EU Agri-Food Industries & Rural Economies by 2025

– Towards a Knowledge Bio-Economy –

Research & Knowledge-Transfer Systems

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EXECUTIVE SUMMARY

1. Europe's agri-food industries and the broader rural economies are being rapidly reshaped, predominantly by international policy developments, combined with a diverse range of non-monetary issues, including food safety/security, environmental sustainability, animal welfare, ethical foods, fair trade and the future viability of rural regions (Section 2).

2. The complex dynamics operating between the domains of agriculture, food, environment, land use, society and rural sustainability, allied to the predominant influences of international policy developments (Section 2) on these vital interactions, point to the importance of consideration being given to the need for a new strategic framework for agri-food research and the related areas of environment and rural economies (Section 3).

3. Among the biggest development changes facing Europe (Section 3) are the construction of the knowledge generation and transfer systems required to support the future competitiveness and sustainability of Europe's agri-food industries and other natural resource-based sectors, and position public research institutions to build a knowledge bio-economy.

4. A two-dimensional research strategy, involving Transition and High-Tech Research Programmes (Section 3.1) may be required to support Europe's agri-food industries in making the radical transformations arising from the reform of the Common Agricultural Policy and the outcome of negotiations under the World Trade Organisation, which may result in freer world trade in agricultural products.

5. The Indicative Research Portfolio for the *Transition Research Programme* includes consumer demands, food for health, new models of farm production systems, environment, sustainable rural economies, regulatory framework, and policy developments; and that, for the *High-Tech Research Programme*, includes plant sciences, animal sciences, environment, diagnostics, and pharmaceuticals (Section 4).

6. In the changing environment in which Europe's agri-food industries must prosper, in the 21st century, new knowledge-based farming systems are required that are profitable at farm level, produce competitive market-required food products, are environmentally sustainable, can cope with emerging climate changes and that, in the circumstances now arising, are energy efficient (Section 3.2).

7. The indicative architecture of new models of farm production systems, illustrated in Fig. 1 (Section 3.2), includes the following constituent components: animal nutrition, genetics, health and welfare, food safety/security and quality (ethical foods), and food for health. Models of new livestock and crop production systems, in terms of the technical objectives of their constituent components, would not be markedly different from that depicted for milk production in Fig. 1.

8. Nanotechnology has the potential to transform agriculture and food manufacture, as well as energy production and health care. Section 3.3 presents a synoptic overview of the nanotechnology agri-food applications, benefits and risks, and public

confidence concerns contained in a report and associated database recently produced by the University of Minnesota, United States.

9. Having regard to the predominance of international policy developments in determining the future competitiveness and sustainability of Europe's agri-food industries and rural economies (Section 1), a more concerted commitment to policy-oriented research is essential, involving closer interactions between policy makers and researchers (Section 3.4).

10. Strategic and institutional capacities in knowledge transfer and creation are of central importance in making the transition from subsidies-driven to knowledge-driven agri-food industries (Fig. 2). Engagement in Foresight can be beneficial in enhancing the strategic and institutional capacities of Europe's research and knowledge-transfer organisations (Section 3.5).

11. In considering organisational structures for effective knowledge creation and transfer, it may be beneficial to benchmark the diverse range of institutional arrangements operating throughout Europe, especially those put in place in recent years (Section 3.5). To derive the expected benefits from the growing tendency to relocate or establish state-supported research institutes/centres on university campuses, proactive engagement between the staff of the research institutes/centres and the universities is an essential precondition. To ensure real industry engagement, an appropriate proportion of the funding for joint programmes should be derived through research contracts from industry.

12. While the number of farmers will decline, agri-food and other natural resource-based industries will continue to be an important component of many of Europe's rural regions. However, the economic and social viability of rural regions will, to an increasing extent, be dependent on the nature and strength of linkages with strategically located urban centres, providing an attractive living environment, with the necessary educational and social infrastructure (Section 5.1).

13. To build strong and diverse rural economies, imperative requirements are (i) responsive and effective institutional structures to formulate and implement policies for multisectoral rural development; (ii) strategic and regionally-specific synchronisation of existing policies and plans; and (iii) initiatives that take account of the changed EU policy environment beyond 2006 (Section 5.2).

14. Provided the necessary strategic actions are taken now to construct the institutional framework necessary, rural regions could (Section 5.3) develop knowledge bio-economies comprising (i) agri-food industries supplying well-researched market demands, (ii) agriculture, forestry and marine providing important sources of bio-energy and valued public goods, (iii) clusters of science-based food, forestry and marine companies, (iv) a vibrant tourism sector, providing knowledge-based environmental goods and services, and (v) manufacturing small- and medium-scale enterprises (SMEs) making sizeable and sustained contributions to rural economies.

15. To raise the capacity of rural regions to generate, absorb and integrate research developments into economic growth, a regionally-focused, demand-driven approach

to research and innovation needs to be developed (Section 5.3). The fundamental requirement in this regard is a dedicated funding system designed (i) to capitalise on the comparative advantages of regions, by mobilising all the resources available, towards the attainment of context-dependent and demonstrably attainable goals; and (ii) to take advantage of best practices and models available in relation to the governance and delivery of research, technology implementation and innovation.

15. The sustained commitment of a sizeable proportion of national and EU science budgets to the systematic transfer and uptake of the existing reservoir of research knowledge would make a more substantial contribution, in the immediate decade ahead, to the future competitiveness and sustainability of Europe's agri-food industries and rural economies than the generation of new knowledge (Section 6).

16. With the objective of detailing best practices, it would be beneficial to document case studies, from different countries, of initiatives being undertaken, including the engagement of *knowledge brokers*, to address the weak technological absorptive capacity that characterises most SMEs and micro-companies, including rural businesses (Section 6).

17. Energy issues are clearly of major import for Europe's agri-food industries and rural economies. Energy efficiency is of central importance in designing new farm production systems (Section 3.2). Bio-energy generation could potentially make an important contribution to off-setting income losses in agriculture (Section 5.1). However, early attention needs to be given to minimising the environmental impacts of intensive, mono-cultural energy-crops production.

1 Introduction

Foresight Reports relating to Europe's agri-food industries and rural economies recently undertaken for the EU Commission have been drawn upon extensively in compiling this report.

An overview of the rapidly changing circumstances that European regions and their economies are facing in the transition to a more competitive and innovative knowledge-based economy is presented in the Blueprint for Foresight Actions in Regions – Synthesis Report entitled *Foresight & the Transition to Regional Knowledge-Based Economies* (2004). The report outlines the main thrusts of EU policy developments, together with a synopsis of global drivers of change. The benefits of a Foresight initiative in the creation of future-oriented and outward-looking visions and strategies, and in making the transition to a more competitive and innovative knowledge economy, are detailed in the Synthesis Report and further developed in its constituent Blueprints. In relation to Europe's agri-food industries and rural economies, the Agriblue Blueprint entitled *Sustainable Territorial Development of the Rural Areas of Europe* focuses on the role that Foresight can play in the formation of policy for sustainable development; the establishment of appropriate knowledge infrastructure for rural economies; and in addressing governance challenges faced by rural regions today.

The Key Technology 2025 Foresight Report prepared for the EU Commission entitled *Agri-Food Industries & Rural Economies: Competitiveness & Sustainability – The Key Role of Knowledge* (L. Downey, 2005) details the implication for Europe's agri-food industries and rural economies of the reform of the Common Agricultural Policy and the World Trade Organisation negotiations, allied to increasing society/consumer demands, as well as other policy developments and international drivers of change. To reposition European agri-food industries and rural regions in the knowledge economy, the report explores the need for a two-dimensional research strategy involving Transition and High-Tech Research Programmes.

Building on these previous Foresight Reports and other related European and national initiatives, this report further develops the need for a new conceptual framework for

research on agri-food and rural economies. The report focuses on the strategic research and knowledge-transfer systems required to build a knowledge-based bio-economy.

The individual sections of the report are framed to deal comprehensively with the specific aspects of Europe's agri-food industries and rural economies indicated in the section headings. While this involves some unavoidable repetition, it allows each section to be read as a discrete entity.

2 International Policy Developments

Rural Europe is being radically re-shaped, predominantly by international policy developments. To a much greater extent than previously was the situation pertaining to agriculture, and currently applying to most other economic sectors, Europe's agri-food industries and the wider rural economies are being fundamentally changed by ongoing international policy developments.

Competitiveness and Sustainability, the two overarching EU goals, present formidable challenges for Europe's agri-food industries and rural economies. As further detailed in the report prepared for the EU Commission (*Agri-Food Industries & Rural Economies: Competitiveness & Sustainability – The Key Role of Knowledge*, L. Downey, 2005), attainment of these goals presents virtually unique challenges for industries which are inherently based on the exploitation of natural resources, such as agriculture, forestry and marine. The growing realisation of the fundamental dependence of agriculture on ecosystems underlines the vital importance of shifting the main thrust of the sector from resource exploitation to knowledge exploitation.

Among the major policy developments and global drivers of change outlined in the aforementioned report, and further detailed in the Blueprint for Foresight Actions in Regions – Synthesis Report referred to in the Introduction (Section 1), two are of fundamental importance. These are the continuing reform of the Common Agricultural Policy, and the outcome of the negotiations under the World Trade Organisation. These two policy developments constitute the predominant determinants of the competitiveness and sustainability of Europe's agri-food

industries and wider rural economies in the immediate decade ahead. In particular, the effectiveness of the response to these policy developments will to a significant extent influence the capacity of Europe's agri-food industries and rural economies to adjust to other major drivers of change (see below) and cope with potential impacts of the *Disruption Scenarios* postulated in the Synthesis Report *(Foresight Food, Rural & Agri-Futures*). The formation of new policies, regulations and measures relating to agri-food and rural economies need to be properly informed and to have regard to the particular determinants of competitiveness and rural sustainability outlined below. These are the:

- Global international competitiveness and associated energy demands and consequential climate change
- European/national concerns in regard to food safety/security and quality, diet-health relationships, environmental degradation, animal health and welfare, and also the appropriate applications of new technologies
- Regional/local concerns in relation to the future economic, social and environmental sustainability of Europe's rural regions

The rural development policy emanating from the fundamental reform of the Common Agricultural Policy (Luxembourg, 2003) can be envisaged as encompassing the following general aims:

- Development of an internationally competitive multifunctional agriculture, producing market-required food products and environmental goods and services
- Diversification of the economies of rural regions throughout the enlarged EU
- Protection and management of Europe's rich heritage of rural landscapes and cultural diversity

This tripartite set of policy aims reflects the overarching EU goals of competitiveness and sustainability. Attainment of the appropriate balance between the seemingly conflicting goals of international competitiveness and the sustainable territorial development of rural regions, constitutes one of the largest challenges facing Europe.

In the context of increasing globalisation, Europe's rural regions will have to ensure their continued economic and social viability by developing effective response capacities to global and EU developments. Two issues of crucial importance in this regard are:

- The re-positioning in the knowledge economy of Europe's agri-food industries and other natural resource-based sectors, leading to the development of a knowledge bio-economy
- The development of rural economies with the necessary institutional framework to develop innovative, indigenous rural businesses and public services.

Knowledge is required to inform policy developments and to support the future competitiveness and sustainability of the agri-food and other natural resource-based industries, and also rural economies. Innovative capacity is an imperative to building industries and rural enterprises with the technological, business and entrepreneurial skills necessary to produce market-required, innovative food products, and environmental goods and services.

3 Research Perspectives

The complex dynamics operating today between the domains of agriculture, food, environment, land use, society and rural sustainability, and, most importantly, the influences of international policy developments (Section 1) on these vital interactions, point to the need for early considerations being given to the development of new strategic frameworks and systems for the planning and delivery of research and knowledge transfer. This need is strongly reinforced in the Agriblue Foresight Blueprint (*Sustainable Territorial Developments of Rural Areas of Europe* (2004)), which, among other issues, focuses on the crucial question – *What kind of knowledge and innovation infrastructure is required to support the future needs of rural economies, including the natural resource-based sectors?*

In this regard, the issue of fundamental importance, which needs to be objectively examined, is the capacity of the existing universities and state research institutions to adjust and re-orient their programmes with the rapidity required to support the international competitiveness and sustainability of Europe's natural resource-based industries and rural economies.

As indicated in the Agriblue Foresight Blueprint, governance issues, including strategic directions, capacities, and organisational/delivery structures, are growing concerns (Section 3.5). Also, as further detailed in Section 6, the need for new funding mechanisms designed to ensure that the knowledge and innovation needs of rural economies are adequately provided for and in a timely manner, is essential.

In considering new strategic research frameworks to support the future competitiveness and sustainability of EU agri-food industries and rural economies, and to build knowledge bio-economies, the five dimensions outlined below merit early consideration. These are the

- Strategic context (Section 3.1)
- New farm production systems (Section 3.2)
- Nanotechnology applications (Section 3.3)
- Policy-oriented research (Section 3.4)
- Research governance (Section 3.5)

3.1 Strategic Context

Having regard to the major policy developments (Section 1) and increasingly competitive climate facing EU agri-food industries and other natural resource-based sectors, as well as the wider rural economies, the need for a two-dimensional research strategy merits consideration. This would involve:

- *A Transition Research Programme* designed to support EU agri-food industries and rural economies in the shift from the production/output bias of the former Common Agricultural Policy to the more consumer/society

concerned multifunctional model o European agriculture envisaged in the reformed policy (Luxembourg, 2003)

- *A High-Tech Research Programme* designed to ensure the international competitiveness of EU agri-food industries and rural economies, in a situation of freer world trade in agricultural products, arising from the ongoing WTO negotiations, or at least from bilateral trade agreements.

The wide geographical variations across Europe, in environmental and climatic conditions and associated regional differences in land productivity, are reflected in the diversity of agri-food industries and rural economies within EU countries, in terms of enterprises, scale, intensity, and regional/local product specialisation. Having regard to the context dependency of research agendas, some indicative topics that may be considered in their formulation are given in Section 4.

The Transition and High-Tech Research Programmes should be designed to support both the competitiveness and sustainability of EU agri-food industries and rural economies. However, the Transition Research Programme is envisaged as being somewhat more concerned with sustainability in the context of the transition to the reformed Common Agricultural Policy. The High-Tech Research Programme is, on the other hand, more concerned with the longer-term international competitiveness of EU agri-food production systems and products, especially in a situation of freer world trade. The two research programmes are not seen as separate discrete entities. They are a complementary continuum. Moreover, EU research capacity in both programme areas needs to be immediately strengthened, closely integrated and linked with wider scientific knowledge systems. The prime purpose of making the differentiation between the two programmes is to highlight the frequently overlooked need for concerted EU research geared to supporting the agri-food industries and rural economies *in the immediate years ahead*, in face of fundamental and continuing changes in the Common Agricultural Policy, declining financial supports for agriculture and growing competitiveness and sustainability challenges (Section 1).

As previously indicated (Section 2), the capacity of Europe's agri-food industries and rural regions to respond to major drivers of change, and indeed cope with the potential consequences of the *Disruption Scenarios* presented in the Synthesis Report

(*Foresight Food, Rural & Agri-Futures, 2008*), will to a significant extent be influenced by how the sectors adjust to the reform of the Common Agricultural Policy and also the outcome of the WTO negotiations. To make the transition from the production/output orientation of the former Common Agricultural Policy to the more consumer/societal multifunctional model of European agriculture, envisaged in the reformed policy, there is a pressing need for Transition Research Programmes designed to meet individual countries' specific requirements. Among other issues (Section 4.1), the Transition Research Programmes should, as further detailed below, (Section 3.2 & 3.4) focus on the following generic research themes:

- Establishment of new knowledge-based farm production systems
- Development of science-informed health-promoting food products
- Further understanding of agricultural systems that are integrated and compatible with natural ecosystem functions
- Closer integration of policy-oriented and scientific research programmes

These fundamental enabling research capabilities are severely depleted in a number of counties. Accordingly, priority needs to be given to rebuilding the national capabilities (both research infrastructure and human resources) required to develop new farm and food production systems that are (i) profitable at farm level, (ii) produce internationally marketable food products, (iii) are environmentally and socially sustainable, (iv) can cope with projected climate changes, and (v) are energy efficient. Further to this, a substantial and sustained commitment of resources need to be dedicated to knowledge transfer and uptake and to the support of innovation by Europe's agri-food industries and other rural businesses. As further detailed in Section 6, this is an imperative. Otherwise, there is a serious risk that many of Europe's rural regions may become economically, socially and environmentally unsustainable in the immediate decade(s) ahead (Section 5).

To illustrate the possible scope and general thrust of the types of Transition Research Programmes required by individual countries, an indicative set of research topics is given in Section 4.1. A distinctive feature of these crucial research needs is that they are not inherently or indeed immediately dependent upon new and emerging

technologies. Clearly, however, applications of biotechnology and nanotechnoloy (Section 3.3) have the potential to provide the leading-edge technological capabilities required in the longer term in relation to a number of the research issues referred to above.

In addition to meeting immediate research needs, a properly resourced Transition Research Programme provides the platform for developing a High-Tech Research Programme designed to support the longer-term competitiveness and sustainability of Europe's agri-food industries and rural economies. Indeed, it may not be overstating the position to suggest that a strategic Transition Research Programme should be seen as a prelude, if not a prerequisite, to evolving a High-Tech Research Programme and capitalising on its outcomes.

A number of countries already have or are currently developing High-Tech Research Programmes geared to their individual needs. These programmes, as distinct from the Transition Research Programmes, will not play a cardinal role in adjustments required in responding to the reform of the Common Agricultural Policy. However, High-Tech Research Programmes are of vital importance in supporting the longer-term international competitiveness and sustainability of Europe's agri-food industries and rural economies. Accordingly, it is imperative that the necessary investment is made now in building the High-Tech research capabilities that will be required in the context of freer world trade in agricultural products, combined with much greater international competition, arising from countries with rapidly developing agricultural economies and where biotechnology and other emerging technologies are to an increasing extent being widely used. The advent of climate changes, combined with the emerging energy crisis, further highlight the strategic importance that needs to be given to developing agri-food High-Tech research capabilities. Some indicative research topics that may merit consideration by countries undertaking the development of High-Tech Research Programmes are outlined in Section 4.2.

An important structural/organisational issue that needs to be taken into account in developing High-Tech Research Programmes is the positioning of such programmes relative to Transition Research Programmes. Unless closely integrated with well-founded Transition Research Programmes, there is a tendency for High-Tech

Research Programmes to become *researcher-driven* and disconnected from the real needs of agri-food industries and other rural businesses. This important concern emphatically underlines the strategic importance of countries having Transition Research Programmes focused on their immediate individual needs. On the other hand, having High-Tech Research Programmes deeply embedded in organisational structures that were designed to undertake traditional agricultural research programmes could constrain the potential of new and emerging technologies in supporting the further development of Europe's agri-food industries and rural economies. However, it should be stressed that a High-Tech Research Programme undertaken in the absence of a strategic Transition Research Programme will inevitably be characterised by *disconnectivity*.

As further detailed in Section 3.5, it should be noted that simply adapting a two-dimensional research strategy is not *per se* sufficient to overcome the governance-related and other inherent weaknesses of Europe's agri-food research systems.

3.2 New Farm Production Systems

With the rapidly changing circumstances facing European agriculture, new knowledge-based livestock and crop production systems need to be developed that

- Produce internationally competitive food products, that are profitable at farm level; and
- Meet animal health and welfare requirements, including the growing demands for environmental and social sustainability and for regional/local ethically produced food products

The initial development of such systems requires strategic research support along the lines of the Transition Research Programme (Section 4.1). A High-Tech Research Programme (Section 4.2) will be required to ensure the longer-term international competitiveness and sustainability of the new production systems.

To illustrate more specifically what is required, the following criteria need to be considered in designing new farm production systems:

- Profitability at farm level
- Production of the consistent quality raw materials required by food processing companies
- Environmental sustainability, involving costed pollution abatement measures, and also taking into account demands on water, as well as other natural resources
- Capacity to cope with the progressive onset of climate change
- Improved energy efficiency

Having regard to these requirements, an indicative model for new livestock systems, in terms of the constituent components, is illustrated in Fig. 1, *Indicative Model of New Livestock Production Systems.* While this applies to livestock production and more specifically to dairying, analogous models for new crop production systems would not be markedly different, in terms of the technical objectives of their individual components (i.e. plant genetics/breeding, crop nutrition/husbandry, crop diseases/management, etc.). Clearly, all of the constituent components shown in the model (Fig. 1) are not equally important. The relative weightings attached to each will vary between farm enterprises, countries and regions. Depending on the circumstances, some components may be omitted and others added. At an early stage in considering any indicative model relating to the development of new systems of farm production, a *Group of Business and Scientific Architects* should be set up to design model system(s) in terms of the constituent components and, especially, the relative importance of the individual components.

The concept of developing new knowledge-based systems of intensive dairy production, extensive beef production, and livestock husbandry in marginal farming areas of high environmental value, is further detailed in the publication entitled *Building a Knowledge-Based Multifunctional Agriculture & Rural Environment* (L. Downey & G. Purvis, 2005) in C. Mollen (ed.) Science & Ireland – Value for Society, Chapter 5, Royal Dublin Society.

From the viewpoint of developing a more conceptual approach to research-strategy formation, the availability of new models of livestock and crop production would provide a framework for the systematic determination of research requirements. Tinkering with the current production systems, by undertaking incremental or curiosity-driven research on a specific issue pertaining to one component of the system (many of which were originally developed in circumstances much different from today) will not provide the knowledge-based farm production systems required in the 21st century. In particular, it will not lead to the development of production systems designed to achieve the difficult balance between the competitiveness of Europe's agri-food industries and society's growing concerns in relation to the industrialisation of food production, which is likely to become more prevalent, especially in the intensive farming regions of Europe. Provision of the knowledge-based understanding of the multifaceted interactive array of financial, technical and social issues involved, requires a more holistic approach to the conceptualisation of agri-food research priorities, both at national and EU levels. Some important issues relating to the constituent components of an indicative model of milk production are outlined below.

Animal Nutrition, Genetics, Health & Welfare: Animal infertility problems are being experienced in virtually all major dairying countries in Europe and elsewhere. Notwithstanding the widespread investments in animal genetics and breeding in recent decades, the expected improvements are all too often not evident in terms of milk production. Conversely, nutritionally-induced stress problems have become more prevalent. This is evident in the post-calving loss of body condition in dairy cows and associated infertility and other nutritionally related health and welfare concerns. Negative energy-balance due to nutritionally inadequate feeding practices can give rise to such problems and also to the failure to deliver on the milk-production potential created by the genetic improvements in dairy herds in recent decades.

Genetics creates the potential – nutrition delivers that potential. The challenge is to achieve the optimum nutritional-genotype interactions, by developing improved nutritional strategies that match cows' nutritional requirements and genetic potential. To ensure that the complex array of economic, nutritional and genetic parameters are fully understood, there is a growing and indeed urgent requirement for a concerted

European research programme on the interactions between the genetic potential and nutritional requirements of high-yielding dairy cows.

The report entitled *Sustainable Farm Animal Breeding & Reproduction – A Vision for 2025* (published in 2006 by the FABRE Technology Platform) comprehensively documents the research priorities in relation to farm-animal genetics and reproduction. In particular, it highlights the need for "*a research agenda focusing on the genetics and genomics of farmed species, quantitative genetics, data collection and management, operational genetics, breeding programme design, numerical biology, the genetics of relevant traits and the biology of complex biological systems*."

As shown in the indicative model for new milk production systems (Fig. 1), animal nutrition is the keystone to delivering on the potential created by animal genetics and in minimising animal health and welfare problems. It is of central importance to the production of food products of consistent quality and enhanced human health attributes. Well-designed feeding strategies can also reduce the environmental overload associated with livestock production, especially intensive systems. To complement the work of the Sustainable Farm-Animal Breeding and Reproduction Platform, consideration needs to be given to establishing a parallel Technology Platform on Competitive and Sustainable Farm Animal Nutrition and Performance.

Food Safety & Security: The unrelenting progressive lengthening of the food supply chain and the lack of transparency and understanding of its detailed workings have major implications for food safety and security, and for consumer ethics, as well as future energy demands. Arguably, this issue of growing public concern presents the greatest challenge for European agri-food industries, apart from the policy developments (Section 1). Clearly, it is an issue of central importance.

Intensification of farm production systems and integration of markets and supply systems across countries have major implications for food security, which are incompletely assessed and understood. The largest and most economically damaging events of the recent decade affecting European agri-food industries and indeed the wider rural economies have been the widespread outbreaks of animal diseases in cattle (BSE, Foot and Mouth, Johne's Disease, etc.), pigs (Classical Swine Fever) and

most recently and worryingly Avian 'Flu in poultry. In addition to animal diseases, there have been numerous incidences of other food scares, due to the presence of banned substances in animal foodstuffs or chemical residues in food products.

A multiple of causative factors are responsible for the widespread nature of these food safety problems, including the removal of EU import controls. However, the unsustainable lengthening of the food supply chain is a common and important underlying cause of the apparently growing incidences of such widespread and indeed global food security problems. As the food supply chain gets longer, the sharing of knowledge, mutual understanding and trust between farmers, food processors, retailers and consumers declines and ultimately ceases. Currently, what is generally referred to as the *food supply chain* is not in fact a chain. Rather, it comprises a series of virtually independent components, each primarily concerned with its own efficiency and profitability. The absence of overall transparency and accountability is seriously undermining consumers' confidence in the prevailing system. BSE in particular, as well as other recurring food scares have changed the attitude of consumers to the current food supply chain. It is now seen as increasingly unsustainable, if not, indeed, an unwarrantable health risk.

Traceability, stricter controls on animal foodstuffs and new food-safety policies and regulations are being implemented in Europe. However, given the growing public concern and mistrust of the present system, these adjustments are increasingly seen as insufficient. As stressed in a number of national reports, a more radical approach is required, involving in particular a shortening of the food supply chain. Having regard, however, for the relentless drive in the opposite direction, it is not clear how this can realistically be achieved. Also, the implications of such a change in direction for Europe's farming regions need to be considered. In developing new livestock production systems, the opportunity exists to improve the safety of meat and meat products. For instance, dietary manipulations can reduce the pathogen contamination of beef carcasses.

Food Quality: Consistency is the most critical determinant of food-product quality. The plane of animal nutrition is a primary determinant of the consistency and storage stability of dairy products. A similar situation may pertain with other livestock food

products, (*Dairy-Product Manufacture & Cow Nutrition – Implications of Seasonal Pasture-Based Milk Production*, L. Downey & P. Doyle, 2008). Accordingly, in developing new systems of milk production, attention needs to be given to employing feeding strategies designed to meeting animals' energy requirements, while minimising feed costs. Otherwise, the composition and processing characteristics of milk and possibly of other livestock products may be seriously impaired.

Food For Health: A concerted European Research Programme on the development of livestock and crop production systems, including product strategies for the nutritional enhancement of foods, would create science-based opportunities for European agri-food industries. Elucidation of the complex interactions between food components and human health is required to alleviate, through food choice, population ailments such as obesity, cancer, diabetes, variant CJD, etc.

In developing new systems of production, opportunities exist to enhance, through appropriate supplementary feeding strategies, the concentration, in milk and other livestock products, of ingredients with potentially important health-promoting attributes. For example, milk containing conjugated linoleic acids and vaccenic acid in levels that protect against some cancers can be produced by pasture-grazing of cows or through other strategic dietary manipulations. Also, selenium-enriched milk may be beneficial to those at risk of colon or other cancers. Weight-gain and obesity may be controlled by dietary supplementation with rennet whey, which is rich in the bioactive peptide termed *glycomacropeptide*, or by supplementation with calcium of dairy origin.

Environment: In developing new systems of livestock and crop production, central importance has to be attached, as shown in Fig. 1, to the environmental component, including the implications of emerging climate change.

The daunting challenge involved in striking the optimum balance between the economic dictates of internationally competitive farm production systems and the protection of Europe's rich heritage of natural and cultural resources, allied to the sustainability of rural regions, points to the concept of envisaging the environment as a *virtual economic entity*, within which a dynamic range of competing developmental,

environmental, and social pressures have to be systematically accommodated, without the demands of one sector impacting unduly on others.

To be effectively managed, the complex interactive issues involved need to be better understood. By providing the integrated knowledge base required, a more concerted European approach to rural environment research would be beneficial in drawing the ongoing environmental research conducted by EU member states into a coherent European framework, with the focus and capacity to address major environmental issues.

The primary function of a co-ordinated European approach to research on the rural environment would be to provide a more comprehensive understanding of the fundamental chemical, biological, pedological, engineering and socio-economic processes involved in the interactions between agriculture and the environment. Such knowledge is essential to the development of knowledge-based systems of livestock and crop production that are internationally competitive but do not impact as adversely on the environment as the intensive system now increasingly being used.

3.3 Nanotechnology

Nanotechnology has the potential to transform agriculture and food manufacture, as well as energy production and health care. However, there are also potential risks associated with the application of nanotechnology in agriculture and the manufacture of consumer food products.

Advances in the use of nanotechnology in plants include the developments of plant-based assemblies of nanoparticles. In addition, progress is being made in self-assembly systems of nanoparticles derived from under-utilised organic wastes, and the recovery of engineered or natural nanoparticles from soil for use in soil detoxification or for the harvesting of desired nanoparticles. Two areas of particular promise are (i) non-heritable genetic modification of organisms (inserted functional DNA is attached to nano-fibres and is not suitable for heritance) to enhance targeted plant nutrition using nanoparticle-bound nutrients, and (ii) “smart dust” technologies in which sensing molecules are used to detect changes and form part of a reporting system composed of “dust” scattered throughout the crop.

Potential benefits and risks of agri-food nanotechnology are detailed in the recently published report (Sept 2006) entitled *Nanotechnology in Agriculture and Food Production – Anticipated Applications* (J. Kuzma and P. VerHage, Centre for Science, Technology & Public Policy, University of Minnesota, US). A synoptic overview is presented below of the core issues dealt with in the report, including the preview of emerging US agri-food nanotechnology applications contained in the online database recently released by the University of Minnesota.

Market Potential: Products from nanotechnology are, according to the US National Science Foundation, expected to have a $1 trillion impact on the global economy in less than ten years and up to two million could be employed in the nanotechnology industry. By 2010, nanotechnology may be incorporated into some $20 billion worth of consumer food products. In these circumstances, nanotechnology can be expected to be a major driver of innovations in agriculture and food in the coming decade.

Applications: Hundreds of agri-food nanotechnology applications are being developed at present. Many of the leading multinational food companies are reported to be investing heavily in nanotechnology developments. Food packaging is the most prominent agri-food nanoproduct currently available on US markets. In particular, nanomaterials are being used to enhance food quality and safety by providing barriers to oxygen and carbon dioxide, and/or by embedding, in the packaging, nanomaterials designed to detect and counteract food-borne pathogens. Further to this, nanomaterials are being developed that provide opportunities to improve the safety of meat and meat products by detecting pathogens in livestock.

Other important applications of nanotechnology are expected to bring major benefits in terms of precision crop and livestock production. In particular, nanomaterials are being developed to facilitate the more precise use of agro-chemicals. For instance, a nanotechnology-based pesticide is being developed that only becomes effective when inside the target insects. From the viewpoint of the environment and food safety, nanotechnology provides opportunities for the more efficient application of pesticides, fertilisers and other agro-chemicals. In relation to *Food for Health*, (Section 3.2), there is the potential to design nanomaterials to block harmful substances in food,

such as cholesterol or allergens, from affecting the body. For instance, a new variety of canola oil is reported to contain nanomaterials that can block cholesterol from entering the bloodstream.

Benefits & Risks: The development of nanomaterials that can penetrate cell walls could bring important nutritional and health benefits. However, these chemicals are inherently different from naturally occurring substances, and could have unexpected side effects. Few assessments are available of the consequences of nanomaterials being inhaled, ingested or dispersed in the environment (see *Database* below). By moving too fast so as to realise the market opportunities provided by agri-food nanotechnology, it is not inconceivable that consumers' concerns with *GM-Free* could easily become *Nano-Free*. It is imperative that the lessons, which hopefully have been learned from the *Biotech Saga*, of commercialising too aggressively and then belatedly trying to allay society/consumers' concerns, are given immediate regard by those engaged in nanotechnology developments. The number of nanotechnology food products on the market is still relatively low. Thus, as concluded in the Minnesota report, there is the opportunity with nanotechnology to *get it right* by developing well-founded scientific information on the potential benefits and risks associated with the widespread application of agri-food nanotechnology. Otherwise, the opportunities presented by this emerging technology will not be realised.

Public Confidence: As evidenced by society/consumers' reactions to genetically modified organisms (GMOs), public perception and confidence in agri-food nanotechnology will determine the successful commercialisation or failure of products and processes using this technology. A cardinal concern in this regard is whether government agencies with responsibility for safeguarding human health and the environment have the legal mandate and capacity, in terms of having the necessary knowledge of the developments being undertaken by public organisations and, more especially, by industry, as well as the technical expertise and resources to deal adequately with the governance issues and implications of integrating this far-reaching technology into agriculture and food. By anticipating and managing the uncertainties that are increasingly being expressed in relation to nanotechnology, public organisations have a central role to play in winning society/consumers' trust in agri-food nanotechnology.

Database: In order to address the knowledge gap in relation to the paucity of information available on pending U.S. agri-food nanotechnology applications, the University of Minnesota, as previously indicated, has recently released an online, searchable inventory on nanotechnology (available at www.nanotechproject.org/consumerproducts). The objective of the database is to provide a perspective of emerging developments and associated potential benefits and risks.

As further detailed in the University of Minnesota report, the database includes 160 projects, largely United States government-funded, application-oriented research and development projects, together with some additional projects for which patents have been obtained. Total expenditure on the government-funded projects in the years between 2000 and 2005 amounted to $15.2 million. The majority of projects in the database were funded by the US Department of Agriculture ($11 million), the National Science Foundation ($3.5 million) and the Environmental Protection Agency ($0.78 million). These projects represent only a small percentage of the more than $1 billion spent annually by the US federal government on nanotechnology, predominantly on basic research and on industrial and medical applications. A further limitation of the database is that it does not include the extensive food industry research and development projects being undertaken by food companies and others.

The majority of the 160 projects in the database relate to food applications. Over half of these are classified as applied research and are expected to be commercialised in 5 to 15 years.

Bioprocessing for food is the predominant topic addressed by the projects. Other important topics are biosensors, pathogen detection and nano-bio industrial products. These are followed, in order of decreasing importance, by projects on plant/animal production, sustainable agriculture, veterinary medicine and environmental processing. In relation to the food-supply chain, the majority of the projects are concerned with post-harvesting (47%), consumer applications (37%), and retailing (27%). This reflects the emphasis on projects concerned with improving food

packaging, detecting or counteracting pathogen contamination and enhancing the biological activity of dietary supplements.

Agricultural applications include projects on the development of more efficient and environmentally sustainable farming techniques, such as the development of sensitive devices to monitor run-off from crop and livestock production systems. Other projects explore the harvesting of nanomaterials from agricultural waste and the use of nanomaterials to neutralise farm pollutants. Also, attention is given to the use of nanomaterials to improve the processing of waste crop materials into ethanol for biofuels.

Risk/benefit ranking of the projects in the database indicates that no projects were considered to be a high health or environmental risk. Laboratory and industry workers were considered to be the groups who may be most exposed to emerging agri-food nanotechnology applications. Consumers may be the next most exposed group, as might be expected from the relatively high number of applications in food packaging. The vast majority of projects were ranked as having high (25%) or medium (61%) health benefits. However, close on half of the projects could lead to nanoproducts which may expose consumers to medium or low health risk. Farmers' exposure to nanomaterials was seen as being relatively low compared to the other three groups referred to above.

From an *environmental perspective*, 75% of the projects in the database (160) were ranked as low-risk and the remaining 25% as medium-risk. Of the 17 projects leading to "ecosystem exposure endpoints", four projects were classified as medium environmental risk and three as low environmental risk.

As noted in the University of Minnesota report, the database and qualitative analysis of project information is seen as a first step in developing a systematic framework for previewing the escalating number of agri-food nanotechnology applications that may soon be on world markets. The further development of the database, combined with the rigorous analysis being undertaken, will provide a more definitive appraisal of the risk/benefit trends associated with the use of nanotechnology in agriculture and food manufacture.

Nanotechnology has, as previously mentioned, the potential to radically transform European agriculture and food. However, its application presents formidable challenges for governments and regulating agencies, as well as for industry. The number of nanotechnology consumer products currently available is relatively small. However, given the pace of nanotechnology applications, the development of an EU database and analytical system analogous to that being established in the US would provide the knowledge base for the proper governance and orderly incorporation of nanotechnology into European crop and livestock production systems and the manufacture of consumer food products.

Further to this, there may be merit in considering an EU initiative along the lines of the meeting being held by the US Food & Drug Administration (FDA) later this year to gather information about current developments in uses of nanotechnology materials. The meeting is expected to focus on, among other issues, nanotechnology that would be used in foods, including dietary supplements and in animal feeds.

3.4 Policy-Oriented Research

As outlined in Section 1, international policy developments in the immediate decade ahead constitute the predominant determinants of the competitiveness and sustainability of Europe's agri-food industries and the wider rural economies. In this regard, the continued disconnectivity between policy makers, policy researchers and those engaged in scientific research is a serious concern. All too frequently, research proposals formulated by scientific researchers highlight the implications of the research for EU and national policies, but show an inadequate appreciation of the complex underlying issues involved. Also, what are purported to be policy research projects are frequently undertaken without any real involvement with those engaged in policy development and its implementation. There is a pressing need for closer interactions between policy makers and scientific researchers. While it may seem excessively restrictive, with few exceptions, policy-oriented research should not be embarked upon without adequate consultation with those familiar with the policy/policies concerned. Indeed, an appropriate level of involvement in the actual research by those responsible for the development and/or implementation of the

policy issues would be beneficial in ensuring the relevance of the research and, more importantly, implementation of the outcomes.

The joint engagement in Foresight initiatives by policy makers and researchers has been useful in bringing about a better understanding between the two sides in relation to policy research needs and what such research can realistically deliver. Further to this, there is a long-standing pressing need for better institutional arrangements to facilitate regular exchanges between research organisations, policy makers, agri-food industries and society.

3.5 Research Governance

As already indicated, governance concerns regarding the relevance, impact and return on expenditure, as well as the management systems of public research organisations, are frequently being raised, as, for instance, in previous EU Foresight Reports already referred to (Section 1).

Many of Europe's agri-food research systems are characterised by a number of inherent weaknesses in terms of funding strategies, project prioritisation, career structures for researchers, the quality of PhD training, and especially the resourcing of knowledge-transfer and uptake systems. The development of a broader and more systemic approach to research and innovation in agri-food and rural economies requires that particular attention is given to the following issues: (i) a sustained commitment of resources to strategic inter-disciplinary research and knowledge transfer; (ii) in evaluating research proposals, the single-minded pursuit of scientific excellence needs to be balanced by criteria that take into account the sectoral priority of projects, their expected benefits, and whether these are realistically achievable; and (iii) the development of professional career structures for researchers, including promotion systems that, in addition to peer reviewed publications, have due regard for other relevant personal attributes. Some of these systemic requirements are outside of the remits of agricultural ministries.

As illustrated in Fig. 2, strategic and institutional capacities in knowledge transfer and knowledge creation are of central importance in making the transition *from subsidies-driven to knowledge-driven agri-food industries.* Horticulture, poultry and pig

production are already more knowledge-driven than the traditionally more subsidised sectors of arable crops, milk, beef and sheep.

Engagement by research organisations in Foresight can be beneficial in raising their strategic and institutional capacities to the levels required to re-orient their programmes with the rapidity required by the radically changing circumstances facing Europe's agri-food industries and rural economies. Strategic capacity building, in terms of mutual learning and shifting mind-sets, is a most important attribute of Foresight.

New organisational structures have been put in place in a number of European countries in the recent decade(s). Europe now has a diverse range of organisational structures, ranging from stand-alone public research institutes, to joint university-state research organisations and to integrated research, advisory and education/training services. While a sizeable commitment of financial and management resources were deployed in developing and establishing the new institutional arrangements, little information is available as to the relative effectiveness of the different models. Also, it would be beneficial to know whether the expected improvements in knowledge transfer were derived from the amalgamation of research organisations with farm advisory and education services. Such information would be invaluable in considering the most appropriate organisational structures required for knowledge creation and transfer.

An important issue in this regard is the growing tendency to relocate or establish state supported research institutes/centres on university campuses. To derive the expected benefits of such arrangements, *engagement* is an imperative precondition. Experience shows that there is little to be gained by simply having state research institutes/centres located on university campuses, essentially as little more than tenants. Equally, having such research institutes/centres totally financed by public funds means that questions regarding relevance and impact will continue to arise. To derive the potential benefits of having state research institutes/centres located in university campuses, *engagement* at three levels is essential. Firstly, appropriate institute/centre research staff need to be engaged in the university education programmes, especially at post-graduate level. Secondly, university staff need to be engaged in joint projects

with the research institute/centre. Thirdly, and most importantly, to ensure real industry engagement with the research institute/centre, a appropriate proportion of the funding for joint programmes should be derived through contract research for private companies.

In planning new research institutes/centres, primary consideration is all too often given to establishing the actual research priorities. By focusing attention on the strategic importance of the organisational structures required, the Foresight could make a major contribution to the future governance of Europe's agri-food and rural economy research programmes.

4 Concept of Transition & High-Tech Research Programmes

The radical transformation of European agriculture by international policy developments (Section 1), allied to a wide range of non-monetary pressures (food safety/security, environmental sustainability, animal welfare, ethical foods, fair trade, etc.) point to a need for consideration to be given to the concept of developing a new strategic framework for agri-food research and the related areas of the environment and sustainable rural economies (Section 3.1).

Being inherently based on the exploitation of natural resources, the overarching EU policy goals of competitiveness and sustainability present virtually unique challenges for Europe's agri-food industries and rural economies, as further detailed in the Key Technologies 2025 Foresight Report prepared in 2005 for the EU Commission (*Agri-Food Industries & Rural Economies: Competitiveness & Sustainability – The Key Role of Knowledge*, L. Downey). Countries that achieve the optimum balance between the economic dictates of profitability in agriculture, and at the same time address environmental and society/consumers' concerns, will have internationally competitive agri-food industries and rural economies in the coming decade(s). *Knowledge is the key to attaining this critical balance*.

The major challenge facing public institutions engaged in agri-food research is to provide the integrated knowledge base, in both the technical and social sciences,

required to achieve the difficult balance between the international competitiveness of Europe's agri-food industries and society's growing concerns in relation to the progressive industrialisation of food production and the sustainability of rural regions. To position public research institutions so as to fulfil this pivotal and vital role, the concept, put forward in section 3.1, of a two-dimensional research strategy, involving *Transition* and *High-Tech* Research Programmes need to be deliberated.

To illustrate the possible thrust and scope of two such programmes, an indicative set of potential research topics, pertaining to both, is given below. These are a further elaboration, in light of emerging developments, of the agri-food research topics detailed in the previously mentioned report, *Agri-Food Industries & Rural Economies: Competitiveness & Sustainability – The Key Role of Knowledge* (L. Downey, 2005). Because of the inherent importance of these indicative research topics to the issues covered in this report, and with a view to building on previous Foresight studies (Introduction) relating to Europe's agriculture and food, they are updated below, with the inclusion of some additional elements, especially in relation to nanotechnology (Section 3.3). EURAGRI and a number of European research organisations, as well as a wide range of researchers, contributed to the compilation of these indicative research topics.

To highlight the need for a Transition Research Programme, it may be noted that, in the immediate years ahead, the competitiveness and sustainability research requirements of EU agri-food industries and rural economies will not be met to any sizeable degree by advances in the new technologies. As previously stated (Section 3.1), the need for a Transition Research Agenda for the EU agri-food industries is frequently underestimated in developing research policies. In the domains of research policy, industry development and social concerns, this issue merits early consideration by EU countries. It is of paramount importance to new member states, where a high proportion of the population will continue to be dependent on jobs in agriculture and food processing in the coming years and where the enterprises are often operating at low levels of productivity.

4.1 Transition Research Programme – Indicative Portfolio

The Food Supply Chain is changing constantly, as technological innovations in farm production, food processing, storage and delivery systems evolve, and processors and retailers respond to consumer demands and expectations, and to economic, social and cultural circumstances. To provide the agri-food industries and rural regions with the knowledge base required to maintain international competitiveness while making the transformations required by the reform of the Common Agricultural Policy and other immediate drivers of change, some indicative research topics that may need to be addressed by a Transition Research Programme are outlined below:

i) *Consumer Demands*: Fuller understanding of the concerns and circumstances that are forming consumer attitudes and choices, and of how these can best be reflected in farm production strategies, is required; also, priority needs to be given to the fuller development of models of consumer preferences, to guide research, product development and innovation

ii) *Food for Health*: To improve the well-being and health quality of society through the wider availability of science-based health-promoting foods, consideration needs to be given to an EU collaborative interdisciplinary research programme (see Section 3.2) on the following aspects of diet-health relationships and the development of effective interventions, including functional foods:

- Understanding of the mechanisms of the action of physiologically-active food components and bacteria
- Food structure and sensory properties that underpin the development of foods for personalised nutrition
- Discovery of new physiologically-active components of natural origin and bacteria with potential for use in functional and probiotic foods
- Development of bioassays and biomarkers related to the clinical efficacy of bioactive food components
- The inter-relationship of gut flora and human health as related to functional food innovation
- Genomic research aimed at discovery of the molecular basis of the health value of food produces, with particular regard to milk, fruits and vegetables

iii) *New Models of Production Systems*: The development of new and improved farm production systems (see Section 3.2) designed (a) to optimise nutritional and genotype interactions in crops and livestock, so as to minimise nutritional stress, especially post-calving loss of body condition, infertility, and other nutritionally-related health and welfare problems, in a cost-effective manner, while taking into account changing work and lifestyle issues; and also the need to improve the use efficiency and protection of natural resources, including soils, water, air, biodiversity and space; (b) to produce high quality horticultural produce, especially vegetables and fruits, both at commercial and familial scales, having regard to increasing urban-peri-urban-rural interactions; and (c) to provide regionally attuned production systems, including small-scale enterprises, suited to local agronomical, ecological and climatic conditions that provide opportunities for building new food chains, based on high value regional products and organic/ethical foods

iv) *Rural Environment* (See Sections 3.2 & 4.2.iii): Research on the environment has largely concentrated on its individual components, such as water, soil, and biodiversity. The mechanisms by which these interact in the complex, real human/ecosystem are poorly understood. Immediate consideration needs to be given to research on the interactions of different environmental and land-use components and the implications for policy makers. To provide the data sets required for establishing the use efficiency of natural resources and for an early understanding of the consequences for the rural environment of expected changes in land use (agriculture, forestry, infrastructure etc.), multidisciplinary research catchments need to be established, spanning a range of agricultural, forestry, and climatic situations across Europe, and taking into account some related national programmes already underway

v) *Sustainable Rural Economies* (see Section 6): To facilitate innovation in rural areas, a better understanding is crucial in relation to the institutional arrangements required to (a) generate economic activities in rural areas, including the role of government (national and regional), the engagement of influential stakeholders (public and private sectors) in regional networks and the preconditions and opportunities for effective clustering of SMEs

with multinational companies, including the differentiated positions and strategies of these companies; and (b) to ensure the effective provision of social and environmental services

vi) *Regulatory Framework*: Cost-effective farming strategies are required for the incorporation into livestock and crop production systems of EU directives and national legislation, in relation to the environment, safety, health and trade

vii) *Policy Developments*: some aspects of policy-oriented research (see Section 3.4) that are important from a competitiveness and trade policy perspective are outlined below. These are:

- The further development of quantitative sectoral and farm models to project the impact on European agri-food industries of reduced price supports (CAP reform); liberalisation of trade and globalisation of markets (WTO outcome), and environmental constraints, including quantification of their impacts, especially on the economic, social and environmental sustainability of rural regions
- Establishment of the consequences for EU livestock, crops, horticulture and forestry sectors of increased global sourcing, allied to new processing and transport technologies
- Evaluation of public research programmes, in terms of their impacts, including the justification of research expenditures; and improving research efficiency and the uptake of research findings, innovations and policy developments.

4.2 High-Tech Research Programme – Indicative Portfolio

Sustained investment in the applications of new and emerging technologies (Section 3.3) is vital to the longer-term competitiveness of the EU agri-food industries. Given the magnitude of investment in developing applications of these technologies, notably in the US, and also Australia, New Zealand, Brazil, India and China, international competitiveness is the cardinal concern, especially in a situation of freer world trade in agricultural products. Allied to this is the imperative to provide society with trustworthy, verifiable and impartial research information in relation to environmental, food safety and other perceived risks associated with the incorporation

of biotechnology, nanotechnology and other emerging technologies into agriculture and food products (see Section 3.3).

Those engaged in new technology developments try to allay public concerns about the perceived risks. However, the actual issue that needs to be addressed is not the risks but the uncertainties. The underlying concern of society is the uncertainties associated with biotechnology and, increasingly, with nanotechnology. Knowledge provided by publicly funded research is the key to reducing these uncertainties. This brings into sharp focus the central role of universities and state research institutes in the application of new technologies in agriculture and food products. The uncertainties would be most effectively addressed by sustained public funding of strategic research programmes undertaken by universities and state institutes. This role cannot be provided by private companies or by research dependent on funding by such companies.

Nanotechnology agri-food applications (see Section 3.3) are being developed predominantly by food companies and agri-businesses. Their reluctance to engage in discourse about pending products is understandable. However, as happened with GM products, there is a serious possibility that society/consumers will perceive that, while they are exposed to the potential risks of nanotechnology products, the actual benefits accrue primarily to food companies and also farmers. To realise the opportunities presented by nanotechnology, government regulatory agencies, in conjunction with public research institutions, have a central role to play in providing impartial, science-based information on the implications of nanotechnology materials for agriculture, consumer food products, and the environment, and especially any consequences for human health.

Few risk assessments are available documenting what may be expected when nanotechnology products become extensive on world markets, are dispersed in the environment or enter the human body. To address these and other uncertainties relating to this rapidly developing and far-reaching technology, a systematic, science-based approach needs to be developed with the objective of informing public authorities of the potential benefits and consequences of nanoscale materials used in agriculture being inhaled or ingested, and entering the gastrointestinal tract.

For the orderly and successful incorporation of new and emerging technologies into the further development of crop and livestock production systems (see Section 3.2) that are internationally competitive and sustainable, some important topics that may merit consideration by countries undertaking the development of publicly funded High-Tech Research Programmes are outlined below:

i) *Plant Sciences*: to improve the sustainable production, yield, quality, nutritive value, functionality, storage stability and processability of important EU food and non-food crops (cereals, legumes, fruits and vegetables, forage crops, oil-producers, important wood-producing trees, etc.) and their genetic resources, important areas in plant research include genomics, biodiversity, non-food uses and the impacts of climate change, with particular regard to the following:

- Molecular understanding of plant susceptibility and resistance to pests, diseases and environmental stress; expected climate changes may increase the diversity and spread of pathogens and impose additional heat, cold and drought stresses on plants
- Plant metabolism aimed at developing plants containing higher levels of important macro- and micro-nutrients (essential fatty acids, oils, vitamins, amino acids, antioxidants, fibres, etc.) and reduced allergen levels; and a better understanding of plant carbohydrate metabolism, especially control of source-sink relationships
- Development of crops and crop production systems that require less usage of fertilisers and other agro-chemicals, and that also require less water resources, based on a fuller understanding of factors regulating nitrate and phosphate utilisation, water-use efficiency and impact on natural resources
- Understanding of soil microbiological communities and their role in plant growth, the retention of carbon and the contribution of soils to gaseous emissions

- Development of breeding strategies for the efficient introduction of desired traits into high-yielding crops, using the vast potential available in genetic resource collections
- Extending the non-food uses of crops, including bio-fuel crops and transgenic crops producing protein products or novel metabolites for the pharmaceutical and chemical industries
- Better understanding of afforestation systems and the provision of more comprehensive knowledge in relation to the selection of sustainable genetic resources and disease management issues in the context of climate change, and tailored to local conditions

ii) *Animal Sciences*: To improve the efficiency and sustainability of livestock production (see Section 3.2), in terms of food quality and safety, the environment, zoonoses and animal welfare concerns, priority needs to be given to the following:

- The identification of genes that control immuno-resistance in livestock, including pigs and poultry, leading to improved disease prevention strategies, for such persistent and costly diseases as mastitis, Johne's disease, parasitic gastroenteritis, Avian influenza, Newcastle's disease, coccidiosis, classical swine fever, etc.
- The development of more compatible livestock breeding and nutritional strategies that reduce nutritionally-related health and welfare problems, especially in high-yielding dairy cows (see Section 3.2)
- The use of nanomaterials in animal nutrition strategies designed to enhance feed-conversion efficiency, leading to reduced animal wastes and gaseous emissions and better control of animal pathogens (see Section 3.3)
- A fuller understanding of the functioning of the rumen ecosystem is required to underpin the development of improved animal nutrition strategies and technologies for the production of health-enhancing milk and meat, and the reduction of gaseous emissions, especially methane production by cattle

- Improving nutrition and welfare in intensive pig production and reducing pollution and food-borne diseases

iii) *Environment* (See Sections 3.2 & 4.1.iv): Ecology, and particularly niche and life-history studies of crops, is pivotal in avoiding new technology-related hazards. With ecology an essential issue in the application of high-tech developments, research priorities should include investigations of:

- The direct impact of GM crops on cropland ecosystems (including pest resistance), relative to conventional and organic crop production systems
- The persistence of transgenic DNA in wild plant populations, following GM crop hybridisation event(s) and the ecological effects of changes in individual plant fitness, arising from the presence of transgenic DNA
- The environmental implications of the widespread use of agri-food nanomatierals, including the impacts on beneficial micro-organisms in soils and other ecosystems (see Section 3.3)
- The use of ecology, human food chain and livestock knowledge to maximise the potential benefits and minimise high-tech associated risks
- The differential understanding of urban and rural societies in relation to biotechnology, nanotechnology and other emerging technologies and of their potential in agriculture and food production

iv) *Diagnostics*: Development of new diagnostic tests for crops and animal diseases, including antibody-based diagnostic chips

v) *Pharmaceuticals*: Development of vaccines for livestock diseases and pathogens, with particular regard to ensuring that inoculated natural infections can be distinguished.

5 Competitive & Sustainable Rural Economies

The foremost drivers of rural change *in the immediate decade ahead* are the policy developments already outlined (Section 1), leading to the development of modern market-based rural economies. There are, however, counter-forces that are challenging the dominant market model. Among these, a number of which have

already been referred to (Section 3.2), are the growing concerns for the environment, energy supplies and sustainable development; for shorter, more secure food supply chains; and for balanced territorial development and cohesion across Europe's regions.

5.1 Changes in Rural Regions

In the immediate years ahead, the number of farmers in Europe will continue to decline. This may not, however, be attended by a reduction in farm output – indeed, it could increase. The agri-food and other natural resource-based industries will continue to be an important component of many of Europe's regional economies, as further detailed in the report entitled *Rural Ireland 2025 – Foresight Perspectives*, published in 2005 (available at www.ucd.ie/bioenvsci/documents/Foresight-050825.pdf). Economic forces which favoured rural regions in previous decades will not be continued. In particular, farmers currently receive substantial subsidies that cannot be expected to be continued at their current levels, especially after the 2006-2013 EU programming period. Developments in the broader rural economy will not off-set the losses in agriculture. Moreover, spatial differentiation in agriculture, with intensive farming becoming progressively concentrated in the most productive farming areas, will lead to growing conflicts in these areas between economic and environmental sustainability, including safe food production (Section 3.2).

The rural economy is not a separate entity from the urban or general national economy. Moreover, the functional interdependencies between rural and urban economies are increasing. Participation by farmers and other rural dwellers in the urban economy is much greater than in previous decades. Increasingly, rural areas will be expected to provide for the energy, recreational, and other needs of urbanised society.

The economic and social viability of rural regions will, to an increasing extent, depend on the nature and strength of linkages with strategically located major urban centres, and will also depend on the capacity of regions to provide an attractive living environment, with the necessary educational and social and IT infrastructure. New types of employment will favour such rural areas.

5.2 Institutional Support Framework

With competition becoming more international and intense, much greater urgency needs to be given to building strong and diversified rural economies, where both the natural resource-based sectors and urban-generated developments contribute to the continued viability of rural regions. An imperative requirement in this regard is an effective, regionally driven institutional support framework. Many institutional and administrative systems tend to become rigid, inward-focused and sometimes excessively self-serving. There is a need to critically assess existing support structures and systems as to their adequacy for the effective implementation of programmes of regional policy. Given the need for rapid changes, what is required is adaptability, responsiveness and flexibility. In particular, there is a pressing requirement for (i) responsive and effective institutional structures to formulate and implement policies for multisectoral rural development; (ii) strategic and regionally-specific synchronisation of existing policies and plans; and (iii) initiatives that take account of the changing EU policy environment (Section 1).

5.3 Prospects for Rural Europe

Provided the necessary strategic actions are taken now to develop entrepreneurial and management skills, and the capacity for innovation in products and business organisation, the prospects for rural Europe could be as follows:

- The agri-food industries could have more developed business, technological and innovative capacities, with a differentiated product portfolio designed to supply well-researched market demands
- A knowledge-based bio-economy could be developed with agriculture, forestry and marine as important suppliers of energy and providers of valued public goods
- Clusters of science-based companies could be developed to exploit the potential of natural resources in food, forestry, marine and tourism
- Tourism could be a vibrant sector of the rural economy, providing knowledge-based environmental goods and services based on Europe's rich natural and cultural heritage

- Manufacturing small- and medium-scale enterprises (SMEs) could be making sizable and sustained contributions to rural economies

An underlying pre-condition for these developments is a high-quality, sustainable rural environment, involving compliance with EU Directives and with farmers receiving payments for the provision of public goods.

The re-positioning of rural economies along the lines outlined above would be close to the situation envisaged in the goals for EU and national policies. Such a prospect for rural Europe is achievable provided action is taken now to construct the institutional framework necessary for the development of innovative rural economies.

As further detailed in the Agriblue Foresight Blueprint (Introduction), a "*regionally based demand-driven approach to research and innovation needs a totally different funding approach from that applied to universities and national research institutes. University research is guided by a focus on global excellence designed to attract the best brains to a curiosity-driven research agenda and national institutes are driven by national needs. For purely practical reasons, neither can respond to the differentiated needs of each region. Knowledge regions are regions in which the knowledge-needs of all producers are met and not just those of large, world class actors, capable of independent research themselves*."

It goes on to conclude, as previously mentioned (Section 3), that one of the most important issues that urgently requires attention is "*what kind of knowledge and innovation infrastructure can best serve the needs of rural economies*?" The single-minded pursuit of global excellence, which characterises much fundamental or academic research in Europe, needs to be complemented by demand-driven research and innovation systems. This will require the development of new models for the organisational structure and delivery of research and innovation.

An innovation-driven approach to research needs a radically different funding system from that conventionally applied to higher education institutes. To raise the capacity of Europe's rural regions in order to generate, absorb and integrate research and

technological innovations and transfer them into economic growth, the fundamental requirement is a dedicated strategic funding system. This needs to be designed so as:

- To capitalise on the comparative advantages of regions, by mobilising all the resources available, towards the attainment of context-dependent and demonstrably attainable goals; and also,
- To take advantage of best practices and models available in relation to the governance and delivery of research, technology implementation and innovation.

6 Knowledge Transfer & Up-Take

The effective transfer and uptake of the existing reservoir of knowledge is potentially a more crucial determinant of the continued competitiveness and sustainability of Europe's agri-food industries and rural economies in the immediate decade(s) ahead than the generation of new research knowledge. However, within the R&D chain, ranging from conceptualisation of the research hypothesis/question to product and process innovations, knowledge transfer is all too often one of the weakest links. This is reflected in the general disparity in the relatively small and sometimes decreasing proportion of national and EU science budgets allocated to knowledge transfer and innovation, as opposed to knowledge creation.

The sustained commitment of a sizeable proportion of national and EU science budgets to the systemic transfer of existing knowledge would be likely to result in more innovative developments in Europe's agri-food industries and the rural economies than will be achieved by investing preferentially in the front-end of the R&D chain, especially in fundamental or curiosity-driven research. Weak technological absorptive capacity is, however, an inherent feature of most SMEs and micro-companies, including rural businesses. Various mechanisms are used to address this widespread problem, including the engagement by companies of *knowledge brokers*. With the objective of detailing best practices, it would be beneficial to have case studies of such initiatives documented from different countries. For instance, in Ireland, a medium-scale agri-engineering company (Keenan & Company Ltd.) has established an International Scientific Advisory Board

of knowledgeable and authoritative experts in economics, nutrition, genetics, agriculture, veterinary and food products. The purpose of the Board is to harness existing knowledge of relevance to the company's business. By applying leading-edge knowledge, the company has added to its core agri-engineering business a science-based, knowledge-intensive animal nutrition service. This is currently available to farmers in Ireland, the UK, France and Australia, and is being extended to other countries.