environment, in particular, regarding the contribution to global climate change.

Food Wise 2025 sees sustainability as an opportunity for farmers and the companies they supply to increase their marketability based on the demonstrable sustainability of the production system. Realising and demonstrating this in a way that is credible to consumers will require the application of a range of new technologies enabling advanced management practices at every stage of the supply chain. It will also require a deeper embedding of production systems in a broader rural economy of services based on the processing of organic matter organised in accordance with the principles of a circular economy.

We should have no illusions about the magnitude of the challenge ahead. Making sustainable intensification a reality will rely on the full implementation of each of the many recommended actions of the *Food Wise 2025* Strategy. This requires the pursuit of new science, technologies and tools for farmers and processors through investments in research. It necessitates a collaborative approach between farmers, advisors, researchers and other stakeholders such as consumer and environmental organisations. This principle of working together should operate, not only at national level but also internationally.

An enabling policy environment only results in sustainable intensification if it goes hand-in-hand with improving practices at farm level. There is an urgent need for additional knowledge transfer initiatives to further enhance farm efficiency. Equally, there is an important role for policy to encourage farmer adoption of knowledge and emerging technologies to achieve the challenging sustainable intensification goals.

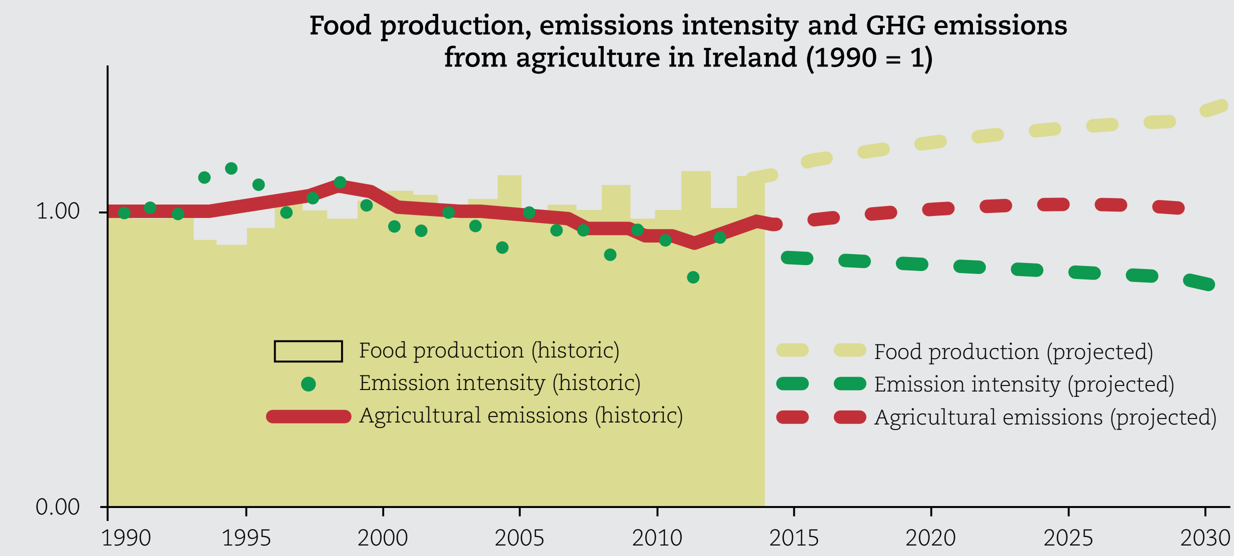
The Sustainability of Irish Agriculture

Over the last ten years, sustainability has become increasingly integrated into the Irish agri-food sector. Where previously 'environmental protection' was considered a constraint to agriculture and food production, the efficient and sustainable use of natural capital is now considered a key driver of growth. We see this new narrative in a wide range of initiatives that would have been considered utopian in the not-so-distant past: the farmers' organisations have teamed up with the Environmental Protection Agency and Teagasc in the 'smart farming' initiative. Many Irish food processors are rolling out ambitious sustainability programmes in collaboration with their suppliers. Bord Bia's Origin Green initiative uses Ireland's 'green credentials' internationally as the unique selling point of Irish produce.

The mainstreaming of sustainability is also evident in the policy process: the new *Food Wise 2025* strategy (page 4) states: *"A guiding principle that Food Wise 2025 will seek to embed at all levels of the agri-food industry is that environmental protection and economic competitiveness are equal and complementary: one will not be achieved at the expense of the other."* Key to achieving this 'parity of importance' between environment and economics is Sustainable Intensification, which "*leverages the strengths of the sector by improving productivity while using natural resources in a manner which protects them into the future.*"

The contemporary challenge for research and for the industry is to turn this laudable objective into a reality. The good news is that Irish agriculture has got smarter. As a country, not only are we now producing more food than ever before, we are also producing it more efficiently. These gains in efficiency are largely driven

Figure 2.2: Food production, emissions intensity and GHG emissions from agriculture in Ireland



Note: while the greenhouse gas emission intensity of Irish produce continues to fall, total emissions are projected to remain static, due to increased food production.[21]

by knowledge and data[20]. This 'knowledge intensification' of Irish farming is now beginning to show results: each plate of Irish food was produced with 25% less nitrogen inputs and with 15% lower GHG emissions than the same plate of food in 1990.

These gains in farm efficiency have contributed to halting the decline of the water quality of our rivers. Similarly, total GHG emissions from agriculture have been remarkably stable, considering the higher output levels (Figure2.2). As a result, it is legitimate to conclude that, during the last decade, Irish farming was producing more food without increased pressure on the environment.

However, the other half of the narrative, equally valid, is that this 'flat-lining' of environmental impact is likely to be insufficient to meet the increasingly stringent environmental targets that agriculture must adhere to. For example, the Nitrates Directive has now been superseded by the Water Framework Directive, which requires that the historic decline in water quality is not only halted, but reversed, so that all water bodies are restored to at least 'good status' by the end of 2027. Similarly, while international policy negotiations at European and global level now recognise that it will prove very difficult to reduce GHG emissions from agriculture worldwide, the forthcoming targets, to be decided on over the next few months, will still require a significant reduction in Irish GHG emissions. The outlook for policies on biodiversity is likewise: while the Irish landscape enjoys a relatively rich heritage of agricultural biodiversity, the outlook for the conservation status of most of our farmland habitats has been classified as 'poor' by the National Parks and Wildlife Service.

20 The Economic Breeding Index allows farmers to select the most efficient animals for breeding, while decision support tools such as the Grass Wedge assist farmers in maximising the use of grass as a resource and minimising 'waste'. The Teagasc – Bord Bia Carbon Navigator gives practical advice to farmers on how to reduce GHG emissions on his or her farm, and is now rolled out nationwide as part of Bord Bia's quality assurance scheme. More recently, Teagasc launched the Nutrient Management Planning Online tool, which presents the nutrient requirements of individual fields, thereby allowing for precision fertiliser applications.

21 Schulte, RPO. *et al.*, Functional soil management: a framework for assessing the supply of and demand for soil-based ecosystem services for the sustainable intensification of agriculture and other land use. *Environmental Science and Policy* 38, 45-58.

Turning Sustainability into an Opportunity for Ireland

Global consumers, particularly those in mature developed markets and the growing middle classes in emerging markets, are demanding products that fulfil a growing range of functional and life stage needs, particularly relating to health, well-being and impact on the environment. They also seek convenience foods and food which can be shown to be natural and sustainably produced, meeting a range of 'free from' requirements. Consumer trends are evolving quickly, but Ireland's capacity for producing high quality, safe, nutritious and sustainable food means that the sector is well-placed to meet these new consumer needs. The development of food solutions to fulfil these needs presents opportunities for significant value addition by the Irish agri-food-sector.

As noted earlier, global demand for protein will increase substantially, driven not only by basic nutritional needs of a growing population, but also by growth of a global middle class population that will increase its intake of high quality proteins, in particular from consuming increased quantities of beef, poultry, fish and advanced dairy products.

The increase in global demand for high quality protein is good news in many ways for Ireland's meat and dairy industry. However, this comes with a caveat. The intensification of production on a global scale will further increase GHG emissions and intensify the challenge of managing production, animal manures and natural capital. This challenge can be addressed, but it will require a comprehensive 'systems approach' involving not only improved data-driven systems at the level of individual farms, but also new value chains at the local, regional and national levels. New value chains of a circular bioeconomy will play a pivotal role in ensuring the overall sustainability of Ireland's increasingly intensified protein production system.

Emerging Economic Opportunities for Ireland

The Circular Bioeconomy as a new Growth Paradigm

In 2012, the European Commission launched a strategy entitled *Innovating for sustainable growth: a bioeconomy for Europe*[22]. This is based on the following two premises:

- Biomass potential is under-exploited, because many waste streams are not used in an optimal way. More material and energy can be extracted from these streams.
- Biomass potential can be enhanced by raising current yields and developing new and improved extraction and processing technologies.

The strategy paper defines the bioeconomy as an economy which encompasses the sustainable production of renewable biological resources and their conversion into feed, food and bio-based products such as bio-plastics, bio-fuels and bio-energy. It includes agriculture, fisheries, forestry, food, pulp and paper, the chemical, biotechnology, pharmaceutical and energy industries. It already employs about 21.5 million people in Europe. It represents an annual market worth over €2 trillion, with significant potential for further growth based on replacing petro-chemical technologies with new sustainable bio-technologies that utilise renewable resources and organic waste streams. At EU level, Member States are now encouraged to prepare for the transitions needed to build a circular economy and benefit from new markets and business opportunities this will provide[23].

Traditional economic activity is based on a linear model whereby valuable resources pass along a value chain to produce goods that are consumed with various streams of waste being produced all along the way. The value chains of the circular economy see waste streams as primary inputs for other businesses. Nothing is discarded. The by-products of one process become the primary inputs for new industrial processes. Transition to a more circular economy requires changes throughout value chains, from product design to new

22 COM (2012) 60 final

23 EC, 2015. Closing the Loop – An EU Action Plan for the Circular Economy. COM(2015) 614 final.

business and market models, from new ways of turning waste into a resource to new modes of consumer behaviour. This implies full systemic change and innovation, not only in technologies, but also in organisation, society, finance methods and policies.

The development of new technologies for the use and transformation of bio-materials has opened up a wide range of potential new economic opportunities for rural areas. Markets for new bio-based products, for biofuels, green chemicals and biomaterials are projected to grow. They have a real contribution to make to the rural economy. Investing in growing these domains creates opportunities in many sectors, more highly skilled jobs, more competitive and sustainable rural economies, as well as openings into new markets. To realise this potential, investment will be required in new technologies, new business models, new models for the organisation of supply chains and value chains, as well as new policies and infrastructures.

The Circular Bioeconomy in Ireland

Ireland has many natural resources that can be exploited to sustainably produce new forms of bio-products. So far, however, the country has not developed a national strategy for the bioeconomy, and is only at the initial stage of its bioeconomy development. As a result, the economic value of Ireland's current bio-products is at the lower end of the value spectrum, namely commodity food products and bio-fuels. The development of more lucrative bio-chemicals or bio-materials outputs has not yet been given much attention.

The Government now recognises the potential of the bioeconomy and under its new strategy for science and technology[24], it commits to investing strategically in the bio-based economy, starting with the development of a national bioeconomy strategy. Teagasc fully supports this policy stance and sees opportunities to create new value chains of new economic activities in the rural economy, offering additional outlets for agricultural production and providing new sources of revenue for producers.

24 Department of Enterprise, Trade and Employment, 2015. Innovation 2020. Ireland's Strategy for Research and Development, Science and Technology.

The Agri-Services Economy in Ireland

A Central Statistics Office report on Irish services exports and imports reveals that the value of services exports in 2014 exceeded €100bn for the first time.[25] The global demand for all types of services is growing, including services related to agri-food. The UK, through its Agri-Tech Strategy, aims to become a global leader in this area.[26] Ireland too can strive for a leadership role in this domain.

Innovative Irish companies are already serving domestic farmers and farmers around the world with a range of technologically advanced products and services, including data-driven services that help farmers improve profitability based on real-time advice on animal health and nutrition. Also, new types of small food companies are emerging engaged in the discovery and development of high-value molecules for use in the food, pharmaceutical, supplement and cosmetics industries.

Ireland is a technology hub of choice for the strategic business activities of eight of the top ten global ICT companies and we also have a growing indigenous digital technology sector with sales of over €2bn per annum. Many of these companies are already working with Teagasc and its partners to develop next-generation technologies and systems to improve productivity and reduce the environmental impact for agri-food producers. Their ultimate goal is to export these systems and services to rapidly growing markets around the world so as to catalyse what is considered by many to be the second major revolution in agri-food and bioeconomy production.

According to Phil Hogan, the EU Commissioner for Agriculture, speaking in Kilkenny in May 2015, "Ireland is very well positioned to take a European and indeed global leadership role in the development of these new products"[27].

We are in a moment of great opportunity and there is a need to bring these players around the table to develop a national strategy for an export-oriented agri-digital industry.

25 http://www.cso.ie/en/releasesandpublications/er/its/internationaltradeinservices2014/

26 Department for Business, Innovation and Skills, 2013. A UK Strategy for Agricultural Technologies. London: BIS.

27 Speech by Commissioner Phil Hogan at ICT-Agriculture Conference. Ireland: Delivering sustainable intensification through collaboration. Friday, 1st May 2015, Kilkenny Castle, Kilkenny.

Revenues from Innovative Ecosystem Services

Although society is increasingly concerned about the environment and assigns increasing value not only to the environment but also to the culture and heritage of rural territories, the provision of these goods is often insufficient and they have been included in the new Sustainable Development Goals adopted in September 2015[28].

Agri-food and forestry have an important impact on the provision of public goods and those involved in the sector have opportunities to increase the provision of environmental goods and services by reducing the impact of their own activities on the environment as well as by off-setting the impact of other economic actors.

This is not an exact process, but it does incur additional cost on different actors throughout agri-food and bioeconomy supply chains. Many of these are not in a position to absorb the costs as part of doing business and will require assistance if they are to continue to operate. So far this situation is managed by paying subsidies to those who otherwise would not be able to survive. However, they must do so while protecting the environment and ensuring the provision of goods such as clean air and water, protecting soils and biodiversity and historic monuments. This situation will be exacerbated as Irish agri-food production intensifies and the demands on those involved in farming, forestry and other related activities increase in response to concerns about natural capital.

The development of new tools for monitoring the environment based on satellites, sensor networks, smart connected farm machinery and drones, suggest that it will become increasingly possible to monitor the environment and quantify the provision of public goods to the extent that it will be possible for farmers to charge fees for the public goods provided. If real markets for agriculture-sourced carbon and other environmental goods are developed between now and 2035, such measurement systems will become indispensable. It is possible to foresee a future where farmers, foresters and other actors will generate significant revenues from the provision of increasingly

sophisticated environmental goods and services on the basis of objectively quantified, auditable data.

Right now research is needed to better understand these issues. Eventually, new policy instruments and delivery mechanisms will be required, as well as new tools for monitoring and decision support. A credible system for the valuation and pricing of public goods, as well as the creation of appropriate policy and market-based mechanisms, may require the provision of public infrastructure, and it will rely heavily on next-generation systems for sensing, communicating and analysing data about the environment. The new digital technologies discussed in the following chapter will greatly assist in all of these endeavours.

Technology Adoption by Farmers

The adoption of new technology and management systems by Irish farmers has traditionally been low. New technologies and farming systems will only contribute adequately to a globally sustainable Irish agri-food and bioeconomy sector if adoption rates are improved. This calls for increased emphasis on education and extension services to help increase the skills and knowledge base of farmers and food producers. The level of expertise and specialist

28 On September 25th 2015, countries adopted a set of goals to end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda. Each goal has specific targets to be achieved over the next 15 years.

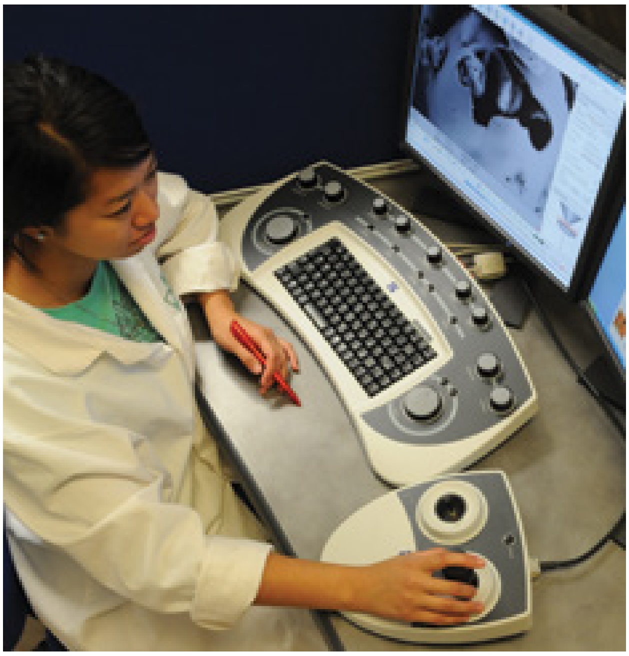
knowledge required for this activity are likely, in future, to both broaden and deepen and will require advisors with new knowledge and expertise to ensure that farmers can fully capture the benefits that digital communication and other technologies can deliver. For example, ecosystem services provision, agro-ecological practices and utilisation of a diversity of IT-dependent precision farming applications, are just a few of the anticipated innovations that farmers are expected to adopt in future. This development will require advisors to be fully informed and conversant with latest developments as well as having an appreciation of social contexts and drivers for change.

The introduction of new technologies may have implications for public engagement and science communication, as consumer acceptance of such solutions will depend on the perception of consumers and their ability to make sense of such technologies. Oversimplified assumptions of consumers' acceptance of novel foods and novel food technologies may lead to counterproductive commercialisation and communication strategies. The role of media in framing these issues needs to be better understood. As a food exporting nation, Ireland will need to be alert to these dynamics and maintain the flexibility and innovation needed to respond on an on-going basis.

Food Company Innovation

A commitment to innovation is absolutely essential to facilitate a move up the value chain and avoid, where possible, head-to head-competition on basic commodities, produced on ultra-scale efficient plants. Premiumisation and market differentiation through customer-led technical innovation is essential across the full product spectrum to commercially underpin the sustainable expansion of the Irish food industry.

To date, there has been substantial public investment in agriculture and food research in Ireland. This investment has helped create an internationally recognised group of highly skilled scientists within Irish research-performing organisations. In contrast, Irish enterprise has not invested significantly in research (BERD 0.65%). *Food Harvest 2020* stated that the industry needed to double investment in RDI by 2020 in order to meet growth targets. The investment by industry in Enterprise Ireland-backed research centres is beginning to reverse the traditionally low investment in food research.



Conclusion

Ireland's agri-food and bioeconomy system is intimately linked to the rest of the world through multiple systems, enabling two-way flows of materials, food products, financial resources, innovations and ideas. As a consequence, our system will be significantly impacted into the future by the global drivers discussed above. While many uncertainties remain regarding the likely impacts of these trends, it is clear that 'business as usual' is no longer a viable option. Ireland, within the context of the EU, can play a leading role in bringing about the necessary transition towards a more sustainable future. This will require a renewed commitment to research in all aspects of the agri-food and bioeconomy sector. It will require the development of new capabilities for research and innovation involving the application of ICT and molecular biology, both at component and system level, to enable next generation management systems and a wide range of new data-driven science-based services for the sector.

03

Future and Emerging Technologies

3. Future and Emerging Technologies

Introduction

Technological progress is critical to achieving sustainable growth and development. Technology represents new ways of doing things, and, once adopted, tends to lead to change. Adopted technology becomes embodied in all forms of capital, thereby enabling economies to create additional value with less input. But, as the economist Joseph Schumpeter noted, the most significant advances in economies arising from new technologies are often associated with a process of "creative destruction," which shifts profit pools, rearranges industry structures, and replaces existing businesses, thereby making old skills and organisational approaches irrelevant. Some new, potentially disruptive, technologies are the focus of the Teagasc Technology Foresight exercise.

The agricultural sector has benefited through history from the application of highly disruptive technologies, from the switch to horse power, to steam power and to the internal combustion engine. Agricultural productivity jumped significantly following the Second World War due to internal combustion-powered-tractors and combine harvesters, chemical fertilisers and the Green Revolution. Through the use of technology, each farmer is able to feed 155 people today, compared to 1940, when one farmer could feed only 19 people[29]. Technological advances have enabled farmers to feed more people with less land, fewer workers and less external inputs and provide sufficient food to a growing population at lower real prices.

Today, many rapidly evolving, potentially transformative technologies spanning information technologies, biological sciences, material science, energy, and other fields, are having and will have an even more profound impact on how we produce,

process, distribute and consume food (Figure 3.1). The big challenge for the foresight exercise was to identify the technologies that could deliver improved production efficiency, protect natural capital, and reduce wastage while meeting the changing consumer demands. The focus was not only on the technologies but also on the wider implications of their application so that scientists, policy makers and the industry could address them.

More than 200 experts and industry stakeholders contributed to the foresight process. Five strategically important priority themes were identified for Teagasc and its research partners, funders, the industry and policy makers:

1. Plant and Animal Genomics and Related Technologies
2. Human, Animal and Soil Microbiota
3. Digital Technologies
4. New Technologies for Food Processing
5. Transformation in the Food Value Chain System.

While we describe each of these five themes separately in the following pages, the really critical point is that these technologies are rapidly converging leading to a pace of change and innovation that is exponential rather than linear[30].

29 Prax, V. (2010, April 28). *American family farmers feed 155 people each – 2% Americans farm*. Retrieved from http://suite101.com/article/american-family-farmers-feeds-155-people-each-2-americans-farm-a231011

30 Garrett, B. 2015. Technology will keep changing everything-and will do it faster. Washington, D.C.:The Atlantic Council .

Figure 3.1: The impact of major new technologies on the agri-food value chain in 2035

We leave out "pipeline" or "drop-in" technologies whose adoption is imminent and under way. We focus on those that will continue to transform existing value chains between now and 2035.

		ICT			Genetics			Microbiotics		
		Low – cost smart sensor networks, remote sensing and GIS, big + small data	Robotics, automation, smart machines, 3D printers…	Decision support, cognitive technologies and AI	Next-Generation Sequencing (very fast, low – cost) and low cost, widespread genotyping	Genetic enhancement – germ line	Genetic enhancement– non – germ line	Whole biome sequencing (enabled by ICT + Genetics)	Nutrition and management of microbiota	Next – generation advanced bioreactors
Agricultural Production	Soil management	✓	✓	✓			✓	✓	✓	
	Pasture management	✓	✓	✓	✓	✓	✓	✓	✓	
	Crop management	✓	✓	✓	✓	✓	✓			
	Animal and plant breeding	✓	✓	✓	✓	✓	✓			
	Animal health	✓	✓	✓	✓	✓		✓	✓	
	Animal nutrition, reproduction and management	✓	✓	✓	✓	✓				
	Quality management	✓	✓	✓	✓			✓	✓	✓
	Machinery and labour productivity	✓	✓	✓						
	Resource management	✓	✓	✓				✓	✓	✓
	Energy, waste and emissions	✓	✓	✓	✓	✓	✓			✓
	Environmental services	✓	✓	✓				✓	✓	✓
Food, Feed, and Bio-Processing, ie Bio-Based	Primary processing	✓	✓							
	Secondary processing	✓								✓
	Functional fractions	✓		✓	✓				✓	✓
	Biofuels					✓	✓		✓	✓
	Green chemistry					✓	✓		✓	✓
	Quality management	✓	✓	✓	✓			✓	✓	
Consumer Services	Industrial distribution		✓							
	Food distribution, retail etc.		✓	✓						
	Quality management	✓	✓	✓	✓			✓	✓	
	Catering and restaurant services	✓	✓	✓	✓					
	Food hygiene and security	✓	✓	✓				✓	✓	
	Food service, health and nutrition	✓	✓	✓	✓			✓	✓	

Theme 1: Plant and Animal Genomics and Related Technologies[31]

Over the next 40 years, biological science-based technologies and approaches have the potential to improve food crop production in a sustainable way. Some of these technologies build on existing knowledge and technologies, while others are completely radical approaches which will require a great deal of further research.[32]

At high speed and very low cost, whole genome sequencing and genotyping platforms will capture genetic data from plants, animals and even whole ecologies. This will facilitate breeding programmes to deliver multi-objective strategies that aim to simultaneously improve the production efficiency, functional differentiation and protection of natural capital of primary production, especially in the dairy, beef, sheep, pigs and crops sectors.

Combinations of these techniques have the potential to transform animal and plant breeding by introducing traits that are important for producers, processors and consumers. Many of these technologies will become embedded in services provided either by the state or by private service providers.

The greater understanding of the biology underlying traits of importance will also allow for the precision management of animals and crops, where management interventions are tailored to suit their specific genotype.

Teagasc and its partners, especially the ICBF, have already taken important steps in the use of these technologies. Capabilities have been developed in the application of modern molecular biology techniques to animal and plant breeding. Teagasc has co-developed genotyping platforms for use in cattle and sheep and has plans to generate more than one million sequences in the coming years. These initiatives already provide Ireland with a unique and powerful platform for developing the kind of "next generation breeding" systems anticipated in this foresight exercise.

The advent of genotyping for the major livestock species, together with the future cost-effective availability of this technology on an individual animal basis, will undoubtedly dramatically improve the accuracy of selection and the identification of genetically superior animals for a host of economically important traits. However, the impact of this technology will hinge upon the equal availability of accurate complementary phenotypes. Although widely available for more easily accessible traits (e.g. growth, carcass characteristics, milk yield, etc.), the adequate availability of appropriate phenotypes for other key traits including those relating to feed intake, GHG emissions, fertility, health and welfare, will have a major bearing on the rate of genetic progress and the more complete exploitation of genomic technology. Thus, in addition to advances in genomic research, equal emphasis must also be placed on the development of accurate and cost-effective methodologies to efficiently capture the key phenotypes essential to the development of future livestock breeding and management programmes.

Currently, selection for fertility traits in most countries is based on calving interval (or days open) and survival (or longevity), but these traits have low heritability. Significance progress in improving fertility of dairy cows has been made by selecting for these traits. It is likely that new traits can be identified that will have greater heritability, but the challenge will be to routinely (and inexpensively) record these on a large population of cows and again to capture the relevant phenotypic data in a central database. The same challenges will be true for animal health and other difficult-to-measure traits.

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31 Following key references are used in this section: The Bovine Genome Sequencing and Analysis Consortium: The Genome Sequence of Taurine Cattle: a window to ruminant biology and evolution. *Science* 2009; 324:522-528.

Meuwissen THE, Hayes BJ and Goddard ME 2001. Prediction of total genetic value using genome-wide dense marker maps. *Genetics* 157, 1819-1829.

Spelman, R.J., Hayes, B.J. & Berry, D.P: Use of molecular technologies for the advancement of animal breeding: genomic selection in dairy cattle populations in Australia, Ireland and New Zealand. *Anim Prod Sci* 2013. Hayes, B.J., Bowman, P.J., Chamberlin, A.J. & Goddard, M: Invited review: Genomic selection in dairy cattle: progress and challenges. *J Dairy Sci* 2009; 92, 433-43.

Dalton, E. et al. (2013). The effect of pyramiding two potato cyst nematode resistance loci to *Globodera pallida* Pa2/3 in potato. Molecular Breeding, April 2013, 31, 921-930

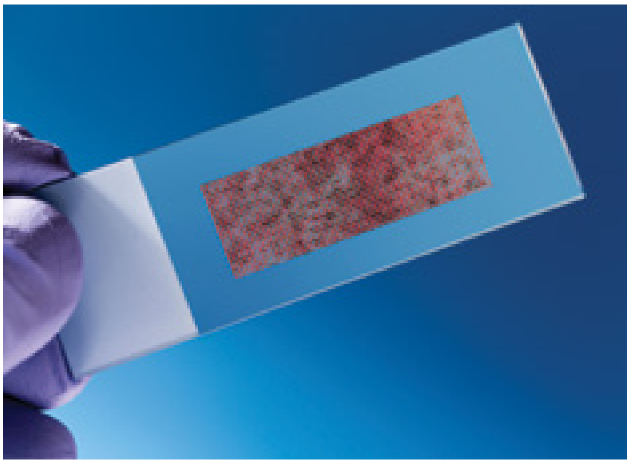
Xie, K. and Yang, Y. (2013). RNA-Guided Genome Editing in Plants Using a CRISPR–Cas System. Molecular Plant, Volume 6, Issue 6, November 2013, 1975–1983

32 The Royal Society, 2009. Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture. London: The Royal Society.

Wearable sensor technologies have become commonplace for humans during the last decade and are now starting to gain increased use in cattle. Phenotypes that can be automatically recorded using accelerometer collars include: calving to first oestrus, oestrus cycle duration, oestrous intensity, oestrus duration, grazing time and rumination time. Tympanic or reticular temperature measuring devices can identify time of calving onset, time of oestrus and some health events (e.g. fever). A milking system with in-line progesterone measurement capability is commercially available and is becoming increasingly popular in large confined dairy operations. This automatically measures the concentration of progesterone in milk and from this information, interval from calving to commencement of oestrous cyclicity, oestrous cycle characteristics, oestrus and time of ovulation can all be determined. From this, the appropriate time to inseminate cows can be pinpointed without reference to oestrous detection. A variety of approaches has been developed to automatically capture body condition score and bodyweight measurements. To stimulate farmer interest and uptake, it is essential that these different sources of information can be used to reduce labour requirements and/or improve animal phenotypic performance.

As this batch of technologies improves and becomes cheaper, it is likely that the use of many or all of these sensors will become economically viable and eventually commonplace, on dairy and other farms within the next 20 years. This will allow interrogation of genetic predisposition to favourable or unfavourable phenotypes and hence facilitate selection based on these new phenotypes where appropriate. The result will be cows that better maintain 'Body Condition Score', promptly resume normal oestrous cyclicity after calving and require fewer interventions for uterine health problems and anoestrous.

The use of sensor technologies that record phenotypes is primarily driven by farmers' need for information necessary for animal management, for example to help the farmer detect oestrus, the onset of calving or lameness. However, powerful additional knowledge is obtained by combining this information with genotypic information to guide management decisions (e.g. bull selection). Once the genotype data are combined with performance data, the question then arises as to how this will drive decisions that will guide actions at strategic and operational levels. This requires a whole other range of technologies to support a much more knowledge – and data-intensive approach to breeding or reproduction, as well as herd management, feeding, animal health and nutrient and pasture management. It also provides "evidence" to support the environmental, animal welfare or consumer health claims that may be made.



Ireland is at the forefront in the development and deployment of genome-based selection. Selection of elite animals as candidate parents of the next generation is no longer just based on the observed performance of the animal and its relatives, but also takes into account the unique DNA or genomic characteristics of the animal. With funding support from DAFM, Teagasc, the Irish Cattle Breeding Federation and industry, Teagasc research resulted in Ireland being the second country in the world (after the USA) to introduce genome-enabled selection into its national dairy cattle breeding programme. This has resulted in an increase of more than 50% in the rate of genetic gain in the dairy herd.

The availability of high-speed low-cost genotyping also creates significant opportunities in crop production, whether the crop in question is for pasture, tillage, forestry or horticulture. As with animal breeding systems, the availability of matching phenotypic information presents a challenge. Whilst on-farm phenotypic information will undoubtedly make a contribution from the collation of field records at a national level, initially, at least, crop improvement will most likely be driven by the collection of phenotypic information in a limited number of research and plant breeding institutes at controlled-environment, glass house and field level. The collection of this phenotypic information at an acceptable cost will rely on the generation and interpretation of data using remote sensing and other relevant technologies.

From a cropping perspective, producers will benefit from varieties that are optimised in regard to their genetic base, disease resistance, environmental adaptation and agronomic performance. This will be delivered by the incorporation of "genotyping by sequencing" approaches into mainstream crop breeding. This will increase the ability to aggregate beneficial alleles over recurrent cycles of selections. In parallel, such approaches will be complemented with the output from gene functionality studies. The latter will associate genes of interest with specific plant phenotypes via gene editing approaches that enhance/disrupt gene function, delivering a proof-of-concept that supports more focused field-based phenotyping.

Combined, these strategies will afford breeding programmes the opportunity to respond to present and future abiotic stresses by delivering region-specific varieties suited to individual sectors. For example, by re-engineering the reproductive biology of certain crop species, it will be possible to develop F1 hybrid varieties that deliver significant yield increases. This will be achieved by the introgression of naturally occurring self-compatibility loci into breeding germplasm, allowing the development of inbred lines for hybrid development.

Fundamentally, improving varietal performance will be achieved by an improved understanding of the interaction between plant genotype, environment and crop management. This will be attained by new systems biology-based approaches built on combining advances in "omics"-style technologies with all aspects of crop management using increased computational power. The inter-disciplinary convergence of "omics" and sensor technologies will also allow for better "knowledge-based management" of crops based on monitoring the real-time physiological status, rate of disease incidence, epigenome, transcriptome, proteome and metabolome of plants.

Specifically, the development of novel varieties equipped with genes isolated from wild progenitor/ germplasm collections, which is already underway in the Teagasc Potato Breeding Programme, will support the delivery of IPM Potato Group's objectives. Employing cisgenic-based strategies, durable biotic resistance will be deployed into varieties to ensure consumer demands are achieved while also improving production efficiency and reducing costs. Such approaches will be complemented by in-field nano-sensor diagnostics, which detect and quantify crop pathogens in real time. This will provide the producer with real-time information on the prevalence of disease-causing strains and through associated support systems provide 'decision to spray' guidance based on disease incidence as opposed to growth stages of the plant.

These technologies are game-changers in the sense that they allow scientists to formulate and seek solutions to challenges that would have been far too costly, time-consuming or complex in the past. This is only the start of a series of industry transformations that will enable us to rapidly increase output while reducing our impact on the environment. Much of the ability of these technologies to solve real world problems will rely on the accumulation of knowledge about the genomes of individual genome species and then how those species interact within their respective biomes and eco-systems. Between now and 2035, these technologies will continue to mature and develop on the basis of shared knowledge of genomes, their roles in organisms, and their interactions with the environment.

Teagasc has made significant progress in the areas of animal and crop breeding. Much of the future work of the Irish research community will focus on formulating breeding programmes that cross categories, involving multiple research teams dealing with animal health, milk or meat quality, animal productivity, feed system design, feed conversion efficiency, animal-level waste, emissions reduction, and productivity of pastures based on new varieties and soil systems. These developments will have an impact on farm management practices and the systems that support them, enabling growth in terms of new products, better performance and increased profitability.

Other New Biotechnologies

Cloning/Reproductive technologies

Although in existence for many decades, further advances in reproductive technologies including synchronisation of ovulation, fixed-time artificial insemination, sex sorting of semen, multiple ovulation and embryo transfer and cloning are warranted if introgression of genes from genetically superior animals is to have the maximum impact in livestock populations.

Genome engineering

With the development of systems like the CRISPR/Cas and TALEN (http://www.nature.com/nrg/journal/v16/n5/abs/nrg3899.html) there is now the ability to precisely edit genomes on a population scale. Simulations suggest a three-fold increase in response to selection when genome editing is used in conjunction with genomic selection, compared to genomic selection alone, with even greater responses predicted for lowly heritable traits. Cheap, whole genome sequencing will almost definitely contribute to the identification of genomic loci suitable for editing, and this will not be restricted to SNP identification as current technologies are. Teagasc needs to be aware and prepared for this emerging area as it promises to be a legal minefield.

Epigenetic technologies

The vast majority of the heritability of most economic traits of interest is not directly genetically determined and is influenced by factors which alter how genes are expressed without altering the underlying DNA sequence. For example, using epigenetic technologies to help inform the role of the environment on the expression of a specific trait will be key to the future capture of that trait, for example the influence of early life events such as pre-natal nutrition or post-natal infection on future productivity issues such as meat and milk quality, as well as lifetime health.

Understanding genotype-environment interactions will help design improved management strategies. Of particular interest from an Irish ruminant production perspective is assessment of the genotypes predominantly developed under conditions which may not be aligned to our forage-based production systems. Epigenetics will also be important for tissue-specific expression of traits as well as the design of next generation vaccines.

Metagenomics

Currently, we can culture only about 3% of known microbes. Next-generation sequencing technologies are culture-independent, meaning that we can now shed light on the enormous complexity of the microbial world. Understanding the interactions between these microbes and host immunity will revolutionise our

understanding of animal nutrition and immunity. Under normal forage-based ruminant production systems, such as those prevailing in Ireland, the vast majority of animals' dietary energy is derived from ruminal fermentation of ingested feed. This, however, comes in tandem with significant wastage in the form of ruminal methane synthesis, a potent GHG.

Current and future advances in metagenomic technologies will greatly advance our understanding of the biology and dynamics of key microbes and microbial ecosystems of fundamental importance to livestock production. This, in turn, will facilitate the development of prophylactic and therapeutic intervention approaches to promote beneficial, or eliminate pathogenic, organisms.

Next-Generation Sequencing, Functional Genomics and Systems Biology

A thorough understanding of the regulation of inter-animal variation in key economically important traits will be fundamental to future progress in the development of healthy, economically and environmentally sustainable livestock. Understanding the factors contributing to inter-animal variation in immunity will be critical to designing improved and better targeted management regimens (i.e. nutrigenomics, personalised nutrition, vaccines) and overcoming future disease challenges. Furthermore, we still investigate diseases almost exclusively on a disease-by-disease basis. There is undoubtedly interplay between susceptibilities to multiple infectious diseases, and improved disease models combined with a systems-level appreciation of the complexity would help us gain deeper insight into the key susceptibility parameters.

Theme 2: Human, Animal and Soil Microbiota

Abundant evidence shows that particular aspects of human health and disease are attributable to the trillions of microbes that inhabit our gastrointestinal tract, collectively referred to as the gut microbiota. Consider that the number of unique genes contributed by the gut microbiota is greater than 150-fold that encoded within the human genome and that the vast number of metabolites produced by these organisms allows effects on distant organs. The composition of the gut microbiota is complex and in addition to bacteria includes viruses, fungi, protozoa, and Archaea. These organisms contribute not only to each other's function and survival but humans have evolved to depend on the extended physiology and metabolism that the microbiota provides[33].

While the study of microbiota in various living organisms is not new, one of the generally surprising recent discoveries in biology concerns not just the diversity and complexity of these microscopic life-forms that inhabit the human body, in particular the human gastrointestinal tract (GIT), the bodies of farm animals and every other corner of the biosphere, but the discovery of the vitally important role they play in the general health and well-being of the individual, the animal and the planet. Specific examples, by no means exhaustive, of the importance of microbiota for food and agriculture are summarised in Table 3.1.

Table 3.1: Role of Microbiota in Humans, Livestock and the Environment

Biome	Role
The human GIT	General health and well being Digestion Protection against infection by pathogens Allergies Food intolerances
The rumen and the GIT of all domesticated farm animals	General animal health Digestion and feed conversion Production of methane
Soils	Plant health and productivity Nutrient availability Water purification and storage Carbon storage Provision of antibiotics, pharmaceuticals, etc.
Water bodies	Water quality Bioremediation Biodiversity, algae, aquatic-plant, fish and insect populations Water management, intense weather and flood control
Bioreactors	Fermentation systems to produce foods and beverages (beer, cheese, yoghurt, tofu and "soon-to-be-discovered" new food categories… this is a major focus for research in countries such as South Korea) Conversion of organic matter (waste or non-waste) into fuels Conversion of organic matter into feeds (silage, insects…) Conversion of organic matter into industrial chemicals and precursors.

33 Editorial from Gail Hecht, Chair of the Scientific Committee of the 2016 Gut Microbiota for Health World Summit. http://summit-registration.gutmicrobiotaforhealth.com/

The complexity of these environments presents a great challenge for scientists trying to understand the mechanisms at work and how to usefully manage or manipulate them. Arguably, we are now at a turning point in the availability of technologies that will accelerate progress in this domain, not only to improve understanding, but also to drive the development of new tools for managing and manipulating microbiota for the benefit of the host, the farmer, the consumer, the entrepreneur and the environment.

With the further development of High Throughput DNA Sequencing technologies, it is now possible to study microbiota at a much deeper level. This is not only revealing the diversity of the organisms present, but also, when combined with other methodologies, such as transcriptomics, proteomics and metabolomics, is providing exciting insights as to the potential of the microbiota to impact on the environment that they occupy, whether it be the microbiota of the human GIT impacting on human health or soil microbiota on carbon sequestration.

The Human Microbiota

A startling revelation over the last decade or so, made possible by NGS technology, is the complexity and diversity of the microbiota found in the human GIT. There is rapidly emerging evidence of the impact of this population of microorganisms on human health and wellbeing.[34] It is becoming ever-more apparent that the composition and function of these microbes is impacted on by the foods we eat. In turn, these microbes strongly influence the way in which these foods are digested and are often responsible for the conversion of food substrates into beneficial or detrimental bioactives. In addition, the microbiota produce a complex mix of molecules that are released into the GIT, many of which function as signalling molecules or have associated bioactivities. This diverse range of bioactive molecules can exert its effect in the GIT, or it can enter the blood stream to impact distal organs. Indeed, some can cross the “blood brain barrier” and exert their impact within the brain.

Our understanding of the GIT microbiota and their influence on human health and wellbeing is evolving extremely rapidly, aided by advances in NGS, proteomics and metabolomics, mass spectrometry, bio-assays, animal models, advanced bioinformatics, big-data

handling and mining, lab-on-a-chip and organ-on-chip technologies, as well as by the use of wearable sensors and life-logging technologies by consumers. In addition, access to ever-expanding information on the human genome and epigenome will complement our new insights into the human microbiota. More specifically, this will enable the development of new food products and services for personalised nutrition, cohort nutrition and ‘medicinal foods’ intended to ameliorate disease risk, allergies, food intolerance or delaying the ageing process. New and emerging disciplines of applied macrobiotics will enable the development of new food concepts aimed at specific groups such as pregnant and lactating mothers, infants in the first six months of life, toddlers, children, teens and young adults as well as foods that provide a feeling of satisfaction and satiety, or boosts to mood or cognition.

Alimentary Pharmabiotic Centre (APC) Microbiome Institute

APC is a a gastrointestinal health research institute based in Cork exploring the role of gastrointestinal bacteria (microbiome) in human health and disease. One of the world’s leading institutes in gut microbiome research, APC is receiving €70 million in SFI and industry funding across 2013-2019. It hosts a diverse group of clinicians and scientists, among whom are global research leaders in food/pharma areas such as gastroenterology, microbiology, immunology, neuroscience, nutrition, neonatology and gerontology, cardiovascular and metabolic health. The academic partners are University College Cork, Teagasc and Cork Institute of Technology.

34 Nature (2012) Special Edition: Human Microbiota

The application of the tools used to monitor and manipulate the microbiota will also be applied to the food chain where they will be used to provide microbiology process maps, identify high-risk areas leading to contamination or for the rapid and real-time identification of pathogens and spoilage organisms. In this way, deeper knowledge of microbiota will result in enhanced food safety, food quality and extended shelf-life for food products. The corollary is also true, as knowledge relating to the microbiota can be applied to the identification of microbial consortia that add to the safety, quality, consistency, flavour, functionality and other desirable attributes in fermented and other foods. Progress will be driven by new and emerging technologies that include microbiota sequencing, advanced bioinformatics and big data handling and mining, lab-on-a-chip technologies etc. When combined with intelligent packaging systems containing embedded sensors to detect changes in the microbiota or metabolites, it will enable food producers, distributors, retailers and consumers to make more informed real-time judgments on foods from a safety and/or quality perspective and to initiate appropriate corrective actions. It will also allow food manufacturers to harness microbiota data to apply desirable microbes to improve their products.

By 2035, the full impact of the microbiota associated with the complete food production and processing pipeline will be realised, and just as the concept of the "Internet of Things" is now emerging, the idea of the "Microbiota of Things" will be well-established as a core component available for scientific and technological exploitation for enhanced sustainable food production and processing and a key driver in human health and wellbeing.

Animal Microbiota

The bovine rumen also holds a complex microbiota that is responsible for the bovine's ability to convert indigestible plant material (hemicellulose, cellulose and fibre) into high-value digestible compounds such as milk and meat for human consumption. The rumen functions as an anaerobic fermentation chamber inhabited by a highly dense microbial community composed of microorganisms from all domains of life, 95% of which are bacteria, with other groups such as fungi, archaea, protozoa and viruses present in lower abundance. Fermentation products of rumen microbial activity, consisting mainly of volatile fatty acids, are absorbed by and serve as a major source of energy for the host animal.

Despite being central to the ability of cattle to digest forages and cereal-containing materials, fermentation by the rumen microbiota is accompanied by the production of methane, a potent GHG. In the rumen, hydrogen is one of the major fermentation products. Methane is produced by methanogenic archaea which convert the hydrogen produced by ruminal fermentation into methane. Although this process assists in maintaining rumen pH by preventing accumulation of hydrogen ions in the rumen, it also results in high methane emissions. In addition, methane production in the rumen is an energetically wasteful process, accounting for up to 10% of dietary gross energy.

A comprehensive understanding of the dynamics of rumen microbiota establishment and development and how they mediate the fermentation process throughout the life cycle of the animal is vital in maximising host nutrient utilisation, health and productivity, *via* dietary intervention strategies (e.g., nutrition models, probiotics, prebiotics and enzymes). This is particularly important in Irish pasture-based dairy and beef systems. In addition, characterization of ruminal methanogen growth patterns from birth may allow for novel, targeted and persistent mitigation strategies. Furthermore, considering the role of the host genetics on the rumen microbiota, it is envisaged that information on the rumen microbiota diversity and functionality will be integrated into future breeding programmes.

The GIT of the pig is well recognized as a very good model of the human GIT and this extends to the gut microbiota. Thus, it is realistic to assume that many of the impacts and advances being associated with manipulation of the human GIT microbiota can be transferred to pigs, where they could be exploited to enhance feed conversion efficiency, production of lean body mass and enhanced health.

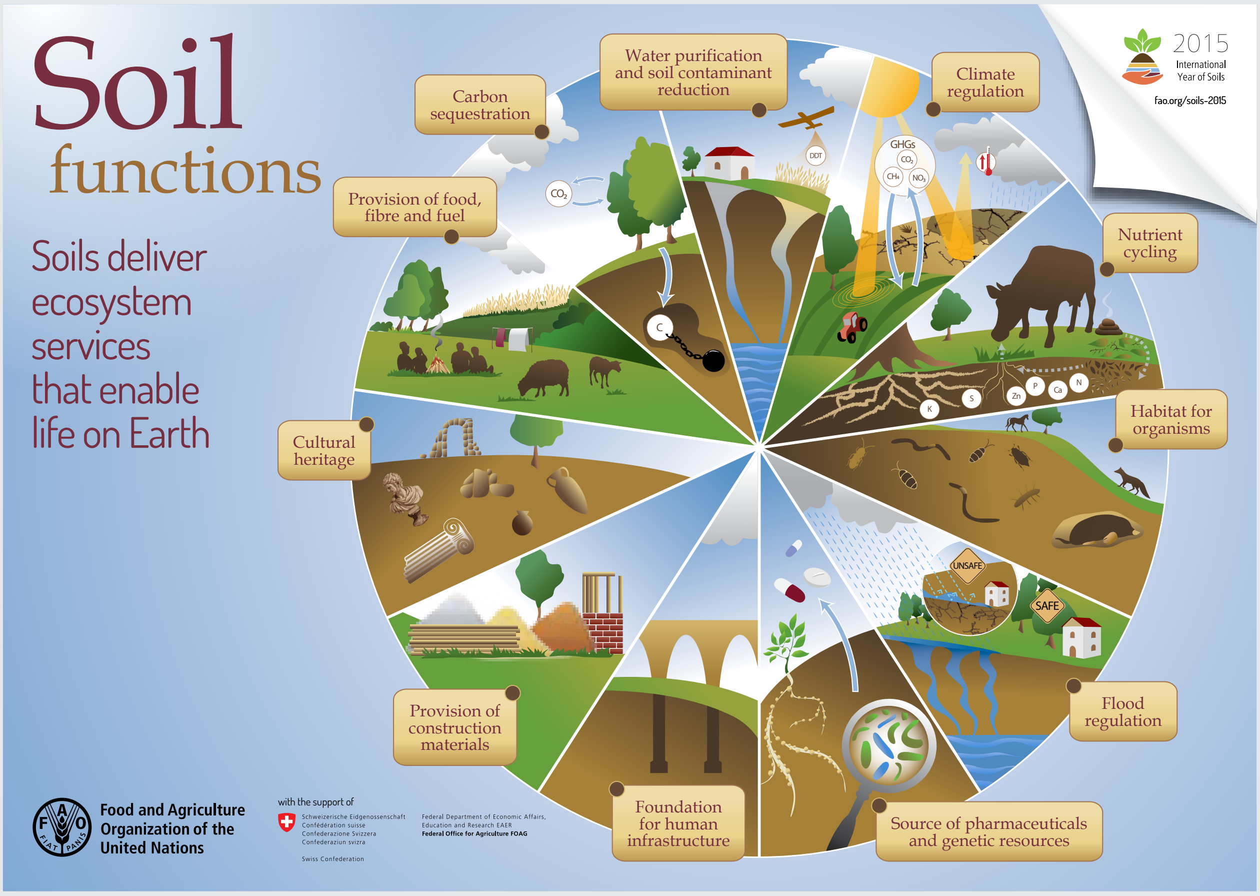
The Soil Microbiota

Soils provide a range of essential functions in agricultural production (Figure 3.2). The soil microbiota plays a significant role in delivering these. We are now beginning to explore the soil microbiota enabled by rapid advances in microbiota sequencing and extension of the database of known sequences so that more accurate identification of species within the biota and their function can be established. Challenges exist in terms of identifying, measuring and relating the performance of the relevant soil functions.

Enhanced understanding will lead to the development of management practices for optimising the soil biome to maximise targeted soil functions, manipulating the soil biome to increase agricultural sustainability, contributing to understanding, isolating and utilising endophytes to enhance crop growth, and developing next generation nanosensors capable of identifying strains of pests and pathogens to more accurately target crop protection measures.

This is key to understanding the functional responses in soil as they relate to the soil biota, including yield, turnover of key soil nutrients, carbon sequestration, reduction of nutrient and pathogen loss to water as well as reduction of GHG emissions.

Figure 3.2: The range of soil functions



Source: http://www.fao.org/resources/infographics/infographics-details/en/c/284478/

Theme 3: Digital Technologies

Over the next decade, emerging digital technologies such as data analytics, sensors and artificial intelligence will transform or replace many products, processes and jobs. They will enable new kinds of tools and processes for co-creation, co-production, co-monitoring and co-consumption. They will fundamentally affect established roles and responsibilities among societal actors, and may even change how we define government, business and civil society.[35]

Most of the technologies discussed in this chapter are directly enabled by, or enhanced, by information technology. The key technologies include:

- Sensors to capture data
- Data storage transfer and communication technology
- Data analytics to analyse data, present data and develop an appropriate response
- Controllers and actuators to deliver a usable response from the analysed data.

Rapid, even exponential rates of development in each of these technology areas promise an exciting potential for the agri-food and bioeconomy sector. The technology developments are frequently driven by markets in non-agricultural areas. There is scope to develop them for application in the agriculture sector as many of the technology providers want to contribute and to seek opportunities for their products and technologies as scale has reduced costs.

35 Policy Horizons Canada, 2012. MetaScan 2: Building Resilience in the Transition to a Digital Economy and a Networked Society. Toronto: Policy Horizons Canada.

Teagasc is partnering with a number of leading research organisations in the development of digital technology solutions for agriculture. In the area of measurement and data capture, we are working with the Tyndall Institute on the development of sensors and with the TSSG (Waterford Institute of Technology) in relation to information networks to allow data from sensors and other measurement points to be captured into databases such as the ICBF's animal breeding database, or Teagasc's PastureBase Ireland. We are collaborating with the SFI funded Insight Centre (UCD) for data analytics on the combination and analysis of large and complex datasets, so that useful information can be obtained and used to develop powerful decision support systems. These will guide farmers and others in the management choices involved in running their farms and businesses.

Further growth of the rural digital economy is being facilitated in many countries by both the rollout of a next generation network broadband and the growing impact of the digital economy in many other economic sectors. The real significance of improved broadband services in rural areas lies in the complementarities that are made possible arising from the simultaneous developments in related technologies. These include:

- **The Internet of Living Things**: Networks of low-cost sensors, actuators and wireless networks for data collection and process monitoring of crops, livestock and agricultural eco-systems
- **Decision support**: Intelligent software that can perform farm planning tasks and support decision-making and optimise large-scale production processes.
- **Advanced robotics**: Robots with enhanced senses, dexterity and intelligence used to automate tasks or augment humans, such as harvesting fruit and controlling weeds and pests
- **Autonomous farm vehicles**: Vehicles that can navigate and operate with reduced or no human control to herd livestock and harvest crops
- **'Farms in the Cloud'**: The simulation of real-time agricultural processes using data and algorithms.

The challenge in many areas however, is to use these technologies in a productive way to ease the task of operators, to translate data into knowledge and, in particular, to allow as a consequence more precise management to improve production efficiency and protection of natural capital.

Sensors and other Technologies that Generate Data

New sensor technology is one of the keys to developing our understanding of soil, plant and animal variation. Sensors must reliably and adequately measure key soil crop and animal parameters at a resolution suitable for reliable analysis and for an appropriate management response. There is already a long list of available and emerging sensor technologies to be deployed around the farm, catchments, in vehicles, factories, stores, shops and homes. This list includes:

- GPS and GIS technologies
- Bar-codes, QR-codes, scanners and smart tags
- Sensors for visual inspection to measure the health of a plant or animal (or human)
- Sensors to inspect the status of a field, machine or facility
- Other biometric sensing technologies for measuring the health or status of organisms
- Sensors integrated into machinery (tractors, harvesters, milking machines, feeders…)
- Sensors integrated into buildings or facilities (farm sheds, fences, troughs, doors and gates…)
- Sensors to measure the presence of identified molecules in the air, soil, foods or water
- Sensors to measure contamination (for food security, traceability…)
- Sensors used in mobile phones, field-based monitoring devices, drones and microsatellites
- Sensors that are wearable or implantable
- Sensors integrated into smart packaging
- Sensors deployed in homes, shops and restaurants
- Sensors to detect the status of a stored good or a good in transit.

Data will also be generated from the global network of Earth Observing Satellites. Advances in the use of high resolution RADAR systems developed as part of the EU Copernicus program, in addition to space-borne LIDAR, will largely eliminate the problem of gathering data through cloud cover in Ireland. Within a decade, advances in the deployment of microsatellites will lead to the availability of multiple high resolution observations each day across the whole of the country.

Sensor technologies for heat detection

It is well-established that efficient heat detection can improve both the submission rate and the rate of pregnancy establishment in dairy cows. Efficient heat detection is therefore an important driver of profit on dairy farms. Wearable sensor technologies for heat detection have existed for a number of years, but technology improvements mean that these devices are now also capable of discriminating between activity and movements associated with eating and ruminating. Teagasc is working with Dairymaster to test, calibrate and optimise the next generation of wearable sensors to identify behaviours associated with oestrus, lameness and illness. The information can be used to provide early alerts to dairy farmers, thereby improving cow welfare and herd performance.

By 2035, it will be standard practice to sequence the genes of farm animals and use this data as an input to systems for the management of breeding, health and nutrition. This will generate huge amounts of data that will need to be stored and made available to different actors, not just researchers but also the providers of sophisticated data-driven agri-food related services. Genetic data will also be routinely collected on the biota of farm animals, on the biota of pastures, plants and soils needed to realise the goal of sustainable intensification of agri-food production. Individual consumers will collect genetic data for themselves and their own biota, with a view to better managing their own health, nutrition and well-being. Add to that the huge amounts of data on the lifestyle, behaviour and health status of individuals, the feeding and performance data of animals, pastures and plots, as well as the real-time environmental status of rivers, fields and hedgerows, and we end up with an awful lot of data!

Big Data and Data Analytics

The data from sensors and other technologies is collected and stored in the cloud along with other data, including data on farm resources, fields, soils and topography, land use and local weather (past, present and forecast microclimate data), farm inputs and production outputs including data on the status of the environment and on the production of environmental goods and services.

Such data often exist in silos, so there are the social and political issues around data sharing. Data sharing is also a technical problem. It is easier to share, integrate, use and reuse data if it has been stored in a standardised format. If it is not stored using shared open standards, then it can become very costly, even prohibitively costly, to integrate data sets derived from different systems. Research is needed on the development of open-standards for structuring data (meta-data, ontologies, taxonomies), as well as open-protocols for data-sharing and open architectures for systems that make use of this data.

One of the issues that these systems will have to address is sharing, ownership, access and fair use of data, especially where sensitive data might be involved. Governments in Europe have taken steps to ensure that publicly owned data is available for any entrepreneur at a reasonable cost. At EU level, there is already an Open Data Directive intended to encourage member states to make public data available as a support for new kinds of data intensive entrepreneurial activity. The G8 has adopted an Open Data Charter and countries such as the UK have an Open Data Institute to oversee the implementation of an explicit Open Data Roadmap. It may be necessary to develop specific policies for the use of data needed for sustainable agri-food production systems.

The ICBF and Sheep Ireland animal breeding database
Achieving genetic gain in animal performance is dependent on having routine access to a large quantity of accurate phenotypic information and known environmental influences on the animal itself and its relatives. More recently, phenotypic information in national genetic evaluations has been supplemented by a large quantity of genomic information. In Ireland, all the phenotypic and genotypic information which can be collected is stored in an enormous database by the ICBF, the government appointed body responsible for genetic evaluations. The ICBF and Sheep Ireland use this information to routinely undertake (inter)national dairy, beef and sheep breeding evaluations and breeding programmes. The database is also used by Teagasc and others for predominantly research purposes. The ICBF database contains information on almost every bovine and almost all flock book sheep in the country, with links to the Department of Agriculture's AIMS database (Animal Identification and Movement System), the various milk recording schemes, animal weight recording in marts, and slaughter data from abattoir facilities, all providing key information for the database. Ireland is one of the few countries in the world to have individual identification and full traceability on all bovines, and to have its animal breeding database in a public/industry ownership structure. Ireland is the only country in the world where individual breeders or farmers can obtain genomic proofs on their animals. The scale, multiple sources and complexity of the data, and the advanced analytics involved in incorporating the data into breeding evaluations make this Irish agriculture's prime Big Data project.

The "Cloud" and the "Internet of Farm Things"

Sensors and other data-generating technologies are only one part of the picture. Data from sensors and other sources needs to be transmitted *via* a network infrastructure and stored in some safe place. Nowadays, the dominant model for transmission and storage is called the "cloud".

Keenan InTouch is a cloud platform which enables real-time access to on-farm and supply-chain data for the management of animal performance, health and nutrition. More than 3000 farms across the world are linked directly to the InTouch centre in Kilkenny. Their cloud solution gathers and stores real-time data from sensors. This data is processed and passed on to a team of skilled nutritionists for interpretation. They then provide advice directly to farmers to help them make better feed and nutrition decisions in the management of their animals, so as to drive performance and profitability.

Big data, by its sheer volume of information and frequency of data collection at varying levels of aggregation-including at the nano-scale, offers a number of opportunities for PA. Where single sensors are not sufficient to predict meaningful soil or biological characteristics, the data from a number of sensors, which individually have weak predictive ability, are combined so that they may more accurately predict the target characteristic. At the most rudimentary level, data can be analysed in real-time to flag critical values which are important for production decision-making. At a more sophisticated level, high resolution spatial maps of soil moisture or soil, grass and crop nutrient status can direct more efficient field operations and application of nutrients. Similarly, detailed maps of pest or disease damage can allow for the precise targeting of controls in-field. At the most advanced level, remote-sensed data, coupled with measurements made with proximal sensors on machines, or arrayed on the ground, can be processed to create a dynamic, three-dimensional picture of soil, plant and environmental properties in a field. This picture would be composed of many layers of data, which singly or together can support specific management decisions.

Dairymaster

Every farmer wants easy and accurate heat detection, more calves at the right time, healthy cows and the best genetics possible: this is now possible with MooMonitor+, a wireless health monitoring system developed by Dairymaster, a world leader in dairy equipment manufacturing, operating from its head office in Causeway, Co. Kerry. MooMonitor+ is a wireless sensor that allows farmers to detect individual cow heats and health events with ease. It monitors cows on a daily basis and identifies specific types of behaviours such as feeding, rumination and levels of activity. These features can aid in detecting heats, monitoring feeding and rumination patterns, monitoring cow welfare and managing the health status of the herd. Through networking and cloud computing, MooMonitor+ literally allows the farmer to monitor his entire herd 24x7 with his phone. The mobile app allows two-way interaction with the system, thus removing the need to go back to the computer. When the system detects sick cows it will send an immediate notification direct to the farmer's phone. Real-time information has always been invaluable to farmers and with the MooMonitor+ accessing that information has never been easier. Decisions can be made more effectively and the data is always at the farmer's fingertips. The data is simple to understand and easy to interact with.

At the individual farm level, more precise data will be used to provide evidence of compliance with regulatory and quality assurance and traceability requirements.

At an aggregated level, use of big data will facilitate benchmarking, enabling farmers to compare their own performance with local, regional and national averages.

Properly pooled, structured and mined, large datasets can also assist the research community by identifying new areas for research, development and innovation.

Analysing this data is key to unlocking the insights to better decision making. These will need specialised big data analytical methods applied to them, which require more advanced artificial intelligence (AI) techniques and cognitive technologies in order to derive meaningful information and insights. It is likely that these new analytical technologies and methodologies will yield considerable insights, which may be derived in near-real time, enabling their inclusion in operational support. Already companies such as Google, IBM, INTEL and CISCO are working on these problems.

Another concept of importance for the future is the Internet of Farm Things or IoFT. This is a variation on the Internet of Things. Most people already associate the internet with a means to access information and services *via* web-pages or send messages using email. The Internet of Things is an extension of this concept to objects. This time it is the objects that access and provide each other with services and send each other messages. The poster child for this new paradigm is the refrigerator that knows when it is out of milk and orders it from a local store. It turns out to be a far more useful idea in the context of a factory. Here machines communicate their readiness for use or schedule components to arrive at an assembly bay. This idea has been extended to the farm and so the Internet of Farm Things involves smart machines such as tractors and feeders, as well as smart infrastructure such as fields, gates, sheds and water tanks, that not only sense their own status and that of the animals and crops but communicate with each other and with farm management systems to carry out tasks. It might be as simple as a video camera observing that an animal has become despondent and operating gates to isolate it from the herd while notifying someone on duty of the incident and logging it in the animal's health record. We are at the very start of learning how this new automation paradigm can be of use to the farmer, improving productivity and output while reducing the burden of work for personnel. Very powerful, easy-to use-technologies such as IFTTT and Realty Editor seem to provide components of the "connected farm"-connected by the Internet of Farm Things – that researchers and entrepreneurs are only now starting to understand.

Automation and Artificial Intelligence

Robotics and automation will play an increasingly significant role in helping producers achieve high levels of production with lower cost to the environment in 2035. For six decades, robots have played a fundamental role in increasing the efficiency and reducing the cost of industrial production and products. In the past twenty years, a similar trend has started to take place in agriculture, with GPS-enabled and vision-based self-guided tractors and harvesters already being available commercially. More recently, farmers have started to experiment with autonomous systems that automate or augment operations such as pruning, thinning, and harvesting, as well as mowing, spraying, and weed removal. In the fruit tree industry, workers riding robotic platforms have been shown to be twice as efficient as workers using ladders. Advances in sensors and control systems allow for optimal resource and integrated pest and disease management. This is just the beginning of what will be a revolution in the way that food is grown, tended, and harvested.

Teagasc Oak Park has just begun a collaborative project with research colleagues in Denmark (Aarhus University), Belgium (ILVO), Holland (Wageningen University) and industry (Gefion) targeting the optimisation of controlled traffic systems in crop production. With increasing weights of farm machinery, there is concern about the potential damage being done to soil structure and productivity. Controlled traffic farming (CTF), by using very accurate positioning technologies, offers scope to limit the soil damage risk. The Irish component of the project will look specifically at damage caused to soil and crops at field headlands. Teagasc will also examine the role of new soil sensors in offering much greater soil sampling resolution necessary for precision farming applications. The primary focus of the project will be to develop an operational tool in the form of a Decision Support System (DSS) to minimize soil disturbance and compaction involving specific operational tools.

The use of robotics, backed by advanced sensing and control systems, has the potential to make farming far less labour intensive, far more resource-efficient and environmentally friendly. Automated drones with appropriate sensors can monitor large fields quickly and precisely. With information from sensors on drones, satellites and ground-based equipment, the logical development is to have an automated managed response delivered either by an automated machine with some manual control or a fully automated robot.

The conceptual difference between full robots, or process – controlled actuators on machines, is largely academic. The concept that a management action or response can be automated to give either more precise control of some process, or to eliminate human effort or error, is the significant step. For example, the field response to crop sensing based on varying the application of inputs such as fertilisers or pesticides may be delivered by a conventional tractor using a fully automated spreader or sprayer. It could also be done using a fully robotic autonomous tractor. Full robotics will be used in certain processes such as automated milking and feeding systems. Robotic pickers will continue to emerge and in time be able to harvest a greater variety of crops. Smart farm infrastructure will automatically separate animals that are at risk of sickness as soon as the first signs of poor form are observed. Systems for strip grazing or the detection of heat will also be automated. These systems will not only automate the tasks, but will also automatically notify the producer that tasks are being carried out and provide a summary of the results when finished. This will save labour, free up the time for other tasks, and if done well, increase margins for producers.

Cost will be an important factor in these new systems. Farmers will only invest in these new systems if they come at an affordable price. Affordability will be just as important as functionality and performance in future research work in this domain. Many systems that have been widely adopted on very large farms in countries such as the US may not be suitable for adoption in Ireland due to the smaller scale of Irish production systems. New systems are therefore required that provide much better returns on investment and that are viable for even very small producers. This may be possible thanks to new revolutionary trends in manufacturing using 3D printing paradigms, open source hardware and very powerful low-cost easy-to-programme computing platforms based on technologies such as Arduino, Raspberry Pi and CHIP.

The use of automation not only applies to physical tasks; it applies to intellectual tasks as well. Unlocking the potential of big data will require a huge effort by researchers. Many of their tasks will be impossible without the help of new and emerging cognitive technologies, using techniques of "deep learning" and "machine learning" to help them manage the vast amounts of data that will be generated. New so-called "cognitive technologies", will help scientists sift through this data, formulate and test hypotheses and discover the key principles needed for a new science of sustainable intensification of agricultural production and, more generally, the sustainable management of agri-food and bioeconomy value chains.

Precision Agriculture

The use of these data collection, storage, analytical and automation technologies in combination in agriculture is generally referred to as precision agriculture. While this term was originally coined for spatially variable crop and field management, it is now used to describe the application of digital technologies to improve management precision in agricultural production.

According to the EU (2014)[36], “Precision Agriculture (PA) is a whole-farm management approach using information technology, satellite positioning (GNSS) data, remote sensing and proximal data gathering. These technologies have the goal of optimising returns on inputs whilst potentially reducing environmental impacts”. Recent research suggests that PA will be one of the ten key breakthrough technologies in the next ten years[37] .

Precision agriculture is an information-based decision-making approach to farm management designed to improve the agricultural process by precisely managing each step and managing variation in crops, soils and animals. In this manner, PA can provide a management approach optimising both agricultural production and profitability. Additionally, part of profitability can come from the optimised use of inputs (machinery, labour, fertiliser, chemicals, seeds, water, energy, etc.), leading to both increased production efficiency and protection of the natural resources.

Precision agriculture is based upon observing, measuring and responding to inter and intra-field variability in crops, or to aspects of animal rearing. The potential benefits mainly arise from increased yields and reduced costs through better management actions. Other benefits come from improved mechanisation efficiency, better working conditions, improved animal welfare and the potential to improve various aspects of environmental stewardship.

Precision agriculture is also applicable in the context of livestock farming, where it is referred to as Precision Livestock Farming. It may be described as an individual animal management concept based upon observing, measuring and responding to the animal and its interaction with its environment. It has been typically applied to the more intensive husbandry of pigs and poultry in the past. However, its relevance and application in dairying is now recognised and is progressing at a rapid rate. Processes suitable for the PLF approach include animal growth, milk production, cow nutrition from grass, the critical points in the dairy cycle that influence production efficiency, e.g. animal

36 EU, 2014. Precision Agriculture: An Opportunity for EU Farmers – Potential Support with the CAP 2014-2020.

37 Griffith, C, Heydon, G, Lamb, D, Lefort, L, Taylor, K, and Trotter, M. 2013. Smart Farming: Leveraging the Impact of Broadband and the Digital Economy, CSIRO and University of New England.

fertility, reproduction, genetics, detection and monitoring of diseases, aspects related to animal behaviour and animal welfare. In controlled horticultural conditions the application of PA is already being extensively applied. A new lettuce growing "factory" to open in Japan in 2017 provides a glimpse of where some visionary producers are heading[38].

Advances in sensing, monitoring and control systems have led to the development of automatic milking systems (AMS), now being marketed by several European manufacturers. In the absence of the daily individual animal contact associated with conventional milking, AMS systems typically use a number of sensors to monitor animal health and production. Systems to sense characteristics such as movement and temperature are also used independently of AMS systems; some may be simple birthing detectors, while others use the density of data and complex analysis algorithms to predict, birthing, oestrus, lameness, feeding and other health issues. These communicate management alerts to the farmer via SMS or phone app.

Precision Agriculture in Soils, Crops and Grass

The original PA concept was centred on precisely managing spatial variation in arable agriculture. Today, the technological infrastructure of PA in terms of positioning and machine control systems is well-developed and the conceptual use in terms of potential improved management is well understood. Machine guidance systems and GPS-based machine control systems have evolved. Consequently, machine efficiency in the field can be increased; inputs can be applied more accurately with automated rate and application control based on in-field position; standardisation of machine communications has improved; and logistics programmes can allow efficient management of machinery fleets in large-scale farming.

Support technologies such as yield monitors for all annual crops are well-developed and the whole area of crop reflectance sensing has expanded with a multitude of satellite, drone/UAV and proximal sensor data sources being available to users. Equipment and service providers are developing services to provide information, data analytics, hardware (machinery, control systems and sensors) and software solutions. All of these developments have increased arable growers' interest in precision crop production.

While harvested grass yield can be monitored, the yield monitor and necessary dry matter sensors are expensive. However, instrumented plate-meter measurement of grazed grass can provide grass growth on a paddock basis at each grazing, which when analysed with other farm management practices and analysed on a national basis, can become a powerful management tool. Satellite reflectance data is also used to monitor grass growth nationally.

PastureBase Ireland

In 2013, Teagasc launched PastureBase Ireland; today there are more than 1100 grassland farmers participating on the system. The PastureBase Ireland front-end is a web-based decision support tool, while its back-end is a grassland database. Numerous collaborations have been generated from PastureBase Ireland. One involves all of the main Irish and European grass seed companies in on-farm grass-variety evaluation. This will soon expand to cover clover evaluation on commercial farms. In the future, it is planned to get to a situation where the grassland information of all Irish farmers will be available in a single system. PastureBase Ireland will continue to play the role of grassland data reservoir for all grassland measurement systems in Ireland, such as the Grasshopper and any new developments which may emerge in future.

Despite developments and grower interest, the beneficial application of PA technologies to spatially manage crops has been relatively limited in arable crops. While the positioning and machine control functionality is now well developed, the cause of variation and the biological understanding necessary to interpret these, and to develop an appropriate management response, are somewhat lacking. There are still significant research and development deficits in:

38 https://www.youtube.com/watch?v=o1QXCnC-2h4

- Sensing appropriate crop and soil characteristics accurately, intensively and inexpensively
- Data analytics
- Understanding causes of variation in crops
- Combining sensor data sources and other data such as meteorological data
- Developing appropriate management responses.

While the current paddock management approach with grass should result in improved management, the issues concerning more precise management of in-field variability for annual crops also applies to grass. There is real potential to stimulate progress in this area, using recently developed data described above. However, in most areas this will require a thorough understanding of the biological processes which underpin crop growth to optimise sensor and analysis development leading to improved decision support. A process of co-development of sensing, data analytics and management response tools is necessary to progress this area. Crop and grass researchers need to be capable of mapping the entire crop production process to indicate the scope for development of PA processes at each stage of crop growth and development including:

- Soil and soil nutrient supply
- Crop establishment
- Early growth and development
- Nutrient uptake
- Pest and disease control
- Growth manipulation to favour grain or vegetative growth depending on the crop.

Within each of these areas, there is scope to develop improved sensor-driven applications. For soil cultivation in advance of crop sowing, for example, sensors for moisture, soil type and aggregate size during cultivation could be used to accurately control the intensity of cultivation and, subsequently, the seeding rate and depth to optimise establishment. This multitude of opportunities demands a prioritisation process to make quick early progress.

Understanding the biological processes underpinning each stage of crop development will help to focus on appropriate sensor and data analytics development, including the likely benefit of integrating other data inputs such as meteorological data to develop models and algorithms that would offer scope to produce more specific and precise management actions. The co-development model is particularly appropriate in the context of data analytics,

where new and more powerful computing skills may be able to identify useful relationships between sensed data and crop performance combining many data sets.

Conclusion

Enhanced sensors, sensor networks and data analytics, along with robotics and artificial intelligence (AI) or machine-learning, will be key components of significant change in many workplaces, including agriculture, around the world. These technologies will transform many jobs where a routine physical or mental task is repeated; robotics and AI will increasingly handle the routine, while workers will be free to focus on the exceptions that AI cannot handle. AI and data analytics will also increase productivity and the demand for non-routine and professional skills by reframing the way we design, coordinate, manage, deliver and assess products and services. Sensors will provide workers with a much broader picture of the processes they manage, improving efficiency and client satisfaction. Cheaper, mass-produced robots and autonomous delivery vehicles will change the flow, timing and flexibility of work.

Farming must become considerably more efficient on existing farmland by deploying more targeted and precise management systems. This requires new cost effective data sensing, storage, and analytical technologies that will facilitate and deliver more precise and accurate management data . Equally important is the research and development of the soil, animal and crop sensors and the data analytical capacity based on a fuller understanding of the complex physical and biological processes that underpin agricultural production. However, integrating these into a structured system is a prerequisite for delivery.

Theme 4: New Technologies for Food Processing

Over the past decade, the food industry has increasingly sought to eschew its image of "food and beverage" provider and position itself as a provider of "health and nutrition." This process is on-going and will continue to unfold for the foreseeable future. This is good news for Ireland as a major producer of pasture – based dairy and meat food products. These products have great potential as a vehicle for functional foods with a demonstrable impact on the health and well-being of targeted populations of individuals. Interestingly, the research underpinning needs of commodity food products has been largely ignored in the past, but since 2015, it is increasingly evident that the provenance of food commodities is becoming a differentiating factor in international trade. In particular, there is an increasing appreciation of foods originating from grass-fed animal production systems.

While this will be an important driver of innovation over the next two decades, it is not the only attribute that consumers desire. Increasingly, they also want food that is convenient, natural, nutritious, safe and sustainable. All of these attributes have implications for the actors in Irish agri-food value chains. Although there are conflicts inherent in simultaneously satisfying all of these criteria, promising new and emerging technologies will help the Irish food industry to succeed in adding value and address the needs of consumers who are increasingly motivated in their food purchases by health, quality and sustainability considerations.

New Food Processing Paradigms

Food Processing and Quality

Most food undergoes some form of processing, which can alter food structure, biochemical composition, nutritional and sensory quality. There is a need to establish the relationship between process-induced compositional changes in food, its processability and its fate in the human body as regards the digestive process and delivery of nutrients.

Novel technologies such as non-thermal can be used to reduce, for instance, thermal loading to maintain nutritional quality of food without compromising safety;

in particular, there is a need for alternative processes for both ready-to-eat and long shelf-life foods. In these instances, processing solutions are required to retain native food structures while not compromising organoleptic or physical attributes. Where possible, it would be advantageous to implement novel technologies which render a product safe and stable but close in nature to its raw state, thereby adhering to the diffuse concept of 'minimally-processed' foods, which is gaining trust amongst consumers.

Zero-Waste Processing

Opportunities can be created in food fractionation and preservation technologies to extend the current diversity of food production. The growing imperative to adopt more sustainable manufacturing processes, including energy and water/wastewater conservation, demands a quantum leap in re-aligning unit operations used in, for example, dairy product manufacture. Dairy manufacture in recent years has evolved along the lines of further processing of by-product streams, which is now proving to be less than the ideal starting point. This is particularly the case when manufacturing specific ingredients, as residual constituents such as minerals frustrate recovery efforts and create unwanted wastewater streams. Increasingly, concept ingredients are only considered valuable if their 'co-products' can themselves serve as raw materials for the development of additional value streams. In this way, the creation of one novel fraction from a food material necessitates pro-active product innovation on multiple fronts. This represents a significant shift from more reactive approaches prevalent in previous decades, where by-product streams were freely discarded to waste until a value-added outlet was developed by those willing to pioneer a new technology.

Promising results from research to date suggests that alternative milk processing scenarios may facilitate multi-dairy product manufacturing including functional and biological ingredients based on a zero-waste concept. At the present time, the enabling technologies to accomplish these changes are well advanced and certainly ahead of market preparedness for the next generation of dairy products and ingredients that may result from such change. Thus, the future may be set for a revolutionary approach to milk processing whereby milk, upon reception in the dairy, will be deconstructed and subsequently reassembled with the precision necessary to produce designated dairy products of consistent quality. The manufacture of a greater range of functional and nutritional ingredients using less complex processes will result. More significantly, there will be less waste to be treated and, consequently, the environmental footprint of the sector will be improved.

The concept can be extended to other foods by adapting scientific disciplines such as soft matter and food physics, which are rapidly providing understanding of physico-chemical forces behind food structure. This knowledge can be used for mechanisation of fractionation technology for more solid-like foods, possibly generating the next multi-fraction super food (besides milk). Likewise, if bio-refining of food is to succeed, new fractionation / isolation technologies are required for extraction of bio-molecules from foods with more viscous and more solid-like behaviour than milk (for example). The learnings from fluid systems can, of course, be used to develop new technological approaches to fractionation of a wider variety of foods.

The two core unit processes at the heart of milk powder manufacture, i.e. evaporation and spray drying, look set to dominate the milk processing landscape in volume terms for some decades to come. Consequently, the sustainability imprint of these technologies compels continual improvement in order to conserve energy and minimise emissions. At the same time, the increasing diversity of products and ingredients to be dried requires greater understanding of fundamentals of spray atomisation and milk drying. Here, technologists face a delicate balance between trying to achieve energy efficient mass transfer of water from the atomised concentrate while at the same time ensuring that product functionality is not impaired.

Nuritas™

Nuritas is a start-up Irish company founded by Dr. Nora Khaldi, a mathematician with a PhD in Molecular Evolution and Bioinformatics, to revolutionize the discovery of novel, natural and scientifically proven active ingredients that promote and manage our health. The company's disruptive computational approach to discovery uses artificial intelligence and DNA analysis to, for the first time ever, rapidly and efficiently provide access to the most health-benefiting components within food called peptides. Nuritas's patented life-changing peptides provide unique solutions for the maintenance of health and wellness, and in less than 12 months Nuritas has discovered 21 novel ingredients with exceptional efficacy, with many more in the pipeline In July 2015, the company received global recognition for the impact its technology will have on the future of food by being awarded the Top Innovation award at the Forbes 'Reinventing America Summit'.

New Processing Technologies

Research in the area of emerging processing technologies has potential to add value in the short-to-medium term to the agri-food and fisheries sector. Novel technologies including cold atmospheric plasma, ultrasound processing, high pressure processing, pulsed electric field, light-based technologies alone, or in combination with existing established technologies, e.g. spray drying and thermal processing, continue to generate interest in the food manufacturing sector. These state-of-the-art techniques can offer advantages when compared to existing processes.

The food industry relies heavily on post-harvest interventions and chemical-based decontamination to ensure microbiological safety and quality. Future research in the area of novel emerging technologies will offer potential new approaches to food manufacture, increasing growth opportunity for an Irish agri-food sector that can clearly demonstrate its comparative advantage in terms of the sustainability of its production systems.

Specific areas of interest in food processing include:

Application of non-thermal technologies such as plasma and power ultrasound for improving shelf-life and altering the techno – and bio-functionality of a range of food products, high pressure with high temperature (HPT) processing; improved safety profile of foods and

ingredients by exploiting synergistic effect of non-thermal combined with conventional thermal processing technologies such as shockwave steam injectors.

Evolution of extraction technologies such as ultrasound, microwave-assisted extraction, high pressure, and super critical fluid extraction for improving extraction yield. These extraction techniques are considered as clean and green, which enhances consumer confidence in food products.

Bio-transformation using microbiological or enzymatic-based fermentation technology for conversion / functionalisation of proteins, carbohydrates or fats. A platform technology for generation of new foods and ingredients with enhanced functional properties including those with potential health benefits.

Freezing technology is evolving rapidly with changes in consumers' lifestyles. Globally, the frozen and chilled convenience food market is a rapidly expanding sector, with the global frozen prepared food industry expected to reach sales of €142 billion by 2015[39]. In recent years, a ground-breaking instant freezing technology developed in Japan known as "Cells Alive System" (CAS) has been gaining attention as a method to address the problem of stability of food texture. With CAS technology, the food is placed in a magnetic field that inverts repeatedly so the food undergoes rapid freezing while being vibrated. According to scientists, the process of CAS freezing occurs instantaneously thus minimising changes to the innate structure of the food. Other emerging technologies for sustainable freezing of food for preservation include high pressure assisted freezing or pressure shift freezing, ultrasound assisted freezing, magnetic resonance, electrostatic, microwave, radio frequency, impingement and hydro-fluidisation freezing, the benefits of which will be improvements in product quality *via* rapid freezing.

Auxiliary to processing – Process Analytical Technology (PAT), which will be core to integration of processing lines throughout modern manufacturing plants of the future. The term "analytical" in PAT is viewed broadly to include chemical, physical, microbiological, mathematical and risk analysis conducted in an integrated manner. It refers to the concept of designing, analysing and controlling manufacturing through timely measurement during processing of critical quality and performance attributes of raw and in-process materials and processes with the goal of ensuring final product quality. Technologies used in PAT include pulsed light or ultrasonic technology in cleaning, combined with the use of spectroscopic analysis to ensure thoroughness of cleaning, imaging systems to ensure homogeneity of blending and spectroscopy for colour control or detection of impurities.

Biorefining

Developments in processing technology, coupled with biotransformation, can realise opportunities for development of high – quality ingredients and compounds from both raw materials and waste side streams. Biorefining can involve transformation of proteins, carbohydrates, fats, fibres or their molecular components into new food materials. Coupled with developments in separation/fractionation, thermal and thermal and chemical processing technologies, a wide range of new food structures can be made. Advances in enzymatic and microbial fermentation technology can be utilised to create new functional compounds from primary and secondary streams during food processing. The technology should contribute to more sustainable food production with potential to substantially reduce food waste. Biotransformation will involve a major investment in identification of novel strains of microorganisms with the ultimate aim of developing new bioprocesses for conversion of food nutrients and associated waste streams into ingredients with new functionality or for other non-food applications.

Synthetic Biology

This describes an emerging field of science whereby biological molecules or indeed microorganisms are synthesised in the laboratory. The capacity to synthesise short single stranded DNA molecules has been available

39 Bord Bia, 2014. Annual Report and Accounts. Dublin: Bord Bia.

for some time and was a major technology in driving PCR, DNA sequencing etc., over the last decades. Peptide synthesis is also possible and is now used extensively in research. Significant advances are being achieved in both areas and individual gene synthesis is now possible. It is to be expected that in the period to 2035 significant advances will be made which will open opportunities for "biological site directed" solutions to resolve current problems in food, nutrition and medicine. Typical initial examples may relate to production of particular flavour compounds or proteins with designed bio – and techno-functionality. As the technology develops, it will lead to more advanced applications where synthetic microorganisms will be used in large-scale fermentation that may include mixed cultures of both synthetic and natural microorganisms producing foods or food ingredients at large scale.

Food and Synthetic Biology

In 2028, synthetic biology will have the potential to produce different kinds of food, including meat and drinks at lower cost than today. By manipulating genes, brand-new foods can be created with new properties or flavours. The bio-production industry is expected to reach $100 billion by 2020 alone. This technology, which uses glass or plastic vats (bioreactors), and needs only sun or sugar, algae and nutrients, can be located anywhere.[40]

Aspects of this technology will emerge during the period to 2035 and some may be quiet disruptive. As the approach will be novel, it will require parallel discussion and education of the consumer to ensure acceptance of these new approaches.

Ireland has positioned itself as a producer of high quality beef from an environmentally friendly pasture-based feeding system. Competition may one day come from new entrants to the meat market such as "Modern Meadows", a company backed by venture capital funds from Google that produces meat *in vitro*. It is another issue whether consumers will want to eat meat grown in a vat. Most likely, this will emerge as a highly efficient alternative to traditional meat production, which initially at least, will mainly find application in prepared food products.

40 Policy Horizons Canada, 2013. Metascan 3. Emerging Technologies.

Cell factories

Gene editing, which enables the alteration of existing genes, is a technology which is currently receiving much attention and is likely to have demonstrated many useful applications by 2035. In addition to using microorganisms, there are many food processing technologies that exploit microbial enzymes or enzymes produced by microorganisms during fermentation. It is to be expected that there will be significant advances in this area during the period to 2035 and, with growing consumer acceptance, cell factory technology will be applied across a range of areas, not only for production of enzymes, but also for the production of particular foods/food ingredients; for example, the technology to produce individual milk proteins already exists and this could be used to produce dairy ingredients comprising of single (or small numbers of) proteins. This will open up a wide range of applications, in particular in the fermented foods area. The advent of stem-cell technology is also opening up the opportunity for the likes of *in vitro* meat production and meats for ingredient application which could become a real scenario for 2035. The uptake of this technology will largely depend on consumer acceptance in the context of an expanding global population mainly outside of Europe.

Single cell foods

A key challenge for the food industry over the coming decades is supplying the growing demand for protein. Existing food production technologies may not be sufficient to satisfy this demand into the medium term. The Cell Factory approach described above could be used to combat part of this challenge, but another approach is to use the microorganisms themselves as a source of protein i.e. Single Cell Protein (SCI). This concept has been studied for some time and there are both technological – and consumer – related challenges. However, it is likely that further research will begin to address these. It is likely that up to 2035 this is a topic that will receive growing international interest and that food or food ingredients based on this technology may be more common towards the end of this period.

3D Printing and Food-Related Robots

3D printing (or "additive manufacturing") allows highly customised parts and products to be printed on demand. It is already being used to produce a wide array of products from furniture and clothes to auto, airplane and building parts. Boeing is working on printing airplane wings without rivets. R&D efforts are increasing the capability to print with a growing number of materials, allowing for ever-increasing sophistication of the products that can be made with 3D printing.

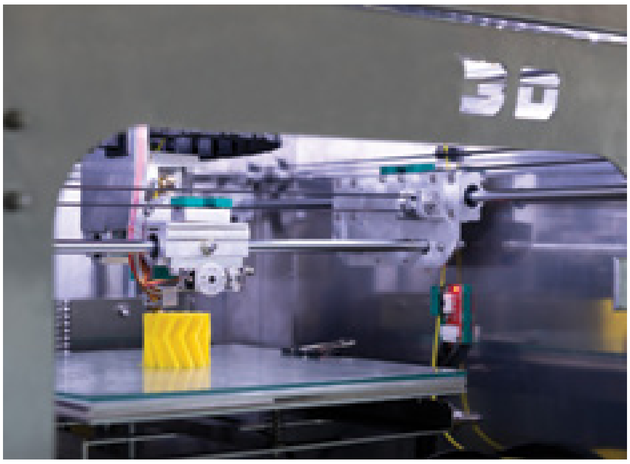
This kind of technology will lead to new types of production systems for the manufacture of complex multi-material products. Applications for this can be found among a whole range of sectors including electronics, solar cells, lighting and food**.** TNO (Netherlands) has already demonstrated 3D food printing, drawing on its knowledge of mechatronics, 3D industrial printing and specific food knowledge in the areas of ingredients, formulae, texture and structure. Some US institutions and private companies have also used the process for creating food products.

By 2035, we expect it to play out in the food industry as an enabler of personalised service, where food is the vehicle for a comprehensive range of nutrition, health and lifestyle related services.

Food for Nutrition and Health

Food structure

A priority for the food industry is to align nutritional science, food and omic technologies to tailor foods for health. Food structure has, and will continue to have, a key role in reducing salt, sugar and fat in food; alterations in food composition will necessitate further research in taste perception physiology and taste receptor function, flavour chemistry technology etc. Replacing sugar in food requires development of natural sweeteners through understanding of the metabolic effects of different sugar molecules, taste and texture. Similarly, reduction in fat will continue to challenge scientists to understand the role of food structure, chemistry and the effects of fat on the physiology of mouth feel and satiety effects.



The applications of this science are wide-ranging and include all areas of lifestyle nutrition including sports, infant, adult and special purpose medical foods. For instance, food can be designed to delay gastrointestinal food passage and slow glucose absorption resulting in less dramatic fluctuations in blood glucose and decrease the need for insulin. Food design may be based on novel protein-carbohydrate interactions, viscosity, fibre content, glycaemic index, energy density, particle size, degree of hydrolysis and insoluble carbohydrates. Ultimately, this can lead to new foods for disease mitigation, often referred to as personalised nutrition for proactive prevention.

Alternative sources of protein

By 2050, it is predicted that more than 30% of protein consumed will be from non-animal sources, giving rise to a need for new sustainable sources of protein to feed the growing world population. Understanding the functionality of these proteins during processing and the ensuing effect on physical properties of liquid or powder have already, and will continue to be a focus of the scientific community. Future work in the area should provide ingredient manufacturers with scientific knowledge pertaining to technological hurdles associated with incorporation of novel proteins into existing foods and beverages. The research will be transferred to industry to reduce cost and provide novel functionality for development of new nutritional products and, in some instances, be extended to development of therapeutic applications for the developing world. The highly functional and structure-forming characteristic of proteins allow for re-formulation and re-engineering of existing foods for value added and future innovations.

Investigating the production of food ingredients, including algal proteins from seaweeds using novel technologies, offers interesting applications in the food ingredient and nutrition field. Algal proteins and other components including betaines, carbohydrates and lipids are known to have antioxidant and other techno-functional and health attributes. Research in this area must be underpinned by novel processing technologies including accelerated solvent extraction, pulse electric field and fractionation technologies to optimise algal cell rupture to enable maximum recovery of components. In addition, high pressure homogenization, cavitation pumping, high shear mixing and ultrasonication as part of a combination process, including drying methods, will optimise algal protein quality, yield and functionality using an economic and environmentally relevant biorefinery process.

Life – stage Nutrition and Healthy Eating

One area which will receive increasing interest is healthy foods for infant and mother or expectant mother. Similarly, by 2050, 22% of the global population will be over 60. Life-expectancy in Europe will be 87.4 years for men and 90.6 for women. Promotion of healthy eating creates synergy between longer life expectancy and longer life with good health. Food design must be tailored to address the ageing target on the basis of taste, appetite, needs of muscles and brain as well as the health of the gastro-intestinal tract.

Scientists believe that diet can enhance cognitive performance and protect the brain from damage and even counteract the ageing process. Protective brain-health benefits of omega-3 FAs have been shown to span from *in utero* right through to later life with associated reductions in the risk of Attention Deficit Hyperactivity Disorder (ADHD), autism, bipolar disease, depression and dementia. An increased intake of omega-3 FAs and antioxidants, even when taken in later life, may be beneficial for the ageing brain. Because ageing is associated with changes in lipid composition in the brain, supplementation with phospholipids, which are fundamental components of neuronal membranes, has been suggested as being an effective therapy for preventing cognitive decline. Milk by-products such as buttermilk are phospholipid-rich as a result of the disruption of the milk fat globule membrane during butter making. There is increasing commercial awareness of the need to develop processes for the enrichment of milk phospholipid-rich ingredients, and further research is needed to characterize the neurological benefits of these fractions.

Advanced Formulation Technologies

With advances in analytical techniques and understanding of food structure, technology to support food engineering will be used to combine proteins, fats and carbohydrates in an ideal solvent, e.g., water balanced with minerals and vitamins. This approach can utilise colloidal, physical and soft matter sciences to form the basis for advanced food formulations targeted at lifestyle nutrition, i.e., foods for the infants, growing-up, teenage, middle-aged and elderly. Additionally, it will enable foods targeted at extremes such as sports applications, cognitive, disease prevention, metabolic syndrome and health in general. The latter can be generalized under ‘food for health’ benefits, while understanding that fresh and fermented foods can also fall under this category. Scientific understanding of food chemistry and physical sciences can allow greater concentration of food formulations during processing for subsequent transport and storage, thus reducing cost throughout the supply chain. The ability to create ‘super concentrates’ will develop from scientists’ knowledge of the behaviour of proteins, carbohydrates and minerals in different colloidal systems. This ability to stabilise complex nutritional concentrates will facilitate reduced processing and transport costs. The concentrates can be for dilution into an end application close to the market for mainstream retail outlets and / or ‘in-office’ dispensers, i.e., the soda stream of the future.

Application of Sensometrics

As a predominantly food exporting country, Ireland’s food producers and processors need to be constantly vigilant to the ever-evolving market conditions and consumer tastes in the countries to which foods are exported. Ultimately, the organoleptic properties of food will still remain as the key consumer selling point for food. Sensometrics is the application of mathematical and statistical methods to elucidate associations between sensory, chemical and consumer sciences, underpinned by increased knowledge of flavour chemistry including volatile and non-volatile compounds. The sensometric approach opens new avenues for creating flavour maps of foods, which can be related to consumer perception and preference. Both descriptive sensory analyses, volatile and non-volatile analysis techniques try to quantitatively determine the key characteristics that define flavour as perceived by the consumer. This is quite difficult and heavily influenced by the complexity of the food product and, in particular, by the fact that some perceived flavour attributes are not produced by single compounds but by the interaction of multiple compounds and the food

matrix. However, utilisation of a chemometric or sensometric approach, which can manage complex independent data sets (chemical, textural, compositional….), can help identify critical trends and associations by linear and non-linear modelling to develop individual flavour maps of products.

Food Quality and Safety

The food industry has seen significant scientific and technological advancements, but food-borne contamination outbreaks and cases of fraud are frequently reported. In an increasingly global food market, changes in food production systems and in consumer eating habits will continue to place a greater burden on global food safety systems. Thus, a greater emphasis needs to be placed on addressing these global food safety concerns and on counteracting the increasing risk for contamination along the food chain. Technological developments will be essential to facilitate the rapid and sensitive detection and tracing of pathogens, chemical contaminants and allergens in raw materials, fresh and processed foods along the farm-to-fork chain. Apart from improving laboratory-based detection technologies, there is a particular need for hand-held mobile devices for use in-the-field in primary production and on-site in food production and processing facilities. Developing technologies in the area of electrochemical, optical and piezoelectric biosensors, ‘omic technologies, whole genome sequencing and mass spectroscopy linked with ICT and big data handling have the potential to provide such solutions.

In particular, the continuing development of molecular techniques will have a major influence on food producers’ ability to detect and identify food spoilage microorganisms in food production plants. For example, it is now possible to map the complete microflora in processing environments, identifying potential practices that might cause microbial contamination.

The detection and identification of pathogens using rapid techniques will improve safety and efficiency of manufacturing. It will be possible to release foods rapidly, reducing inventory and increasing throughput in food processing plants. The rapid emergence of new regulations for residues and other contaminants represents a further challenge.

The generation of advanced analytics to understand food chemistry, structure and functionality during manufacture and extended supply chain can be utilized here to ensure food safety in the future. The area of food safety considers food traceability from consumer to farmers and producers and will promote transparency as to how food is produced and processed.

Continuing developments in instrumentation and methodologies will lead to greater sensitivity of testing and ability to measure a greater range of contaminants in food matrixes and this trend will impact on global food trade, highlighting the need for harmonized risk assessments among regulators and risk managers.

Advances in novel processing technologies (including non-thermal), which can be implemented to reduce contamination along the chain, have the potential to greatly enhance food safety and extend shelf-life. However, it is essential when introducing such new technologies that a full risk assessment is also conducted to ensure they do not introduce new food safety risks.

Advanced Packaging Technologies

A key aspect in future development of food products is the development and application of novel packaging technologies. In order to reach distant markets that present more logistical challenges to the movement of food and beverage products throughout the ever-expanding distribution chain, packaging materials must evolve to provide the technical functions of containment, protection and preservation to an even greater degree. Consequently, packaging materials must be capable of addressing greater environmental extremes of temperature, humidity, handling and so on, while still providing the seals, barriers and strengths necessary to deliver extended product shelf-life in an environmentally-friendly manner. Additionally, the global growing trend for convenience is continually creating 'demands on' and 'opportunities for' the food industry and as convenience is very much linked to the provision of information, the provision of product convenience through novel packaging development is now a fundamental issue that must be considered as part of new product development. For example, the provision of convenience through packaging allows for products to be more easily-opened by consumers such as the elderly, yet provide information on whether these products have been tampered with or counterfeited in some way. The functionality of the pack itself (self-sealing, self-heating, self-cooling, self-insulating, self-cleaning) can be a powerful differentiator for food and beverage manufacturers in a future global marketplace.

Future packaging technologies include the development of smart systems which; contain nano-technologies, are active in nature (which interact with products to extend shelf-life), are intelligent in nature (which inform on the quality or safety aspects of the product) or which can provide all of the technical functions of packaging, but be derived from sustainable resources and be compostable or biodegradable. Active packaging incorporates technologies to control deteriorative processes in food and beverage products such as oxidation, microbial growth and so on. Intelligent packaging concepts provide information that assist in monitoring food quality or safety through the use of indicators, sensors or biosensors. The use of radio frequency identification (RFID) tags or labels can be used for the tracking and identification of food and beverage products. Coupled with nano-electronics, packaging materials have become a media source and an advertising platform, i.e. digital flexible packaging – a concept that could support delivery of foods, bought over the internet, to the workplace in emerging megacities around the world. In this instance, the packaging material could be reusable.

Theme 5: Transformation in the Food Value Chain System[41]

Introduction

Technological change is any change to the production system that results in a change in productivity. Yet the concept is often only used to mean the adoption of new technologies in the form of "things" or services, involving, for example, the emergence of new products or production processes. However, some of the most important forms of technological change have stemmed from changes in the structure of the production process, for example, changes in scale, changes in specialisation or changes in the relationships between components of the value chain. The most famous technological change in industrial history is the development of the "assembly line" by the Ford Motor Company, which falls into this category. It is these types of technological changes that are considered under this Theme.

Primary Production

The structure of farming has changed very little in the last two to three decades, with the total number of farms declining by only one per cent per year. The widespread availability of off-farm employment

41 STOA, 2013. Technology Options for Feeding 10 Billion People: Synthesis Report: Options for Sustainable Food and Agriculture in the EU. Brussels: European Union.

European Union, 2015. Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy – A Challenge for Europe. 4th SCAR Foresight Exercise.

opportunities throughout the 1990s and early 2000s, and the increasing value of decoupled direct payments, have allowed even low-income farms to remain in business and have acted as a barrier to major structural change in the sector. The land-based, decoupled direct payment policy regime is likely to continue into the next decade and possibly beyond and, as such, will continue to be an impediment to major change in land ownership and structure. Notwithstanding this, there are a number of major catalysts for change looming on the horizon namely, the removal of the milk quota regime, the low-cost and widespread availability of technologies, the pressure to farm in a more environmentally friendly manner and growing societal demand for non-production land uses.

The removal of the milk quota regime can be considered a “trend-breaker”, as it presents Ireland’s most profitable farm sector with the first growth opportunity in a generation. It is envisaged that Ireland’s milk production will grow significantly over the next decade. This will give rise to highly specialised dairy farms with many traditional activities outsourced, such as the rearing of replacement animals, slurry spreading, silage making etc. This will create demand for a larger and technically more sophisticated ancillary farm contracting sector. Furthermore, there will be greater demand for labour-saving technologies, such as robotics and sensor-based technologies, to assist with milking, feeding and herd management, as well as greater demand for and use of sexed semen and genomics to increase the overall productivity of the herd.

The removal of the milk quota will also likely stimulate restructuring of land use. While changes in land ownership may be slow to occur due to a myriad of socio-cultural and policy factors, alternative models of land use and management are likely to emerge to facilitate change. Already there is a growing demand for long-term leased land, supported by recent taxation incentives, and collaborative farming models such as partnerships, share milking and contract rearing. It is likely that such models of farming will become more common and will be a channel for new entrants to the sector, even perhaps more diverse entrants from non-traditional farming backgrounds. Furthermore, such farm models will facilitate the transfer of skills and knowledge among farmers, increasing the human and social capital of the farming sector. The flow of new entrants to the sector will also be a catalyst for change as they are likely to be younger, better educated and more receptive to a wider range of technologies.

The lower cost and more widespread availability of technologies in the future may be another “trend-breaker”. To date, the non-dairy farm sector in Ireland has been characterised by relatively low rates of innovation and technology adoption, with the cost of many technologies such as robotics, precision agriculture and digital based technology being prohibitive for the large numbers of small, low-income farm holdings in Ireland. The recent emergence of the smartphone as a cheap and accessible technology platform has changed farmers’ engagement with technology and will continue to do so in the future. It is now plausible that even small, low income farms may embrace a wide range of technologies to increase the technical and economic performance of their farms without substantial investment requirements.

The need for sustainable intensification will also be a major catalyst for change in Irish farming and may be considered another “trend-breaker”. Over the coming decades there will be increasing pressure, both from international agreements and consumers, to produce growing volumes of food in more environmentally friendly ways. This will give rise to changes in land use and will stimulate changes in production systems and the use of technology. Farmers will explore ways to exploit technology to reduce their carbon and water footprints. Sensor-based technologies will be used to understand and improve livestock nutritional strategies and fertility management, while genomics will be used to breed more carbon efficient animals. Precision farming will be used to support more nutrient efficient farming systems, while alternative cropping systems like min-till and zero-till may become more commonplace. More functional land use policies are likely to emerge, which will balance the need to use land for production with other uses such as carbon sequestration by encouraging the planting of forests and other carbon sinks and the rewetting of marginal lands.

Land use change may also arise in response to the growing demands from society for non-production uses. Social farming, urban farming and recreational land use are growing in the densely populated countries of Europe and it is a trend spreading to Ireland. This will present farmers with both the challenge to balance this increasing societal demand with their traditional production opportunities and the opportunity to exploit the commercial aspects of this growing market.

Processing

There is no doubt that by 2035 the food processing sector (mainly dairy, meat and prepared consumer foods) will have experienced structural changes relative to today. Many of these changes cannot be anticipated at this juncture.

In dairying, we will continue to see change in the Irish dairy product mix. There has been a strong increase in cheese consumption and a diversification in cheese varieties and these are important developments in broadening the market base (number of countries) into which Irish cheese is sold. There has also been the move upward in the value chain towards the production of food ingredients to be used in further processing (including milk proteins) rather than the more traditional milk products that Ireland had been known for internationally. These trends are likely to continue, as is the trend towards greater integration of the dairy sector across the whole of the Island.

By 2035, Irish milk deliveries will have increased significantly. This presents the sector with clear challenges. It will need to find markets for the additional milk and there is a need to at least maintain, and ideally increase, the overall margin achieved across the entire milk pool in line with this expansion. Higher margin markets, such as the domestic Irish market and the market in Western Europe, are mature and will grow only slowly, if at all. The important UK market has seen its dairy sector recover at farm level in recent years, which may limit export growth potential to the UK for Irish dairy products. Collectively, this suggests that the growth in Irish milk production will be more easily absorbed on the global market, outside the EU.

It may be desirable to limit the increase in commodity production that takes place, as this is a highly price competitive market for comparatively homogeneous products. However, due to the envisaged large increase in Irish milk production, a redoubling of effort in the development of markets for higher value dairy products is required. The current product mix still relies on a very high share of milk being processed into basic commodities. For example, were this product mix to be maintained, then a market would need to be found for an additional 150,000 tonnes of Irish butter annually over the next 15 years. Alternatively, by further developing niche product areas, the dairy sector in Ireland may be able to divert a considerable proportion of its increased production towards higher value products, supplying markets with higher margins and facing less price competition from competitors.

Some of the issues which the Prospectus 2003 report[42] identified have been acted upon. The Irish dairy sector has seen movement up the value chain and there has been some consolidation of processing activity. However, at the time of writing in 2003, the Prospectus report envisaged a more challenging trading environment than has actually emerged over the following decade and hence we have not seen the extent of industry consolidation in the processing sector in Ireland that the report recommended. It can be argued that the economic forces were not there to necessitate a greater degree of consolidation over the last decade or so.

The pressure to increase processing scale will continue. Scale here has two interpretations, namely the capacity of a processing facility (hourly capacity of dryers etc.) or overall business entity scale (how large the business becomes in terms of turnover).

The building of larger processing plants is something of a “race to the top” in that trying to match global leaders in processing scale is like trying to hit a moving target. What is large scale today may be considered of average size in 10 or 15 years’ time. The relentless pursuit of processing scale is only necessary if the only strategy is to be the cheapest producer of a highly standardised product. New Zealand has adopted this strategy out of necessity, in part due to its remote location and also due to its vast export capacity. Ireland does not need to follow suit. There are virtues in retaining a moderate processing scale, if the strategy is to try to produce more tailored products that are fully aligned to the specification of various business customers. This type of alignment cannot be achieved if very large scale processing capacities are selected. The flexibility offered by moderate scale to better meet customer specifications can therefore be seen as advantageous.

By contrast, with respect to the scale of the business entity, there is certainly scope for increasing scale in the dairy processing industry in Ireland. International comparisons of processing industry concentration are complicated by data limitations. However, even a simplistic comparison with some competitor countries in

42 Dairy Industry Prospectus Report 2003 – Strategic Development Plan for the Irish Dairy Processing Sector
http://www.agriculture.gov.ie/publications/2000-2003/dairyindustryprospectusreport2003/

terms of the share of the national milk pool processed by the largest processor, is revealing. In Ireland the largest processor has about 30% of the milk pool, whereas in the Netherlands and Denmark the corresponding figure is closer to 80% and in New Zealand it is about 95%. Scale can achieve a range of efficiencies in a processing and distribution context. But scale can also spread R&D and marketing expenditure across a larger turnover volume, creating greater scope for product innovation and brand development. Increased processing industry concentration would also likely reduce the competition between processers in terms of milk price. A possible long-term adverse consequence of the high degree of pricing transparency in the Irish milk sector at present is that it creates perverse incentives. Price transparency may discourage some processors from adopting a more long term perspective and adversely influence their attitude with respect to R&D, marketing spend or overall investment in brand development. There may be excess focus on the *here and now* and money invested in R&D and marketing by a processor to bring future benefits might be seen as putting too much pressure on short term capacity to pay a competitive milk price. Such thinking is not in the long-term interests of the sector at either a processing or a farm level.

Consideration of the appropriate consolidation of the existing processing infrastructure may need to take place in both an economic and political context. It is not clear that the environment currently exists that would allow for consolidation, given the different perspectives among processors in various parts of the country. There are strong local political factors that may militate against mergers and acquisitions. In the short term, the economic arguments for consolidation may have been reduced due to the removal of milk quotas, which will allow processors to expand their business through increased milk volume, rather than exclusively through adding value to a fixed milk pool. The existence of a greater number, rather than a lesser number, of processors may, on the one hand, create competition for milk which might benefit farmers in terms of milk price, at least in the short term. However, it might be more advantageous from a processing industry perspective to have fewer processors competing to sell to supermarkets and other customers, both in Ireland and internationally. The pros and cons of having greater market power along the supply chain needs to be considered from multiple perspectives.

Small scale Irish artisan dairy processors will continue to innovate and produce niche products, mainly for the Irish and possibly UK market. However, there will be limits to the contribution that artisan-type production can make to the development of the overall dairy sector. The scale of Irish milk production relative to the size of the domestic market will be a constraining factor in the growth of the share of the milk pool represented by artisan production. Given its very high self-sufficiency in milk, the situation of the Irish dairy sector is similar to that of New Zealand and contrasts strongly with that of a deficit milk producer (such as the UK), with a large affluent domestic customer base and a home country product preference.

Internationally, new markets for dairy products will be developed, particularly in Asia as incomes continue to increase and consumers gain a greater exposure to Western foods. Establishing Irish dairy brands in these markets will be challenging, but there is a considerable first-mover advantage associated with being among the first into these new markets. Irish processors remain small in scale by international standards and may lack the resources individually to establish themselves in these new markets. There is therefore a role here for collaboration between processors and between other entities with a responsibility for the marketing of Irish food.

Infant formula production represents a success story for the Irish dairy sector, but to fully exploit the financial rewards of this high margin product, opportunities for brand development, particularly in newer markets may need to be explored. Otherwise, much of the price premium will be retained by the international brand owners. Just as in any niche market, profits will dissipate as competition increases. However, branding and perceptions of quality, are a strong feature of the IMF sector, so that may limit price competition and solidify Ireland's competitive advantage in this market.

There are risks, however, that competitor countries could secure investment from the big players in the IMF market and thereby challenge Ireland's position. The fact that the Irish dairy sector is a supplier of raw materials for the end product, rather than the brand owner remains a limiting factor, as is the fact that we only supply the protein requirement for IMF. The end product is much higher margin than traditional dairy products but there are limits to which brand owners will be willing to pass that margin back to Irish dairy processors and onto the milk producer. The sector in Ireland has some bargaining power because international IMF manufacturers are already located here and would face costs were they to leave and re-establish elsewhere. But there is nothing to stop these IMF producers from importing some or all of the protein required for IMF production into Ireland rather than source it here in Ireland.

Food Service, Distribution and Retail

One of the most important drivers of change in the food industry is change in life-style and other behavioural patterns of consumers. These changes will have an impact on food supply chains, propagating backwards from the consumer and distributor all the way to the producer, influencing the varieties produced, the way they are managed and the manner in which they are harvested, driving the demand for services for farmers able to draw upon the extraordinary advances in service design and implementation. This will be made possible by the convergence of powerful new low-cost, high-speed technologies in genetics and microbiotics, sensors and communication, as well as by advances in the interpretation of big data using cognitive technologies, machine learning and artificial intelligence.

Behavioural science used to be a soft science that relied on observation and interviews with relatively small groups of people. It faced significant challenges due to the complex nature of the phenomena it tried to understand, as well as the often subjective nature of views accessed on the basis of interview, as well as external observations of scientists and field workers. This has changed with the advent of the internet and even more so with the widespread adoption of mobile technology. It is set to change even more thanks to the availability of ubiquitous connected sensors driven by developments in nanotechnology. Over the next 20 years, it could drive a radical transformation of the food sector based on the introduction of personalised value-added data-driven services to accompany consumers as they shop for food, order at restaurants or eat at home.

These new services will embed insights from genetics, microbiotics, medicine, nutrition and behavioural science, made actionable by advances in wearable and embedded technologies, as well as social and companion robotics, enabling companies in the 'health and nutrition' sector to extend traditional food products with value added services.

New insights are paving the way for new types of food-related entrepreneurial activity that will radically transform the experience of shopping for food, eating at restaurants, at home or at work, between now and 2035.

This will be driven by an abundance of personalised data that was previously unavailable at reasonable cost and sufficient scale, including data related to the genotype of individual consumers. Based on the extraordinary rate of progress in genotyping technology, scientists believe that somewhere between 100 million and 2 billion people will have had their own genotype sequenced by 2025. Whatever the figure, it seems likely that by 2035, most consumers in advanced economies will have sequenced their own genotype, either out of curiosity or because it is routinely required by their insurance companies and healthcare service providers.

Another source of data is that provided by the whole area of wearable technologies. This domain of applied ICT is being pioneered by consumers interested in performance for work or sports for elite performers. It is also being developed by communities that are under-served by current medical approaches to chronic conditions related to diet and well-being, as well as by an increasing number of people interested in environment or animal rights who want to consume in a way that is consistent with their personal beliefs and values.

We are on the verge of an ICT revolution that, driven by nanotechnologies and carried to the consumer by wearable devices, will enable each individual to track what they eat, how, when and in what quantity, as well as the immediate and longer term impacts this has on performance, health and well-being. We are only at the start of this revolution, but it will provide food – and lifestyle-related service entrepreneurs with the ability to track consumer behaviour in real time and intervene using mobile and other devices to nudge people towards healthier lifestyles and better patterns of consumption.

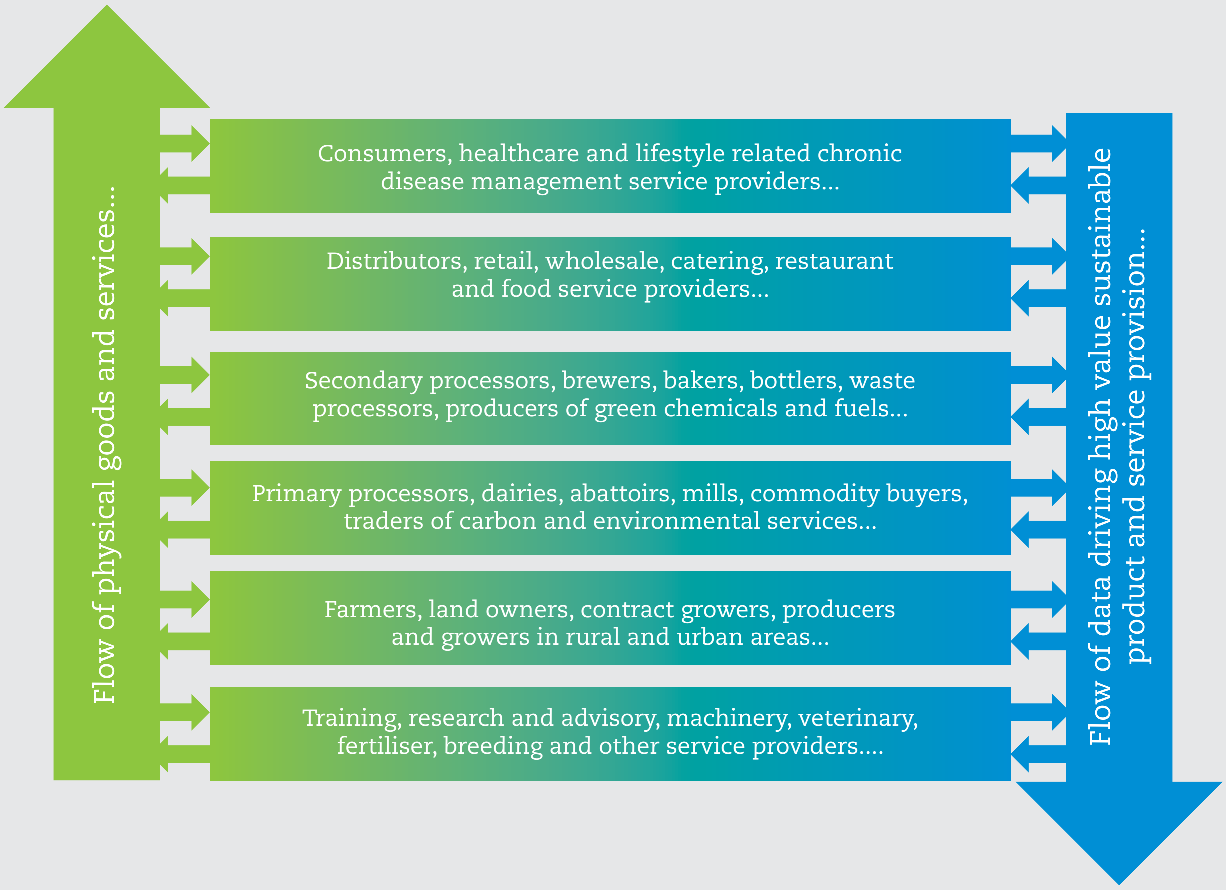
In an increasingly connected, interactive world consumers will increasingly engage with other actors in the food system and will expect food companies, in particular, to seek out and address their opinions and wishes on an on-going basis. The need to respond and facilitate consumer engagement will be crucial in determining, both their future health and wellness, the sustainability of the food system and the progress made with the introduction of disruptive new technologies.

Impact of "Big Data" on the Food Value Chain System

All components of the food value system will be affected by the "big data" revolution (see Figure 3.3 and the Table 3.2). This development has the potential to greatly improve efficiencies across the chain by improving communication among the various components and by reducing price volatility. It will also enable greater precision in the responses of producers, processors, distributors and retailers of food to consumer requirements, including at the level of the individual consumer.

The value chain in 2035 will include a very important counter flow of data being progressively transformed along the way by a range of dedicated providers of services ranging from data gathering, storage and transmission, to primary processing and re-purposing of data using techniques of artificial intelligence and

Figure 3.3: The Food Value Chain System



cognitive science, to secondary processors who add-value based on their deep understanding of the fields of human, animal and plant health and nutrition, agronomics, accurate local weather and climate forecasting. This will enable the provision of personalised services for health and nutrition at the consumer end, energy and resource management services for intermediaries, performance and productivity – enhancing services for growers and producers, as well as combinations of fee and subsidy-based ecological and environmental services for the public sector.

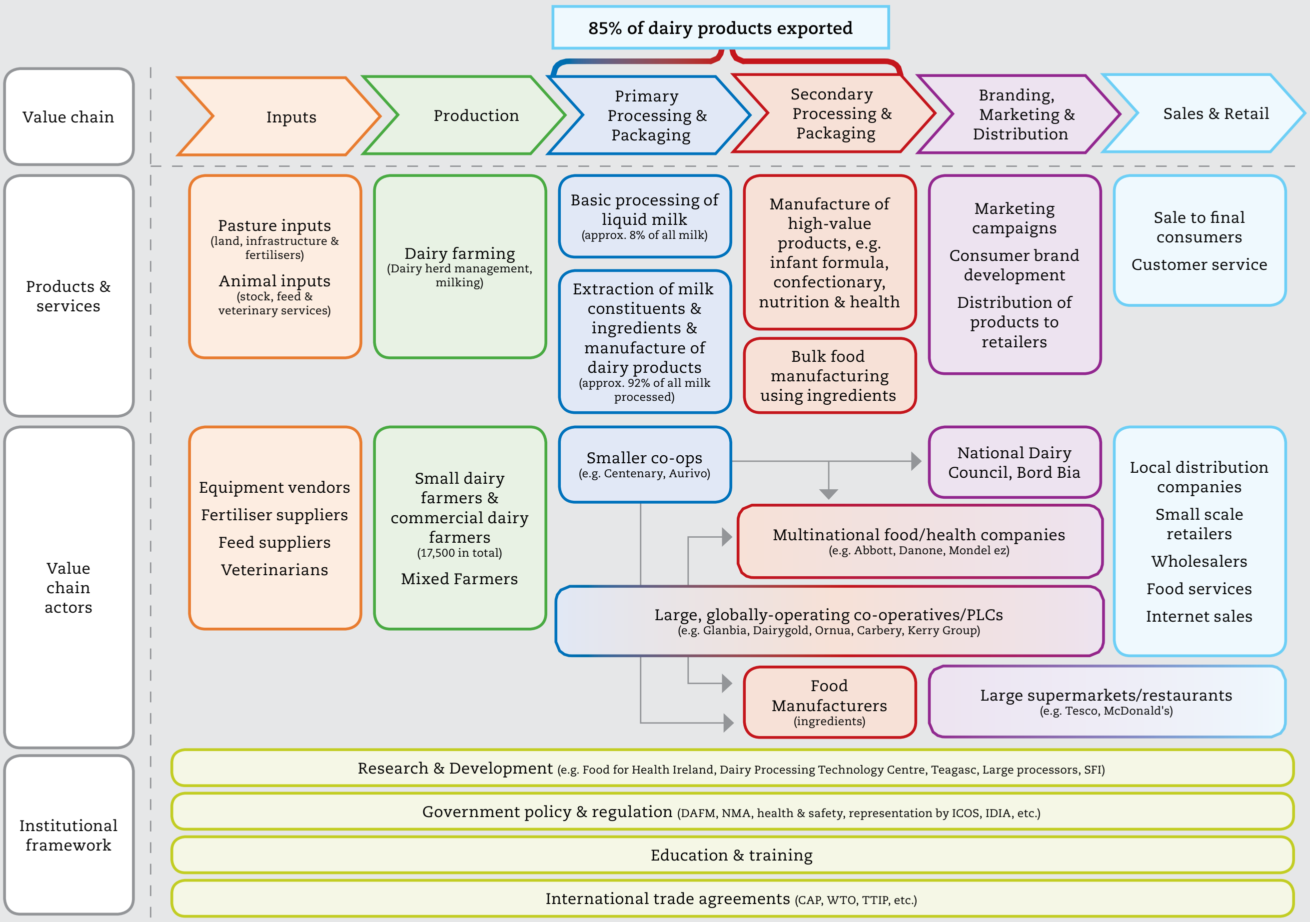
Just as it has taken decades to develop high-performance value chains for the transmission of physical goods from farm-to-fork all over the world, it will take another 20 years to complete this new chain by adding to the traditional agri-food chain, high value-added contra-flows driven by the big data, small data, open data as well as private and confidential data. This development will enable Ireland to intensify production and increase its competitiveness, while respecting the environment and fulfilling its obligations in terms of quality to the consumer and the achievement of climate change objectives.

Table 3.2: The Food Value Chain System and "Big Data"

Supply Chain Actors	Data Drivers ...	... of Value Creation and innovation
Consumers ■ Babies ■ Children ■ Mothers ■ Sportspersons ■ Elderly	**Performance Data**: Continuous data on diet and behaviour of consumers – wellness, appetite and weight, sleep and exercise, fitness and energy levels, blood sugar, allergies, intolerances... **Genetic Data:** The genetic sequences and meta-genetic data of individual consumers... **Biomic Data:** Data on human microbiota of the skin, hair, stomach and digestive tract...	Based on a better understanding of ■ How food affects the microbiota of the human body ■ How together these affect the health, nutrition, performance, mood and well-being of individuals ■ Depending on their age, health status and genetic make-up ■ To drive the discovery of new market segments ■ Development of new products and services aimed at these segments ■ Discovery of new high value molecules and other components that can be extracted from produce and sold as additives or functional food ingredients
Distributors ■ Retail chains ■ Markets and D2C farms ■ Restaurants and caterers ■ Food Service providers...	**Performance Data:** Data on hygiene, quality, freshness, traceability, waste streams, GHG emissions, energy intensity, and renewable energy share... **Biomic Data:** Whole biome sequences and sampling of microbiota that inhabit the storage spaces and transport environment...	These data streams will drive improvements in terms of ■ Compliance, process improvement, decision-making and innovation in relation to quality assurance, hygiene, safety and freshness of food ■ Cost related energy, carbon and GHG emissions related to distribution, retail, preparation and food service ■ Losses due to waste. In combination with data produced at consumer level ■ Innovation in data intensive food services aimed at helping the consumer to achieve their health nutrition and lifestyle objectives...
Processors ■ Dairies ■ Abattoirs ■ Secondary processors ■ Waste processors	**Performance Data:** Yield data in terms of weight and quality of carcasses and cuts for wholesale or retail, quality of milk yields, waste management and recycling, energy, renewable energy share and GHG emissions... **Biomic Data:** Whole biome sequences of work spaces and bioreactors related to food processing (for brewing, fermenting, panification and other forms of biotransformation) as well as transformation of organic waste into energy, green chemical and other useful products...	Insights support ■ Quality assurance programs with objective data ■ Development of next generation production and farm management systems ■ Systems for the trading of carbon and the management of GHG emissions ■ Sale of ecological services...

Supply Chain Actors	Data Drivers ...	... of Value Creation and innovation
Producers ■ Dairy and Beef... ■ Pigs and poultry ■ Sheep ■ Cereals and fodder crops ■ Fruit, vegetables, mushrooms... ■ Aquaculture... ■ Forestry...	**Performance Data:** Hi-res geo-localised time-stamped yield-data from animals, pastures, crops and fields. Input data on feed, fertiliser, irrigation and weather. Status data on weather and moisture, animal behaviour. The growth of crops and pastures, the status and biodiversity of soils, the water bodies and local ecologies, biodiversity of local ecologies. Detailed input data in terms of feed and fertiliser, animal and plant healthcare interventions... continuous monitoring of animal and plant health, grass height, growth, water quality and biodiversity... **Genetic Data:** Genetic and related data from individual animals and plants... **Biomic Data:** Whole biome sequences of the digestive tracts of individual animals, especially of ruminants... whole biome sequences of grasslands and soils...	In combination with data from processors and other supply chain actors for the development of ■ New functional varieties of crops ■ Sward mixes for pastures ■ Breeds of farm animals with superior performance traits ■ Improvement of soil management schemes ■ Development of new feed, fertiliser, animals and plant nutrition schemes ■ Improvement of carbon sequestration in soils ■ Reduction of emissions, resource consumption, ■ Trading of carbon and the management of GHG emissions ■ Sale of ecological services...

Figure 3.4: Mapping the Irish Dairy Value Chain



Potential for New Value Chains

While a national bioeconomy strategy does not yet exist in Ireland and thus priority areas have not been identified, examples of the types of new value chains that may be possible can be seen elsewhere. Below are five quite generic value chains identified by the Bio-Based Industries Consortium in 2013.

- **Lignocellulosic feedstock, advanced biofuels, bio-based chemicals and biomaterials** realising the feedstock and technology base for the next generation of fuels, chemicals and materials
- **Next generation forest-based value chains** utilising the full potential of forestry biomass by improved mobilisation and realisation of new added value products and markets
- **Next generation agro-based value chains** realising the highest sustainability and added value by improved agricultural production, and new added value products and markets
- **New value chains from (organic) waste** problems to economic opportunities by realising sustainable technologies to convert waste into valuable products
- **Integrated energy, pulp and chemicals biorefineries** realising sustainable bio-energy production, by backwards integration with biorefinery operations isolating higher added value components.

Most of these value chains offer opportunities for Ireland based on considerations relating to the natural resource base in Ireland, the technologies available/in development and market demands. However, while second generation biofuel technologies have been available for some time, financial aspects, such as low fossil fuel prices, the cost of biofuel production, and the scale needed to establish an economically viable industry suggest that such an industry may not develop in Ireland, particularly if Government policy measures such as the biofuels obligation scheme do not favour indigenous production. On the other hand, government policy to enhance the role of bioenergy to make a significant contribution to renewable energy production (target of 16% by 2020) and greenhouse gas mitigation, and national and local government policy to move away from overdependence on landfill places importance on value chains associated with optimising the use of waste for energy e.g. waste to energy and anaerobic digestor plants.

Additional value chains likely to be of relevance to Ireland include those related to the marine, whereby a wider range of marine-derived resources than are currently commercially exploited (e.g. marine by-products and algae) are used to produce food, food supplements and non-food products (e.g. high value products such as cosmeceuticals) using environmentally-friendly processing methods.

Other value chains drawing on our strengths in grass-based dairy (Figure 3.4) and beef production are also likely to be prioritised in Ireland and are in keeping with the “food first” principle proposed for the bioeconomy. However, opportunities could also manifest in non-food arenas. For example, organic materials originating from food side-chains hold some potential for biogas generation, but more interest is evident in biomaterials or biomedical arenas. For example, collagen and other functional biomolecules can be extracted for connective tissue sources for tissue scaffold generation for use in wound repair etc. Generation of bioactive peptides from protein rich sources may have downstream applications in e.g. immunological antihypertensive applications. It should be noted that development of many of these chains will require integrated action at several points. For example, the forest-based value chain will include improved methods aimed at achieving higher productivity in forests along with a lower impact on the environment. It could also require the development of tree varieties with a tailored chemical structure to meet demands arising from downstream processing into chemicals and/or new materials. In keeping with principles related to the circular economy, the selection of value chains to be prioritised in Ireland should be based on consideration of the opportunities that could arise when these separate chains are integrated. For example, new chains from (organic) waste may be more attractive if developed alongside next generation agro-based value chains.

Enhancements in Human Capital

Technological change over the next 20 years, whether it arises in the form of the adoption of new production techniques, new products or services or structural changes of the form set out above, will require changes in the stock of human capital throughout the value chain system. Producers will require to be more highly educated and skilled than ever before, not only to maximise profits from their businesses, but also to deal with a constantly changing set of sustainability and regulatory constraints. Farmers of the future will have to be entrepreneurial and to adopt a more business-like approach to their farms.

Our educational and training institutions will also have to adapt radically to respond to this requirement.

Likewise, our food processing companies (dairy, meat and prepared consumer foods) will have to invest much more in their innovation capability, primarily through the recruitment of skilled scientists up to and including Ph.D. level. Our universities, institutes of technology and agencies like Teagasc will also have to be responsive to the innovation needs of industry.

04

Implementing the Vision

4. Implementing the Vision

Introduction

The Irish agri-food sector has many opportunities, but also faces significant challenges. Low profitability at primary production, climate change, water quality, biodiversity loss, antimicrobial resistance, food innovation, food safety and rural development are among the significant challenges for the sector. Developing more sustainable and resilient food production systems will require the support of the new technologies discussed above. It will also need the identification and active dissemination of current best practice and accumulated knowledge, as well as the further refinement of those practices.

The Royal Society[43] and the Government Office for Science[44] called for the joint application of new technologies along with traditional agricultural technologies to achieve sustainable intensification. The latter states that "a pluralist research portfolio is essential: the magnitude of the challenges is so large that no single research avenue will address all the new knowledge required." This highly influential report asserts that no techniques or technologies should be excluded from consideration: a diversity of approaches is needed in order to address the differing requirements of specific enterprises, localities, cultures and other circumstances. Such diversity demands that the breadth of relevant scientific enquiry be equally diverse and that science needs to be combined with social, economic and political perspectives.

The importance of bringing together new technologies with longer-established agricultural, food processing, engineering, environmental and other technologies and practices can be illustrated in many areas. The concept of PA, for example, involves the application of many rapidly developing technologies; however, unless these are linked with the complex biological processes involved in the production of crops and animals, the gains achieved will be limited. Similarly, the soil must be protected and receive specific consideration in order to ensure sustainable productive capacity. This requires a greater understanding of the functioning of the soil and the impacts of management practices, confirming the need to mobilise and focus the new technologies onto the complex but key soil resource, on which agriculture's production depends.

The big challenge to be confronted in harnessing the power of new technologies is their inherently disruptive capacity and their ability to serve up surprises. The greatest surprise is likely not to stem from any individual technology, but rather from the cross-symbiotic impact of a number of emerging technologies interacting with each other[45]. Dealing with these complex matters will call for an unprecedented level of national and international collaboration across public and private sectors.

Harnessing the power of new technologies will also require Teagasc to fill staff and expertise deficits in the areas of animal and plant genomics, in precision animal, grassland and crop agriculture and precision soil management, in modelling and data analytics, in microbiota as it relates to soil, animal and food applications, in advanced food technologies, and in value chain analysis and development. Other expertise required such as sensor development and networking and big data analytics, are likely to be at least partially met by partnering with other institutions with expertise in these areas. Addressing these deficits will allow the contribution of the technology areas to be harnessed in the areas of enhancing productivity and profitability, climate change, water quality, food innovation, etc.

43 The Royal Society, 2009. Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture. London: The Royal Society.

44 The Government Office for Science, 2011. Foresight. The Future of Food and Farming. Final Project Report. London: The Government Office for Science.

45 The Atlantic Council of the United States, 2013. Envisioning 2030: U.S. Strategy for the Coming Technology Revolution. Washington, D.C.: Atlantic Council.

Moreover, social concerns around new technologies could seriously jeopardise even the judicious application of such new science and technology. If this is to be avoided, technology innovation has to take fully into account the health and environmental risks to which new technology may give rise. Serious and thorough attention needs to be given to risk analysis and communications policy.

Accordingly, Irish policy makers, scientists, farmers, food processors and consumers need to prepare for future technology. To do this well, they will need a clear understanding of how technological change might shape the global economy and society, as well as their own sector, over the coming decades. They will need to decide how to invest in new forms of education and infrastructure and figure out how disruptive economic change will affect comparative advantages.

The Teagasc Roadmap to 2035

For its part, Teagasc will prepare for the new age of technology **by appointing a Foresight Implementation Team (FIT) reporting to the Director, which will be tasked, in the first instance, with the preparation of a detailed roadmap identifying the short, medium and long-term actions and responsible people/ organisations for these actions to ensure that the Irish agri-food sector and rural economy benefit to the maximum extent possible from the development and implementation of new technologies**. This team will partner with other organisations, enterprises, government departments and agencies to see these actions delivered.

The FIT will also monitor and review the implementation of the Foresight Roadmap and engage in on-going horizon scanning to ensure that the sector continues to benefit from new developments in the future. As the real benefits of foresight are best realised through frequent iterations of the process, the FIT will arrange to repeat the Technology Foresight at regular intervals, again with the objective of ensuring that the Teagasc programmes continue to reflect the very best technologies needed to support Irish agri-food.

Teagasc Research and Knowledge Transfer Programmes

As a first step in the 2035 Roadmap, Teagasc will develop new research and knowledge transfer (KT) programmes. Teagasc has already commenced on the implementation of a number of the technological priorities identified in previous chapters. Working with new partners in the ICT sphere, such as the Tyndall Institute, Telecommunications Software and Systems Group (Waterford Institute of Technology) and the Insight Centre (University College Dublin), the organisation is already investing through its on-going research programme in bringing the digital farm to both crops and livestock sectors. Working closely with the ICBF, our expertise in modern genetics and breeding is already paying dividends in the livestock sector, while Teagasc and its partners in University College Cork and Cork Institute of Technology are globally recognised for their work in the area of the human microbiota.

However, there is now an opportunity to systematically use and combine the five technology areas, identified in this foresight project, across our research programmes to ensure that Ireland participates in the total transformation of agriculture that is required to meet future food and nutrition security while maintaining the resource base and responding to new challenges.

Accordingly, the priority action for Teagasc on the road to 2035 is, in consultation with our national and international research partners, stakeholders, policymakers, industry and funding bodies, to build capacity or partnerships in the five technology areas and embed these technologies in our research and KT programmes. We must ensure we have a research programme that will fully reflect the technological priorities identified in the foregoing and will be the source of the new knowledge, technologies and processes which will enable the Irish agri-food sector and bioeconomy to realise the ambitious Foresight

vision. This exercise will commence immediately and will also set out the new types of skills, infrastructure and scientific resources needed to deliver the necessary innovation for Ireland's long-term future.

It is important to establish that these technologies will not replace our existing scientific disciplines and research areas. Rather, they will be become part of the suite of tools that our scientists use in addressing the major challenges faced by the agri-food sector. There are many examples of how this happened in the past: Best Linear Unbiased Prediction (BLUP) statistical analysis transformed animal breeding; analytical chemistry transformed food and nutritional science; general equilibrium modelling transformed economic analysis; GIS and remote sensing transformed soil and landscape mapping; intake measurement in grazing animals via marker techniques such as n-alkanes transformed grassland research; in crops, marker-assisted selection has transformed potato breeding. In the same way that these tools or technologies became standard procedures for animal, soil and food scientists and economists, the new technologies will become essential tools for the current and next generation of animal, grassland, crop, food, soil, environmental, social and other scientists.

Knowledge Transfer Programmes

As a second critical step in our 2035 roadmap, Teagasc will continue to accelerate the process of transformation of our advisory and education services to equip clients and students with the motivation, confidence and opportunities to engage in participatory processes, to develop the skills to think for themselves and to constantly innovate and reinvent themselves and their business models with the support of independent advice and education opportunities.

An innovation – ready population of farmers will need the support of a proactive and experienced advisory service. An increasingly technology-driven industry will require practical, multi-skilled farmers and workers, trained using practice-based applied education, combined with an apprenticeship model (mentoring). The new disciplines and skills required for agriculture include robotics, computer-based imaging, GPS technology, climate forecasting, environmental controls and more. To make the best use of all these technologies, it is essential to educate farmers and farm managers in their use.

How Will New Technologies Contribute?

The agri-food sector faces several major challenges in achieving the Foresight vision. Research has a major role to play in finding lasting solutions and the technologies identified in this report will be essential if significant progress is to be made. Some examples of where and how this will arise are outlined below. They will not, of course, be the only mechanism by which progress will be made, but they will be significant agents of change.

Enhanced livestock and crop productivity

The power of new genomic technologies in animal and plant breeding will allow much more rapid progress in breeding animals and crops, thus contributing to higher productivity. Precision agriculture and other digital technologies will allow better management decisions and improved performance across livestock and crop farming systems. Precision grassland management will be widely enabled by new technologies that will increase grassland production and utilisation and lead to a much greater degree of control in how grazing animals are managed. Soil fertility will be measured and managed at a high degree of spatial resolution. The outcomes will be reduced inputs, increased outputs, lower costs and a reduced environmental footprint.

Farm level profitability

The power of new genomic technologies in animal and plant breeding will allow much more rapid progress in breeding animals and crops (including difficult-to-measure traits such as animal health, feed efficiency, crop disease resistance and nutrient efficiency), thus contributing to higher output with reduced inputs. Precision agriculture and other digital technologies will allow better management decisions and improved performance: better animal health and fertility, improved feed efficiency, improved milk and meat quality, improved crop yields and quality and improved financial and business planning. These improvements will contribute to higher productivity. Understanding and managing the rumen and soil microbiota will help to achieve better feed efficiency in animals and better crop growth, again contributing to improved profitability.

Climate change

The power of new technologies in animal breeding will allow much more rapid progress in breeding animals with the difficult-to-measure traits of greater feed efficiency and lower GHG emissions. Understanding the rumen microbiota will allow scientists to seek solutions to reduce methane production. Likewise, understanding the soil microbiota will assist the development of strategies to reduce soil GHG emissions and increase carbon storage in soils. Precision agriculture and other digital technologies will allow better targeting of inputs and optimisation of outputs, thus delivering sustainable intensification.

Water quality

Precision agriculture and other digital technologies will allow better targeting of nutrient inputs to grazing and crop systems as well as optimising outputs, thus delivering sustainable intensification and contributing to improved water quality. Precision and digital technologies will help farmers more reliably link their activities to changes in water quality thereby identifying farm specific actions required.

Biodiversity

Precision agriculture and other digital technologies will ensure targeted applications of pesticides, helping to preserve biodiversity in conjunction with other approaches. Advanced genomics and planned mating schemes will assist the preservation of genetic resources in highly managed livestock production systems. Advanced genomics will also assist crop breeders to product crops that are more resistant to pathogens and the resulting reduction in the load of pesticides will help to preserve biodiversity. New sensor developments will facilitate improved biodiversity monitoring and allow the development of targeted payment schemes for the delivery of these services.

Antimicrobial resistance, resistance of parasites to anthelmintics and resistance of crop pathogens to pesticides

The power of new genomic technologies in animal and plant breeding will result in animals and crops with greater resistance to the pathogens and parasites causing animal and crop diseases. Genomic technologies will also allow the identification of specific resistance in plant and animal pathogens and parasites so that appropriate and effective antibiotics, anthelmintics and pesticides are used, and that they are used in a manner that minimises the build-up of resistance to control agents.

Digital technologies such as in-field and pen-side diagnostics will be used to measure the level/strain of parasite or pathogen and the required response so that antibiotics, anthelmintics and pesticides are only used when necessary and spatially targeted when used. For example, individual quarter testing of dairy cows will be done at drying-off and antibiotics will only be used in quarters with high infection levels. Digital technologies will enable development and deployment of systems to deal with the development of resistance in pathogens at a regional and national scale, contributing to effective risk assessment. These technologies will supplement other control strategies such as integrated pest management.

Added value in food

New food technologies and a greater understanding of the fundamental chemical and physical processes inherent in food processing will lead to improved and enhanced ingredients and food products with higher value. The understanding of the effect of the human gut microbiota and how to manage it for optimum health and wellbeing will create opportunities for food companies to create and market high value speciality foods to segments of the population (e.g. infants, elderly, high performance). Genomic technologies applied to consumers will lead to the emergence of personalised nutrition in health and performance-conscious consumers, creating demand and markets for customised, high value food products. At the farm level, genomic technologies will allow herds to be bred that can produce milk with specific characteristics that can be processed into very specific, high value foods. Likewise, precision nutrition and management of animals and crops will result in high quality animals and crops that will be streamed into high value speciality products.

Food safety and quality

New food technologies will lead to improved detection and control of pathogens and contaminants in food right along the production and processing chain. New technologies will also lead to extended shelf-life, and smart packaging systems that advise consumers on the suitability of foods for consumption. Food processing plants will use advanced microbiota screening to develop enhanced control strategies. Sophisticated traceability systems based on DNA and digital technologies will reduce risk and increase confidence in the food system. Advances in analytics will lead to ultra-low levels of contaminants in food products.

Rural development, including the circular bioeconomy

Information and communication technologies (ICT) will be vital in overcoming the drawbacks associated with rural remoteness and will, therefore, play a lead role in helping create new business and employment opportunities that would not have been possible in the past. ICT also opens up opportunities to renew business models in the food and non-food value chains, by connecting producers to consumers. For example, it will be possible to develop innovative marketing channels, such as new modalities of short food supply chains, or to improve logistics. They make possible innovative solutions which can help modernise the provision of services and ensure efficiencies for both providers and citizens in a context of lower population density.

Teagasc will commence in 2016 with an intensive review of its core education and training programmes for new farm entrants. Aside from the constant competitive need to farm at high levels of technical efficiency and business expertise, future farmers will require a much greater proficiency in the areas of intensive sustainable farming and ability to use information technologies and applications. We will undertake this review in consultation with a wide body of stakeholders to ensure that our education architecture is both fit-for-purpose and to future proof it in terms of emerging industry needs.

In the area of knowledge in the food sector, Teagasc is equally committed to transferring its latest discoveries from the research lab to industry for the benefit of the Irish economy through facilitation of access to our cutting-edge research, infrastructure and highly qualified and skilled employees. The Teagasc Food Gateways Technology Transfer programme will ensure that the benefits of advances in technology can be leveraged by the food industry.

The Need for New Leadership Roles, Partnerships and Coordination Mechanisms

The transformation of the agri-food and bioeconomy sector, one which has started already and which will continue to unfold between now and 2035, is not the result of any one technology, but of very many technologies that will work with each other, one reinforcing the impact of the other, giving rise to complex data intensive science-driven systems. Every step along this path involves choices that are economic, scientific, technical and systemic in nature, choices concerning infrastructure, norms and standards, as well as the business models of new service concepts that effectively distribute the burden of effort and distribution of reward between public and private actors. Technologies are only useful if they are affordable and if the benefits are at least equal to the cost of adoption. In some cases, the new services will only be effective if adoption is swift and universal at the level of whole supply chains and catchment areas. These complex systems will also be shaped by ethical considerations and issues of public perception.

Teagasc is well-positioned to assume a leadership role in the management of such far-reaching technology-driven change. Leadership in this case will involve a role of architect of the systems that will serve Teagasc clients of the food, forestry and other subsectors of the bioeconomy. As architect, it can ensure that services are designed to be affordable and easily adopted by the communities that will use them.

Teagasc will also play the role of arranger and organiser, understanding who needs to be around the table to discuss high-level issues of design, who needs to collaborate, and who needs to be informed if the transition is to contribute to both job creation and wealth generation in 2035, especially for the smaller players in the system. Without choreography of the full complement of stakeholders, and not just the researchers, it will be very difficult to arrive at a system which creates jobs and equitably distributes the gains realised by the coming technological revolution.

Creating platforms for implementation

For each of the five thematic pillars described in Chapter 3, there is a need to create a platform for collaboration that reconciles the pressure of ongoing activities with activities that have a long-term perspective so as to ensure the realisation of the foresight vision.

The proposed platforms are not for operational purposes but to focus on the strategic dimension of activities that will enable Teagasc, together with its partners, to collaborate in a way that optimises the benefits that accrue to the deployment of future technologies.

Each platform will operate differently, but each will need to consider the following basic activities:

- **Baselining,** with partners to make sure that everyone around the table is informed of the direction that technology is taking, the complexity hidden behind the vision expressed in Teagasc 2035, and is sensitive to the need for collaboration to achieve ambitious goals.
- **Roadmapping,** to ensure that the Foresight vision is accompanied by a compelling theory of change linking research, innovation and entrepreneurship to the development of norms and standards, the provision of infrastructure, where necessary, the identification of new economic models based on pilot and test bed activities, all the way up to adoption based on training and advisory services.

- **Programming,** to make sure that the roadmap is fully implemented drawing on funds from national and regional, EU and private sources, so as to progress from one stage of maturity of the vision implementation to the next.
- **Communication**, not just in traditional terms of press releases to document progress in the implementation of specific projects, but also in strategic terms explaining the benefits of the changes to the public at large, as well as to the end users who are increasingly involved in user-led innovation activities.

An IoFT Platform

The IoFT represents a future populated by many data-intensive services. The maximum benefit for the country will only be derived if a critical mass of farmers adopt these services and if food companies connect with and use the data provided by the farm digital networks. It will only be good for the farmer if the cumulative cost of these services is at least equal to the extra revenues earned. Achieving this goal will require a collective effort involving technology companies and the clients they intend to serve.

This effort will have to address the work of norms and standards for data and communication protocols, as well as for quality of service, revenue and pricing models better linked to the value created, as well as the interoperability of systems.

The other big issue that needs to be addressed by the IoFT platform is the management of data. This is more complex than it appears at first sight and goes beyond the obvious issues of ownership, access and digital rights management, to include subtler issues, to safeguard legitimate rights to privacy or protection of confidentiality. It touches upon almost philosophical issues such as the relationship between the performance data of a field, animal or privately owned variety, the need to gain access to performance data and the impact this could have on price of land, animals or varieties. If a sale is made does the performance data get transferred as well and what are the rights of the buyer and seller in this regard?

The IoFT platform could produce among other things a "National Data Strategy for the Agri-food Sector, the Climate and the Environment," as well as a document aimed at the technology sector explaining in more detail the emerging vision of the IoFT and the opportunity it creates for technology entrepreneurs who will pilot in Ireland the systems and service concepts that they may one day export all over the world.

The widespread adoption of digital agriculture in cropping and livestock industries requires coordinated action across sensor developers, product manufacturers, telecom providers, agri-food researchers, farm advisors, and most importantly, farmers. This difficult objective will take time to achieve. However, well-executed demonstration projects can greatly enhance adoption. **Accordingly, Teagasc proposes to develop a National Digital Farming Test Bed (NDFT) to support Irish farmers in dramatically improving their efficiency and sustainability through the widespread use of ICT**.

We will work with partners in the public and private sectors to establish the NDFT, covering both livestock and crop production, to develop new technologies, explore and demonstrate the impact of broadband and related digital services for Ireland's farmers and rural entrepreneurs, evaluate existing technologies, and provide a platform for commercial enterprises to develop and test relevant innovations at a pre-competitive stage. Teagasc will also be able to use live data streams from the NDFT in our education programmes to educate new generations of farmers and those in the food sector in the use of cutting-edge technologies.

These projects could also explore some of the emerging opportunities and drivers for adoption of digital services for the food sector, including:

- Integration of sensor data and related digital services into vertical supply chains to create efficiencies and innovation in processing, distribution and marketing
- The increasing focus by agribusiness companies on using digital services to optimise supply chains and complement their traditional focus on physical products and processes
- Biosecurity and food safety initiatives that will increasingly use agricultural sensor data for early detection and monitoring of incidents
- Growing consumer demand for information about food provenance that can be used to add value to food and provide more customer choice.

In association with the many multinational and indigenous innovative ICT companies, the NDFT could also help expand and promote the already growing and ambitious agri-informatics technology sector in Ireland. With the emergence of new agricultural technologies, new opportunities will arise for existing and new companies from developing innovative Ag-Tech products and services configured as smart farming solutions. The further growth of this industrial sector will not only help underpin productivity growth in Irish agriculture, but could also generate more export income from technology products and services.

The Role of Public Sector Research

Many of the developments in digital technologies and the IoFT will be driven by the private sector seeking to develop new products and services that producers or other actors in the food chain will pay for. There is also a key role for publicly funded research. It must research, with the private sector, the development of the underlying technologies in sensors, platforms for their deployment, and the communication networks which collect their data and link the multiple sensors to be deployed in the field. Publicly funded research also has a role in developing the underlying data analytics tools and processes which can turn the data harvested from sensors and other sources into useful information, which can then be incorporated into decision support systems for farmers, food companies, government and its agencies, and other actors in the agri-food chain. There is also a role for publicly funded research in devising standards and protocols for data collection and interoperability, and in researching issues around data ownership and privacy.

Teagasc on its own cannot provide the diversity of research expertise needed to deliver on this agenda, but it can play a leading role in co-ordinating the different expertise that needs to come together. Teagasc will also play a leading role in identifying the key parts of the production system where new information (from sensor platforms or other data collection methods) can be useful, helping to test sensors in the context of the underlying biological, chemical or physical process being monitored, analysing the data to provide useful insights, and developing decision support systems to improve decision making at key times and points of the production cycle.

Agri-Food Genetics Platform

There are many actors in this space who stand to benefit from the analysis of genetic and performance data. There is a need to break down the silos between domains so that they contribute collectively to the realisation of a national plan to fully transform the sector by fully exploiting the revolution enabled by high-speed, low-cost next generation sequencing technologies applied to animals and plants. Ireland is very well served by the ICBF which operates one of the most comprehensive and effective databases of animal information for animal breeding purposes in the world. This is a platform to build on for the future. The sector could benefit from a national strategy for the exploitation of agri-food genetic resources.

The other side of the coin is the manipulation of the gene using the vast array of techniques that include traditional breeding, genetic engineering, gene-editing and other advanced techniques of molecular biology such as gene stacking, RNAi spraying and CRISPR. These could be of tremendous benefit to society, but they need to be understood and investigated. The benefits need to be validated and explained. This needs to be communicated to society, targeting, on the one hand, farmers so they are ready for adoption when the time comes and, on the other, consumers so that they are fully informed.

An Applied Microbiotics Platform

Teagasc is in a lead position in elucidating and exploiting the opportunities arising from new insights in this area as it has already established a state-of-the-art NGS DNA Sequencing Facility. Exploiting this technology and our partnership in the APC Microbiome Institute has already enabled Teagasc to gain global leadership with particular reference to the human microbiota and, more recently, in the area of food microbiota and their role in product quality. The key challenges over the period to 2035 will be to design food solutions that will promote a healthy gut microbiota. During the period to 2035, major efforts will be made to bring our knowledge of the contribution of microbiota to soil fertility, enhanced crop production, improved feed conversion efficiency in farm animals and environmental impacts relating to GHG emissions, CO_2 sequestering etc., and to develop methodologies to apply this knowledge in a practical setting.

Success in this area will require coordinated cross programme activity within Teagasc and **it is proposed that a Microbiota of Agri-Food Things (MAFT) Platform is established across the Research Directorate** to coordinate this activity and to build on the capability already established within the organisation. This platform will be used to build new and enhance existing national collaborations in this area. In addition, it is unlikely that Ireland can go it alone. It will need the benefit of large-scale collaboration at EU and international level, as well as the benefit of cutting-edge cognitive technologies using deep learning and world-class computing resources.

The MAFT platform will need to maintain the NGS capability that already exists and identify and secure new cutting-edge technologies that are likely to become available during the period to 2035. It will also need to develop systems to test and manipulate the different microbiota and confirm outputs in

commercial and field trials. Two key objectives will be to secure a large national funded project in the area of the MAFT and to mobilise large-scale collaboration at EU and international level, and perhaps even lobby for a significant EU flagship project to secure global leadership for Europe in the application of this exciting emerging domain.

New Value Chains Platform

This platform will bring together a diverse range of actors to develop a roadmap for the data intensification of agri-food supply chains stretching from the farm to the fork. It will clarify issues related to privacy and consumer protection, issues of professional ethics and codes of conduct. It will also focus on the behavioural dimension to utilise new ICT and data initiatives to maximise organisational innovation through greater trust between value chain actors, better information sharing, coordination and value generation.

Achieving this will require a leadership initiative to develop the vision in collaboration with relevant stakeholders. It will also require us to initiate programmes that will benefit the agri-food sector, in particular the food SME and small farm sector, so that they will benefit from the transformation, and enjoy adequate levels of support in the form of financial assistance or enabling legislation.

New technologies for food processing platform

New food technologies can prove to be very sensitive issues with consumers, as there is a rather low degree of public knowledge about how food is produced. Experience with technologies such as GM and irradiation indicates that potentially useful technologies can be rejected by consumers. Yet increasing awareness of these technologies does not necessarily increase acceptance. Moreover, in the case of some technologies, such as genetic manipulation and nanotechnologies, acceptance by consumers depends not only on its promised benefits but also on the perceived risks, general attitudes and values, and appropriate regulatory frameworks. At industry level, absorptive capacity and technological capability, as well as attitudes to innovation amongst individual companies, can influence adoption. Characteristics of the technology itself in terms of complexity, relative advantage, and compatibility are also important. Furthermore, companies need to be stimulated /animated to ensure they recognise the imperative to adopt new food technologies. This platform will bring together all interested parties in the food value chain to share information on developments in the area and to clarify the potential application of developing technologies.

Conclusion

New technologies will drive profound changes across many dimensions in the lives of citizens, in business and across the global economy. Many technologies, including advanced robotics, and next-generation genomics have real potential to create significant benefits for quality of life, health and the environment. Many of them could also influence how and what consumers purchase, or change overall food consumption patterns. Others could fundamentally transform the nature of work, both on the farm and in the food processing plant. Almost every technology described could change businesses, creating completely new products and services, as well as moving value between producers or from producers to consumers. Some, like automation of knowledge work and the mobile Internet, could also change how companies and other organisations structure themselves, facilitating ever more flexible patterns and styles of work.

As these disruptive technologies continue to evolve, it will be a matter for farmers, business leaders, entrepreneurs, policy makers and citizens to maximise their opportunities while dealing with the challenges. One thing is for certain, Irish agri-food businesses, both farming and processing, cannot in the medium-to-long term ignore these developments. The first step is for leaders to invest in their own technology knowledge. Technology is now the enabler of virtually any strategy, whether by providing the big data analytics that reveal ways to reach new customer groups, or the Internet of Things connections that enable a whole new profit centre in after-sale support. Food producers, processors and others are, accordingly, likely to persist in driving towards new technology solutions and organisation forms across the networked society.

However, in conclusion, it cannot be stated strongly enough that future progress in applying new technologies hinges on partnership approaches right across the food system in which all actors, including consumers, are fully engaged and fully apprised of both the benefits and risks of such new technologies.

Annex
Acknowledgements

Annex: Acknowledgements

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