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Global Challenges and the Critical Needs of Food Science and Technology

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Global Challenges and the Critical Needs of Food Science and Technology (FS&T)

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Executive summary

Increasing global population and its increasing affluence will cause a growing demand for food. Climate change and water shortages will disturb even current practices. With predictions of population increasing to at least`9.5 billion by 2050; the limiting availability of cultivatable land; the impact of global climate change on agriculture; overfishing of the oceans; and the waste of edible material throughout the food chain; even greater efforts will be necessary to avoid a future food crisis.

Global opportunities and challenges for the science base of food, nutrition and agriculture sustainability have been recently been analysed in a number of Inter Academy Partnership (IAP) projects, covering Europe, Asia, Africa and the Americas. (IAP Interacademy partnership 2017,2018) These reports have examined science requirements across the food chain from primary production to diet and health. The critical needs of FS&T are often hidden. However, FS&T are fundamental for the conversion of agricultural raw materials into safe and healthy food products of high quality.

To date, FS&T has focused on raw material conversion and its safe delivery to the consumer. In future, challenges to this science base will come from the change in input raw material supply and the need to improve the health status of its output products. There will be a greater need to promote cohesion between FS&T with Nutrition in order to ensure not only low cost, convenience and palatability, but also the requirements for nutritional balance in whole diets. Also, food technology needs to be increasingly aware of how consumption is linked to economic, demographical and cultural change, and individual health requirements.

In the *Global Vision* report (Hermansson and Lillford 2014), a mapping exercise was made of how regions and countries included FS&T in their strategies to delivering food and nutrition security. There was a strong correlation between governmental strategies that included Food Science, Technology and Nutrition security and the public-sector research funding allocated to advance the Science and Technology base

The aims of this report are to reveal the vital position of FS&T and their essential role to adapt and find solutions to global challenges in relation to food and nutrition security. To demonstrate the critical needs for all disciplines, we have identified challenges in the form of "Mission Oriented" research and development. This allows for the identification of the critical needs for future FS&T, in the context of input from other scientific advances throughout the food chains of the future, and highlights the need for collaborative, multidisciplinary research

The following missions have been analysed with regard to the critical needs of FS&T

Mission 1. To introduce more diverse and sustainable primary production. For conversion of new raw materials into products there are needs for advancement of measurements techniques to understand and control the behaviour of raw materials and ingredients during processing, to deliver products acceptable for the consumer.

Mission2. To design sustainable process and system engineering including novel processes using reduced water and energy. Critical needs for engineering are processing with reduced water and energy consumption and with less waste. This requires increased efficiency of unit operations and improved quality in preservation; and optimisation of all processes in manufacturing and distribution

Mission 3. To eliminate waste in production, distribution and consumption Waste is analyzed throughout the whole food chain. There are needs to improve storage stability; transportation conditions for primary produce; adding value to side streams from production and a need to engage with the packaging industry for new sustainable materials; and for smart sensors for safety and eating quality

Mission 4. To establish complete traceability and product safety. Product safety is fundamental and required in a global perspective, meaning traceability of primary source, processing conditions and product composition. New techniques are needed for identification of toxins, allergens, pathogens and spoilage mechanisms through the food chain.

Mission 5. To provide affordable and balanced nutrition to the malnourished. There is a critical need to reformulate food composition and modify processing to provide balanced nutrition and consumer acceptability at a *low cost* together with education about cost and health

Mission 6. To improve health through diet. Modern biology and multiOMICs techniques are fast developing and can couple nutrient intake to metabolic needs for prevention of non-communicable diseases on an individual or group basis. This is an interdisciplinary area and there are critical needs for FS&T to explore the release of macro and micronutrients through the alimentary tract from whole foodstuffs and provide healthier food.based on new data from medical nutrition.

Mission 7. To integrate Big Data, Information Technology and Artificial Intelligence throughout the Food Chain. The use of digitisation of food chain information is mandatory, making Information Technology a key element in the future of FS&T. Examples of critical needs are models for material/process interactions in food manufacture; statistical and causal relationships between diet and health; validated data and methods to enhance traceability

All the IAP reports recommend that integration ALONG the Food Chain will produce optimal strategies, and that collaborations of all stakeholders need to be maintained. Technical education and training of research "Thought Leaders" is a global need, as is a continuous supply of broadly educated and skilled operators of manufacturing processes. The consumer is probably the most important member of the chain. It is no longer appropriate, and they will not accept change without their involvement and acceptance. This means that they must be provided with balanced arguments, in understandable language, for any innovation that influences their health and wellbeing.

Introduction

Despite the rapid increase in population in the 20th century, technology has so far managed to provide sufficient food for most of the population. However, with predictions of population increasing to at least`9.5 billion by 2050; the limiting availability of cultivatable land; the impact of global climate change on agriculture; overfishing of the oceans; and the waste of edible material throughout the food chain; even greater efforts will be necessary to avoid a future food crisis. A recent study has detailed the problems of sustainability of the food chain. and made new dietary statements. (Willet et al 2019)

The Challenges

The Global Challenges have been formalised as the 17 United Nations Sustainable Development Goals. (SDGs-see Appendix 1) and for each of these, targets have been set. It is obvious by inspection that food production and consumption is involved with most of these and action will be required throughout global food supply chains. Most obviously relevant to Primary Production are: -

Climate action (13), Life below water (14) and Life on Land (15).

Of particular relevance to this report are: -

*Goal 2-End Hunger, achieve food security and improved nutrition, and promote sustainable agriculture***,** and

Goal 3-Ensure healthy lives and promote wellbeing for all at all ages

These cannot be achieved without increased output throughout the Food Chain which, in turn, will require continuous improvement of FS&T and its linkage with the growing understanding of the effects of food on human biology.

Further examination shows many other Goals are relevant. Since most of the world's food supply depends on the industries of food manufacture and distribution, and the skills necessary to innovate, we also address

Goal 9- Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation and

Goal 4-Ensure inclusive and equitable quality education, and promote lifelong learning opportunities for all

Global opportunities and challenges for the science base of food and nutrition security and agriculture have been recently been discussed and analysed by scientific academy networks in an Inter Academy Partnership (IAP) project. (IAP Interacademy partnership 2017, 2018) These reports cover **Europe** by EASAC (European Academies Science Advisory Council), **Asia** by AASSA (The Association of Academies and Societies of Sciences in Asiao), **the Americas** by IANAS (InterAmerican Network of Academies of Sciences, and **Africa** by NASAC (Network of African Science Academies).

Among the main topics examined by all regions were the science opportunities associated with the following.

• Ensuring sustainable food production (land and sea), sustainable diets and sustainable communities, including issues for agricultural transformation in face of increasing competition for land use.

• Promoting healthy food systems and increasing the focus on nutrition, with multiple implications for diet quality, vulnerable groups, and informed choice.

• Identifying the means to promote resilience, including resilience in ecosystems and in international markets.

• Responding to, and preparing for, climate change and other environmental and social change.

All the surveys identified that food supplies should not just be sustainable but result in healthier products and diets. This requires food technology to be increasingly aware of how consumption is linked to economic, demographical and cultural change, and individual human health requirements. A distillation of the main scientific recommendations can be found in Appendix 2, and the broad recommendations include stronger connections across disciplines and cutting-edge research

Recently the fifth overarching Global Report was published. Outputs from the four regional assessments, together with global analyses, were used as resources to generate the global report. The following main conclusions were made:

"Collectively, there is need to be more ambitious in identifying the scientific opportunities for sustainable and healthy diets."

" Food systems are in transition: living within planetary boundaries (including those for nutrients, water and climate) and having healthy populations requires new approaches to food systems."

"There is need to build critical mass in research, teaching and innovation and to mobilise those resources in engaging with policy-makers and other stakeholders."

These reports focus on primary production, diet and health. The critical needs of food science and technology (FS&T) are often hidden. However, FS&T are fundamental for the conversion of agricultural raw materials into safe and stable food products, whether it is performed in the home, by catering establishment or within centralised factories and their distribution chains.

The *Global Vision* report published by the International Union of Food Science and Technology, (Hermansson and Lillford 2014) showed a correlation between governmental strategies that included Food Science, Technology and Nutrition security and the public-sector research funding allocated to advance the Science and Technology base. Unfortunately, despite the objective of SDG Goals 2 and 3, the mapping exercise showed that many of the counties and regions most at risk appeared to have no developed strategies for its support, and therefore critical investment in this science and technology base is lacking.

The aims of this paper are to reveal the vital position of FS&T and their essential role to adapt and find solutions to global challenges in relation to food and nutrition security. We begin by examining the current capabilities of FS&T, and the future critical needs for development, integrating its contribution throughout future supply chains. (Part 1)

To demonstrate the needs of FS&T in an interdisciplinary scenario, we have identified challenges, and constructed programs in the form of "Mission Oriented" research and development (Part 2.) We hope that these examples will stimulate others to examine other Challenges, and their solution at a global and local level. Our particular Mission statements are listed in the Table below.

Missions	**Key drivers of change**
1.To introduce more diverse and sustainable primary production	Climate change, land use, soil sustainability, Reduction of GHG
2. To develop new process and systems, to ensure more sustainable manufacture.	Energy and water reduction. Reduction of GHG Alternative raw materials Reduction of material losses Distributed versus Centralised Manufacture
3. To eliminate material waste in production, distribution and consumption	Reduction of environmental load More available food from same inputs Improve local infrastructure in low income countries Increasing population and wealth
4. To establish complete traceability and product safety	New technologies and origin of components International trade Prevention of health risks such as food poisoning and allergic reaction
5. To provide affordable and balanced nutrition	Price Health and Sustainability Consumer acceptance
6. To improve health through diet	Prevention of non-communicable diseases, Reduction of obesity and overweight Increase Consumer engagement with healthy diets
7. To integrate Big Data, IT and Artificial Intelligence throughout the food chain	Efficiencies in production, conversion, distribution, safety and health provision Traceability

None of these actions will be successful without a continuous supply of well-trained staff, to improve current practice, communicate with the public and to generate "Thought Leaders" for research and business strategy. Support mechanisms will need to be strengthened globally. (Part 3)

Part 1. Food Science &Technology - Past and Future

Food Science and Technology already enable agricultural produce to be preserved and converted to a vast array of food types; and delivered safely to the consumer, either for immediate consumption or stored for future use. In future, there will be a greater need to promote cohesion between FS&T with Nutrition in order to ensure not only low cost, convenience and palatability, but also the requirements for nutritional balance in the whole diet. Because of the understandable focus within the SDGs on agriculture for sustainability and on human biology for diet and health, the need for skills in food science and engineering are hidden. However, the EASAC report includes a version of the figure below:

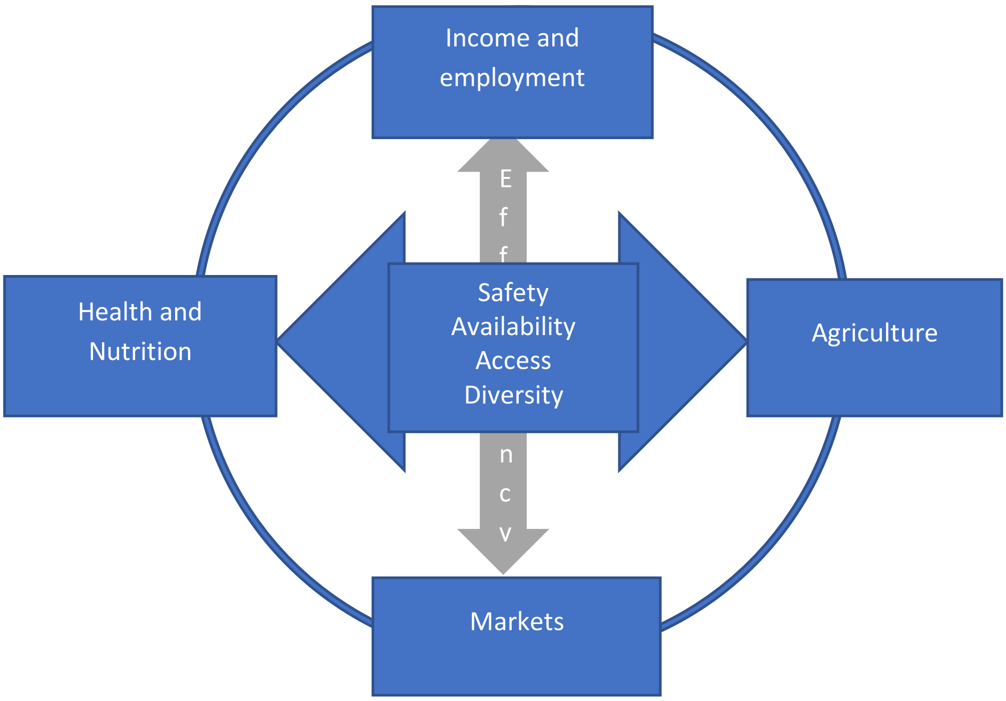
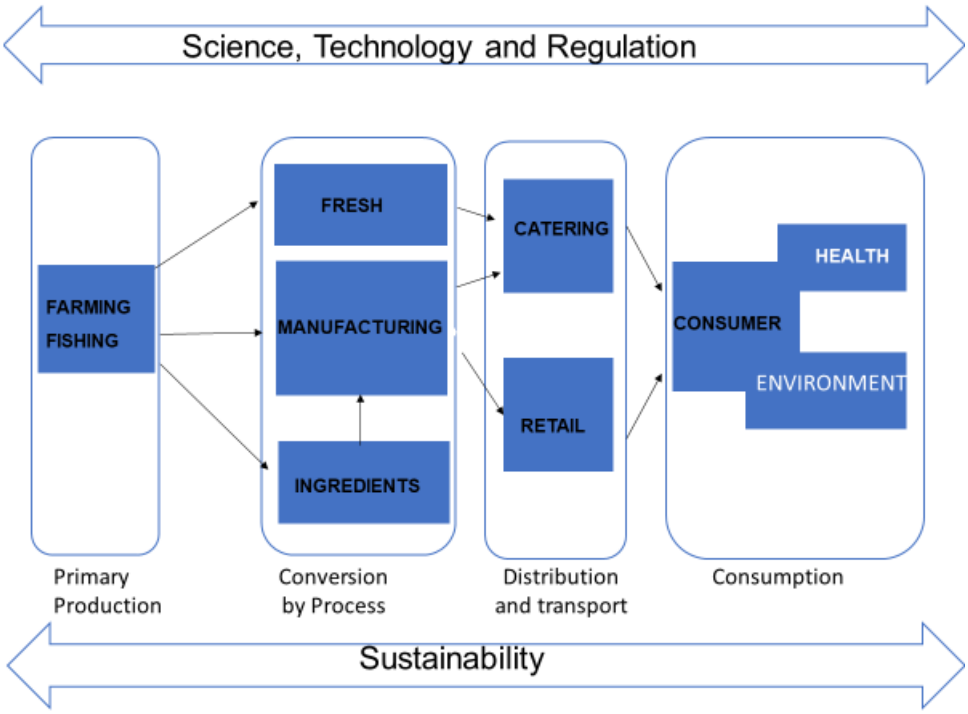


Figure modified from von Braun, 2017.

FS&T are the collection of disciplines by which the very heart of this conceptual pattern, (Safety, Availability, Access, Diversity and Efficiency) is delivered. We would comment that Palatability is also a key to the translation of Agriculture to Health and Nutrition, and this too is part of the existing remit of FS&T. Examination of how this will be achieved, requires an operational flow chart of the food supply chain. This is shown schematically below



This basic process applies to every supply chain, from subsistence farmers, rural markets and home cooking, to national and global provision via specialised industries trading for profit. To date, FS&T has focussed on raw material conversion and its safe delivery to the consumer. (Farm to Fork). In future, the most interesting challenges to this science base come from the change in **input** raw material supply, (driven by Climate Change, the need for environment protection and the emerging benefits of new plant and animal science); and the need to improve the health status of its **output** products, (guided by the increasing knowledge of the influence of food product architecture on nutrient bioavailability and the rapidly advancing sciences of human and microbial biology, which determine its nutritional impact.)

One of the great successes of large-scale food manufacturing is the control of raw material variability by crop and animal selection, the use of standardised, refined ingredients, and "process aids". This has led to the global dominance of a few crops (maize, rice and wheat); the selection and breeding of livestock for rapid growth (chicken, pig and beef); and accelerating demand for fish (whether hunted or farmed). Large scale continuous processing is now remarkably efficient, but because of its empirical optimization, is not flexible.

The science and technology must now move towards a strategy to "design and build" acceptable foodstuffs, instead of the former, "copy and upscale". There are still major gaps in knowledge which slow down any predictive approach, so that the advent of a new material still requires manufacturers to adopt an empirical approach.

Again, the future is recognised to be dramatically different, so these **internal** challenges to the existing capabilities of FS&T are now compounded with the new **external** challenges; - the influence of climate change; land, water and energy availability; the influence of sudden shocks to materials supply etc.; so that there are continuous risks that challenge the sustainability of current practices.

FS&T has flourished in the high-income world by collaboration between academics and the larger manufacturing businesses. It has been assumed that the primary target for food manufacturing is to produce safe foods which people enjoy. The targets have been to upscale the processes occurring in (western) culinary practice, using the same raw materials, and with the target of minimal change to the recognisable sensory appeal of traditional finished products. This is because the final arbiter of success is the palate of the human consumer, a product quality control test that is unique to the food chain. The parallel assumption has been that nutritionist and medical advisors will choose and recommend diets, and consumers are responsible for their overall nutritional status. These assumptions are now being challenged.

Furthermore, current mass production methods have developed in a context where raw material and energy supplies have been stable or increasing, and costs have been predictable. Water supplies were not restricted, and waste disposal was a relatively minor cost. This is now challenged by the need for alternative raw materials, protection of biodiversity, response to climate change, additive free formulations, maintenance of micronutrient levels and reduction of the energy density of popular foodstuffs.

Food is a perishable product, so supply chains require that acceptable products be preserved in a stable and safe state throughout the distribution chain. As a result, the microbiological sciences, physico-chemical analysis and sensory testing of finished goods have been simultaneously developed. Together, these developments have been technically and economically successful, allowing the food supply chain to become global in its reach.

Not only must a food be manufactured to give a recognisable and safe product, but the consumer then judges its quality during eating. Understanding the architecture (microstructure) of foods has become increasingly important, because this is the target of all raw material conversion, and source of all sensory response. The criterion of success is still the consumers enjoyment of the finished product, yet the dynamics of the eating process is still poorly understood, and the toolbox to examine structural changes during the processes of mastication and digestion is still limited.

These are the challenges to FS&T even in existing supply chains and will be amplified by the need to make food production more flexible and sustainable. The need to enhance the research base is urgent.

FS&T links with Agriculture and Healthy Diets

The Sustainable Development Goals cannot be fulfilled by the simple provision of more commodity crops or finished foods.The overall benefit to the population of appropriate nutrition is required. (Goal 3). The IAP reports clearly describe where malnutrition (starvation , stunting, micronutrient difficiences) and increasing overweight and obesity occur on a geographic basis- but also at a local level, even within the same household.

The IAP and EAT-Lancet reports are very clear in their conclusions that the science and technology required to meet global challenges cannot be applied uniformly around the globe.

More importantly, without regards to consumer culture and better education in dietary needs for health, even the best science will not provide acceptable solutions. Are there any general conclusions that can be drawn as to the challenge to FS&T in these environments, where the application of the Nutritional Sciences has historically appeared more relevant?

Basic Nutrition is taught in most food science courses. Its science base has developed in parallel to those of food production and concerns the effects of the total diet and the requirement for macro and micronutrients for the health and well being of humankind throughout their growth and ageing. It is also multidisciplinary, encorporating chemistry, human biology and behavioural studies, and has focussed on the composition of food types and their assembly into a complete diet. It also explores the digestive process to account for bioavailability of nutrients. The recent exploration of food breakdown properties during oral processing and the delivery of nutrients throughout the alimentary tract, has shown that the impact of food structure on bioavailability of nutrients during mastication and digestion is as important as its composition.

These studies can already be related to the needs of particular groups (young, old, male, female etc.) but food is now recognised as a form of preventive medicine and crucial to the overall wellbeing and performance of any individual, so the concept of personalised nutrition is emerging. Recent advances in molecular biology are revolutionising the study of Nutrition. It is already possible to tailor nutrient intake, coupled to metabolic need. This is visible in sports diets, endurance rations for the military, and selected diets for recovery from injury or illness. This will develop further to the prevention of non-communicable disease including mental status. Furthermore, the response to diet is also dependent on an individuals' genome, gut microbiota, metabolome and prior dietary history and lifestyle. Research and development related to these topics is underway, but knowledge is only just emerging. We note, however, that large food manufacturers are already equipping their consumers with personal kits to monitor their metabolic state (Nestlé, 2018).

The implication is that diets and even food products will need to be tailored to the needs of differing nutritional groups and even individuals. This suggests a more varied product range, and therefore will require more flexible manufacture. This must be achieved within the constraints of sustainability, requiring maintenance of high efficiencies in manufacture, distribution and consumption. To develop a sound, factually based approach to this new challenge, closer collaboration between FS&T (food assembly) and modern nutritional and medical science (the effects of consumption) is self-evident. Some example of where there are opportunities for advancement are: -

Integration of agriculture and health

Except for the "Fresh" chain of fruit and vegetables (fig2), people do not eat agricultural produce. Most primary materials are processed in a kitchen or factory, to produce sensorially acceptable products which are combined to form diets which then impact on health. Traditionally, nutrition identifies the composition of produce, and relates its nutritional value to its chemical composition. Much more specific requirements regarding the delivery of nutrients and the consumers' metabolic response will be identified in future. Nonetheless, foods will still have to be manufactured, and trends towards urbanization suggest that food processing may move out of the home. Whatever scales are used a critical need for collaboration is emerging. As nutrition and medical science define individual requirements for foods, FS&T must achieve their safe manufacture and distribution.

Conversion, Distribution and Consumption

No food has a nutritional value unless it is consumed. and the intention to purchase and consume is most often determined by the "quality" and preference of the eating experience. The sensory appreciation of food is part of the current FS&T base and in recent years specific attention has been placed on oral processing and the kinetics of digestion. This clearly shows sensory appreciation and nutritional benefit cannot be linked directly to composition or formulation. We have examples already, where the simple reduction of salt and fat on nutritional grounds requires a detailed understanding of the structural adjustments to food types that are required to reach the same level of sensory appreciation.

The overarching requirement for nutritional value is that the product must be safe to eat. Many agricultural products contain antinutritional factors and allergens which require removal by processing. Once an acceptable food product is available, it must reach the consumer in a similar state. This almost always requires some form of packaging which protects against microbial contamination, metabolic senescence and physical damage. At present, most foods are overpackaged to ensure safety, and shelf -life is described by precautionary date stamping at the time of manufacture. The result is excessive waste, first in the packaging itself, but also by precaution of the manufacturer, retailer and consumer.

The Consumer's Needs and Knowledge

There is continuous feedback from the consumer to all parts of the food chain. We cannot assume that technological developments will aways be readily accepted.

For primary produce, genetic manipulation is still the most contentious global issue. The growth of international supply chains, whilst economically successful, leads to concerns of excessive Food Miles (the distance food is transported from the time of its production until it reaches the consumer), uncontrolled animal welfare, and ethical labour treatment. All of these issues are crystallised in the consumers concerns for traceability

Consumers automatically question innovation in food processing when this is not related to their own experience of culinary practice. Resistance to novel processing methods such as irradiation, high pressure etc and the use of chemical additives has lead to the PAN (reverse engineering) concept, suggesting that food processes need to be adapted to the Preferences, Acceptance and Needs of the consumers rather than adapting raw materials to the process requirements.

Retailers can monitor immediate consumer reaction to product innovation by repeat purchase data, and this determines the amount and position of products in the supermarket. Consumer choice does not necessarily follow sustainability or health recommendations.

Most worryingly, international and regional government recommendations on healthy eating and diets are not immediately accepted, despite the fact that no consumer has an intrinsic desire to become unhealthy.

These uncertainties highlight the need for increased knowledge of the drivers of human behaviour. FS&T does not lead such studies, but it is recognized that in all the following Mission proposals, this is vital input information and will be a guiding principle in the preferred action planning.

Part 2. Responding to the Challenges-by Mission Oriented Research

In previous sections, we have revealed the strategic significance of FS&T in the context of Global Challenges. Now we examine possible approaches by which FS&T must contribute if these Challenges are to be resolved. We have chosen to use a structure of Mission Oriented programmes, since these most easily demonstrate the need for broader collaboration of the skills in Primary Production, Conversion, Distribution and Health benefits (See Fig 2). Quoting Mazzucato, "Missions provide a solution, an opportunity, and an approach to address the numerous challenges---", and Mission-oriented programmes "--draw on frontier knowledge to attain specific goals or big science deployed to meet big problems--" (Mazzucato, 2018). This does not deny the value of enquiry driven research but identifies the future needs for the directed deployment of existing knowledge and the critical needs to fill identified gaps. We acknowledge that R&D has built background knowledge, but this approach justifies continuous and increasing investment in the science and engineering base now. Without this, the missions, cannot be achieved in the appropriate time scale. Some of the needs discussed in the missions are already important research areas within Food Science and Technology, but need more attention and further advancement in order to achieve the challenges of the missions. Other critical needs open up completely new interdisciplinary fields of research with access to new research tools

Mission 1 - To Introduce more diverse and sustainable Primary Production

As new materials are to be introduced into the food chain, the critical needs for FS&T will be:-

- ***To develop accurate tests for the functionalities of new raw materials (crops and animals) and ingredients, in conversion processes and final product performance***
- ***To understand and control the behaviour of raw materials and ingredients in the unit operations of conversion to foods, relating their materials science to the kinetics of conversion.***

Justification of these needs are presented in the examples below: -

Yields and functional performance of commodity crops

Routes to increase arable yields, with fewer inputs of water, fertiliser, herbicides and insecticides, can be achieved by "Smart Farming". Modern molecular biology will accelerate selection and breeding of drought, heat tolerant and nitrogen fixing crops. However, yield (price) is not the only criteria needed for efficient food processing and manufacture. Only if these yield traits are accompanied by retention of similar materials behaviour of the macronutrients (fats, protein and carbohydrate), and retention or increase of micronutrients, can these new materials be “dropped into” existing food chains where raw materials are converted by separation to ingredients, or conversion to complete structures. (Fig2) The identification of functional performance of crops and their components is part of the existing skill base of FS&T, so future collaboration is obviously necessary to fulfill these extra production targets. New screening methods for functional performance will need to be developed, since this cannot yet be directly related to gene based traits. In the event that yield and function cannot be matched, then existing down stream processes will need to be modified to deliver flexibility of processing with minimal change in product quality. This means greater research investment in materials science and process engineering.

Novel and ”Orphan” Crops

We must also expect crops already suitable for arid,warmer or salt tolerant conditions to be increasingly used. These sources (eg sorghum , millet etc) are not novel in themselves but are not global commodities like maize, rice, wheat and soya. In addition there are crops gathered or grown locally for animal and human consumption, but which have not been improved by agricultural practice or breeding, often described as “orphan crops” Their use is still based on traditional recipes.

All the same issues arise as for commodity crops, but for these, their agricultural production (yield delivery) and the details of their performance in subsequent processing have not been widely studied. There will therefore be a vital collaboration between agronomist, plant scientists,food scientists and engineers. These crops are not globally available so, even if they are recognised as a vital input to future world food supplies, existing short supply chains must be improved and downstream processing must become just as energy and water efficient as current large scale manufacture using global “commodity” crops .

The functional performance of their major components (proteins, starch, fibre and soluble sugars) will be different in behaviour to those examined previously. Rather than simply upscaling traditional recipes, (“copy and upscale”), or perform endless empirical studies of their use (the “cook and look” approach), a more systematic “design and build” methodology should be invisaged, where systematic studies of their materials properties and restructuring by process are planned. Investment in this science based approach will eventually make product development far more efficient.

Animal protein replacement

Animals provide a dominant input to the protein requirements of human food, (meat milk eggs) and their proteins are of high nutritional quality. Yet reduction of animal consumption would be environmentally beneficial in terms of efficiency of protein production and reduction of GHG’s.(Willet et al 2019) Any successes in its replacement would release huge areas of arable land, (and the volumes of its output) to the human food chain, since more than 40% of commodity cereal crops go to feed.

Meat

Genomic applications to improve animal breeding are in progress, but just as for crops, a continuous input from FS&T will be required if eating qualities of individual cuts are to be evaluated.Animal proteins also have high nutritional quality, but the proponderance of saturated fats in land animals represents a dietary problem.

Whilst changes in feed type can modify the levels of saturated fats, offcuts of fat, sinew and bone represent a waste whose value could be increased by processing to higher value products, not always within the food chain. This also requires competences in materials science and engineering, to produce fatty acids, peptides etc. as precursors for synthetic chemistry.

Tissue culture to produce muscle protein *in vitro* has already been demonstrated, and offers a benefit to consumers concerned with animal welfare. Its large scale implementation will depend on very cheap sources of tissue nutrient, and if meat textures are to be produced control of the fibrillar assembly must be achieved. It is more likely that actomyosin proteins will be produced from novel sources which can be restructured by existing technologies into meat-like comminuted products. (e.g. sausage, and patties).

Change from animal to vegetable proteins is in progress, but the texture of meat provides a pleasant sensory experience . To replace the eating performance of muscle in its various forms is a major challenge to FS&T. Some technology is available (fibre assembly, extrusion) but few provide realistic and acceptable meat- like sensory properties, so a major investment in process and product characterisation is required if textures and flavours are to be accepted. Furthermore, to match the amino acid composition of meats, a combination of vegetable sources or fortification will be required.

Fortunately, vegan, vegetarian and "flexitarian" dietary habits are increasing. It may well be that new vegetable based foods, and those prepared from traditional recipes become more acceptable. Even so, it will take considerable investment in FS&T to generate these products efficiently, or on a larger scale. Studies of the functional role of proteins in these products will be necessary, to reduce the waste of empirical process development, and to reach consumers sensory expectations.

Meat products_(sausages, pate etc.)

These require the gelling properties of the dominant protein of the muscle myofibril. Gelling vegetable protein from soybean, groundnut, peas and pulses can be isolated by existing technologies, but without expensive refinement their colour and flavour is not acceptable. A fusion of the fermentation processes of traditional asian culinary practice with meat product technology may provide unique solutions, but requires considerable investment in FS&T research and innovation.

Milk and Milk Products

This combination of approaches has already taken place in the replacement of dairy by vegetable proteins. Physico chemical and fermentation technologies have produced quality products in vegetable based equivalents. (milks, cheese , yoghurt etc). This is a clear demonstration of the capabilities and necessary deployment of FS&T, without which acceptable and safe products would not be available.

Eggs

Eggs are a ubiquitous protein source in most diets. The albumin functions as a gelling, foaming and emulsifying agent in many recipes. Recently, whey albumins from milk provide an alternative, but as yet there is no single direct protein replacer from a vegetable source, largely because the storage proteins of seeds are dominated by globulins with different solubility. The lipoproteins of yolk also have no direct vegetable analogue. In both cases, to generate a non animal equivalent, the exploration and modification of functional performance of protein from seeds and tissue will be required.

Food from the sea

Animal products

Recent reports indicate that even despite conservation attempts, up to 90% of natural stocks are overfished already, and that farmed fish are not filling the demand. Since this is a major source of high quality protein in the human diet, and of high acceptability in most cultures, steps to fill this inevitable gap must be urgently considered.

The science and technology of conversion of caught fish to food products is reasonable well studied and understood, though one species cannot be immediately replaced by another, either in technical function or consumer acceptance. All of the technical issues examined in detail for meats (above) apply equally to fish and its products, and will need to be deployed, with at least as much urgency.

Marine plants

Plant based marine species (algae) have been eaten for millenia, and coastal populations have a variety of food recipes wherein red and green seaweeds are a component. A more important opportunity arises from the capacity of marine plants to produce components for both nutritional benefits (micronutrients) and the structural elements of foods and feed. Already, claims are made for health benefits of their minor components, and the gums and mucillages derived from marine plants provide soluble fibre, and some are identified as prebiotics.Their proposed increase in use presents many challenges if they are to be restructured to acceptable product forms. For efficiency, ALL of the algal biomass needs to be used. A biorefining strategy is required, to add value to the protein, oils, carbohydrate gums and fibre. This will need a significant investment in greater research into separation sciences, materials behaviour, and process engineering.

Insects

Edible insects have recently attracted attention because of their production efficiency, particularly of proteins. Consumer acceptance of the intact organisms will be slow, and a more acceptable incorporation into human foods may be their use as a source of nutrients (protein, fats, etc.), in particular their protein which is comprised largely of muscle types. However, the possibility that “foreign” proteins from this novel food source are safe, and do not produce allergenic responses will also need careful testing. Their potential use will require application of separation sciences, characterisation of functional performance, and in particular their conversion into stable ingredients for reformulation into new and existing product types. Hence, their conversion to more readily acceptable structures represents a major challenge for FS&T.

Mission 2 - To develop new processes and systems, to ensure more sustainable manufacture

Modern food manufacturing derives from culinary practices, which have evolved to produce safe and palatable products. (Many food factories ressemble large kitchens). The available technology can be applied to the large scale production of any culinary product, though each new raw material will require empirical optimisation. In future this must be carried out with reduced water and energy consumption and with less waste. This requires increased efficiency of unit operations (Process Engineering); reduced energy and improved quality in Preservation; and optimisation of all processes in Manufacturing and Distribution (Systems Engineering)

The critical needs are :

- ***To further develop precision engineering to reduce and recycle water and heat across all the unit operations of conversion, cleaning and preservation. (This may include novel unit operations, such as high pressure, PEF, ultrasound etc, where their extra efficiencies can be utilised.)***
- ***To develop conversion processes which cause minimal damage to reactive micronutrients***
- ***To develop low temperature conversion via enzymic and fermentative processes***
- ***To improve drying and rehydration to minimise product and ingredient weight in distribution, while maintaining function and performance***
- ***To explore the relative merits of centralised versus distributed manufacture for sustainability for example,by scaling down existing processes for local applications without loss of operational efficiency***
- ***To promote the harmonisation of metrics of sustainability measurement, of product and process,from primary production to end of life.***

Process Engineering

"Precision Engineering"

The current paradigm of mass manufacture is to construct continuous processing with standardised raw material input, optimised unit operations, and running at maximum throughput.Product quality is then monitored "off-line". Unfortunately, because biological materials are intrinsically variable, this procedure needs to repeated whenever raw materials change, either by season, crop type or variations in ingredient supply.

In future new process models, with sensors, which continuously measure the condition of components in any formulation should be linked to flow rates,shear, heat and mass transfer,etc. allowing optimisation and tuning line performance in real time. This will require rapid capture and processing of massive data sets, which digitisation is now making possible. (see also Mission 7)

The advantages will be much greater flexibility of plant and equipment, allowing either a wider variety of input materials or different product types from a single process line.

New unit operations

Some success has been achieved through the use of unit operations not usually associated with kitchen practice (e.g Extrusion,High pressure, Pulsed Electric fields, Ultrasonic crystallisation and even 3D printing). However they must add value. Any new process must include the maintainance of product function (as an ingredient or a finished food), not just increase process efficiency in terms of energy and water usage. (Knorr et al 2018)

Micronutrient Sensitivity

As well as manipulating the macronutrients to provide product structure, sensitive micronutrients need to be protected. This is often incompatible with the need to eliminate toxins , antinutrients , allergens and microbiological contamination. A reexamination of current operations and their selective improvement will be necessary.

Bioprocessing

There is a growing awareness that fermentation and enzyme processes are traditional practices, using low energy, allowing longer product shelf life, and demonstrating a very interesting principle of product protection by biochemical routes. This may also be improved by research and application to a wider spectrum of primary produce. Under controlled conditions such approaches not only protect products but will produce recognisable or novel textures with considerable consumer appeal, and may even provide a nutritional benefit.

Reaction Chemistry

Any new process or material, will give rise to new reactive chemical species. The products may be beneficial (colours, aromas and flavours) or create off- notes, carcinogens etc. The reactive chemistry of foods has been continuously studied for many years, but the over-riding requirement to produce safe and palatable products will need continuing investigation.

Preservation

Packaging

Unless food is consumed immediately after preparation, packaging is a major requirement for product safety and stability, and is a major investment in the cost of manufacture. FS&T has made contributions by introducing modified atmosphere packaging (MAP), and defines the states of food which need to be preserved. As packaging material is lightweighted, modified to be biodegradible, recyclable, fossil fuel free etc., FS&T will need to be closely integrated with all innovations to ensure product safety and quality are not compromised. Developments in “smart packaging” are in progress. Chemically active species are encapsulated in the packaging material, controlling oxidative state, antimicrobial activity etc,often via the use of nano particles. It will remain essential to prove that the actives are not transmitted to the edible product.

Higher quality in dried products

Most foods have a high water content so that the costs of transportation are very high.To this must be added the energy costs of preservation via heat (sterilisation and pasteurisation), cooling (chilling and freezing) and more recently by high pressure and pulsed electric fields. Drying therefore has a major advantage if product is to be stored or transported, but the complex architecture of most foods is currently damaged, even in freeze drying. Major savings in energy during transport and storage could be made if drying and rehydration of food structures (rather than simple ingredients) were possible.

System Engineering

The current paradigm is that upscaling the systems of manufacture will lead to economies (via efficient deployment of inputs). The combinations and scales of unit operations during conversion need to be considered as a whole. This includes water and heat used during cleaning, without which no safe products can be reliably manufactured. (ie. the whole "system" of manufacture needs to be re-examined for its sustainability).

Furthermore, foods are perishable and require preservation in any supply chain. As chains become longer and larger, traceability of the history of components is lost, and as distribution costs increase the system becomes unsustainable. Recently, the option to shorten chains, reducing distribution costs, and meeting consumer preferences are being examined. This "Distributed Manufacture" will require more flexible processing , tailored to local materials. (Angeles-Martinez et al 2018)

Finally, there is an urgent need to harmonise measurement methods of the relative efficiencies of manufacturing systems, using Carbon Footprinting, Food Miles, Life Cycle analysis, etc.over a range of scales and product types. Without this, novelty in processing could either increase or decrease its effects on Sustainability. This will be discussed later in Mission 7-The integration of Big Data, IT and AI.

Mission 3 - To eliminate material waste in production, distribution and consumption

(Energy and water wastes in Manufacturing were covered in Mission 4.2)

All biological material is unstable, and prone to degredation by autolysis and microbial degredation,when stored. An approach where no components are stored, can be considered on a local basis, and is even now practiced across national borders.("Just in Time" manufacture- See Mission 4.7). However, for global security and manufacturing efficiency, buffer stocks of material will always be required at each stage of the food chain, simply to cope with disruptions anywhere within it. These can already be seen as a result of climate variability, transport failures, civil strife etc., and even variability in consumer choice.Inadequate preservation is the primary cause of waste, in primary production, manufacture,distribution and the home.

The data collected so far indicates that in low income countries, the proportion of wastage is highest in losses of primary production, due to inadequate post harvest storage of primary materials and poor distribution infrastructure (road and rail). In high income countries it is weighted towards product distribution and the home (supply surpluses).

The critical needs facing FS&T are:-

- ***To improve storage stability of primary produce, to cope with inefficient transport and downstream use; by developing low energy drying, chill and frozen distribution using solar energy and other forms of sustainable power.***
- ***To develop rapid sensors of :- primary product condition and safety; eating quality and nutrient status of finished products.***
- ***To restructure the ingredients and food assembly industries to add value to all side streams.***
- ***To engage with packaging producers, allowing reduced levels of petrochemical materials in products, and development of novel forms (recyclable, biobased materials etc.)***

The Science and Technology of Preservation

This is fundamental to all segments of supply chains. Current best practice needs to be harmonised worldwide, but novel routes need also to be developed and deployed at scale.

The advantages of cereals as a primary food source can be related to their safe storage. They are dry and if handled properly, stable to microbiological attack. This is not the case for most food materials since fruit vegetables and meats are high in moisture. Wet preservation by sterilisation, freezing etc, is energy intensive, expensive and can damage micronutrient status.The development of more sustainable, energy efficient processing (solar, wind powered) at a local level, would significantly reduce primary produce losses without a further load on petrochemical energy sources. It is proposed that losses in low income countries can be reduced by digital integration and greater openess of supply and demand, (eg. Blockchain approaches- See Mission 7). However, the net effect on sustainability will only be positive if small scale, local processing with high efficiency is available. (Mission 2)

In high income countries, the majority of waste occurs with finished product. This includes packaging. Even worse, Retailers and Consumers simply do not use what foods are provided and foods are disgarded because of real or perceived health or quality risks. (see Missions 2 and 4). This waste not only contains the biological material, but also the embedded water and energy used in its production, and the packaging materials necessary for its safe distribution. Better sensors for deterioration in safety, eating quality and nutritional value will be required to increase usage, whilst maintaining safety and quality.

Sustainable Bioeconomy and circular economies

This requires a major rethink of raw material refinement and argues for restructuring the Ingredients business to produce zero waste, by maximising the functional performance of all side streams. Rather than processing towards optimisation of a key ingredient, the concept of “Biorefining” where no side streams are wasted, must become the norm. This does not simply mean the extraction of higher value components, but the optimisation in value of all the product streams. FS&T can define the function of components and thereby their potential application and added value. There will need to be a move from definition of ingredients by type (protein, starch, fibre, micronutrient etc.), towards a description of their “function” in product creation, (Flavour delivery, thickening, emulsifying, antioxidant activity, nutrient delivery etc.)

Mission 4 - To establish complete product safety and traceability

The critical needs of FS&T required to deliver this mission are :-

- ***To make best practice in food safety available globally.***
- ***To develop validated rapid methods for identification and quantification of toxins, allergens, pathogenic and spoilage organisms across the food chain***
- ***To understand the epidemiology of microbial growth and genetic variation in the food environment.***
- ***To prevent the transfer of resistant (AMR) organisms to the food chain, working with veterinarian and medical microbiologists.***
- ***To provide traceability of products by introducing robust documentation of product histories, including primary source, processing methods and labour utilisation, product composition and safety***

Delivery of safe products

The fundamental requirement of food is that it is safe to eat. To achieve this, toxins, antinutritional factors, and allergens in the primary source must be removed or inactivated. Most of the processes we practice , in the kitchen or the factory have developed to achieve this, and the concepts of "Hurdle Technology" and HACCP are a success story for Food Science and Technology. However this has been developed using a limited set of input raw materials and processes.

As new materials and processes are introduced to the food chain, quantification of novel toxins, antinutritional factors and allergens will need to be introduced. It will not be possible to assume that simply because some societies have routinely consumed a raw material, it can be "Generally Regarded as Safe", particularly if the traditional conversion process to a finished food is changed. Instead, there will be a need for rapid analytical methods to establish safe levels in any new raw material and process.

Pathogenic organisms must be eliminated or inactivated and as well as heat processing, high pressure, radiation and other "emerging technologies" for microbial protection can be deployed, both singly or in combination, to provide sufficient "hurdles" for microbial growth.

Microbial spoilage remains difficult to assess rapidly and leads to precautionary practices in packaging and labelling advice to consumers. Climate change threatens the spread of new pathogens and spoilage organisms, which will be active in the raw materials and will need to be managed in finished products. Whilst the principles of microbial management are well known, the problems of bioactivity of both the changing microbial population and the specific behaviour of new host crops will need continuing research.

Microbial resistance

Changes of practice along the food chain can lead to new microbial hazards. Lysteriosis transmission via the food chain was first detected in 1981, but because of the organisms resistance to freezing and chill storage, its incidence is increasing as these preservation processes become more common. Its detection and elimination is still a significant problem for the food chain, including the domestic handling and hygeine of fresh and ready to eat products.

Antimicrobial resistant (AMR) bacteria, have been detected within the food chain, and represent an emerging threat. Genomics are capable of tracking the changes occurring in populations but their cause is complex and multivariate, requiring constant vigilance by food microbiologists. It appears that the primary cause is the use of antimicrobials in preventing infection of primary produce (plants and animals) but also the release to the environment of species used in human clinical treatments. Global concerns of the spread of resistance is already an active area for research. Food microbiologists must work with medical clinicians, to understand the genetics and epidemiology of resistance development, together with rapid methods of detection and remediation.

Processing with enzymes and cultures

These technologies offer a set of low temperature processes which not only effect conversion, but in the case of cultured products, can provide a hurdle to future microbial contamination. FS&T should explore the the potential of these processes across a wider range of materials.

Traceability

Consumers are increasingly purchasing prepared foods, because of their convenience and acceptable eating quality, but at the same time are becoming more conscious of production methods, authenticity,ethics of animal handling and labour exploitation. These concerns are summarised in a desire for greater traceability of supply. Whilst the introduction of digitised, open source supply chain data (Distributed ledger or “Blockchain”etc.) will have a major impact on traceability of source materials and their safe processing, data entry will require improvements in quality control measures and therefore require a basic training in FS&T, as well as Information Technology. (See Mission 7)

Mission 5 - To provide affordable and balanced nutrition to the malnourished

This Mission relates directly to Sustainability Goal 2-End Hunger. However, the issues are complex, since it includes not only the agrarian poor in low income countries, but also malnutrition in the deprived sectors of regions where food is available. The statistics compiled by international agencies (FAO and WHO) indicate that 820 million people suffer from chronic hunger (FAO, 2018). However, when the numbers who are deficient in micronutrients are added the total rises to more than 2 billions (WHO, 2006) (Gödecke, Stein, & Qaim, 2018).. FS&T must contribute, via its input to:-

utilisation of local crops available now, or improved by breeding; downscaled but efficient processes of conversion; waste reduction; safety.

Therefore;-

- ***All the critical needs identified in Missions 1-5 must be fulfilled.***

and there is a further need-

- ***To reformulate food composition and modify processing so that balanced nutrition, convenience. and consumer acceptability is provided at low cost.***

The agrarian poor in subsistance farming

Climate change in some parts of the world may make human survival unsustainable. In the meantime, drought and floods can produce famine, rendering some societies dependent on international aid which has to be provided from preserved buffer stocks.

The IAP reports refer to the differing scientific needs on a regional basis, but recommend that improvement will depend on advanced technologies in primary production coupled to analysis of the critical deficiencies in nutrition.

We emphasise again that advances in agricultural practices can increase local yields, but without an efficient food chain this will merely increase losses and waste. The primary need is to transfer existing best practice in FS&T from academia and industry to the regions in need, but the focus on local and regional needs implies that technologies will need to be efficiently downscaled and all the technical needs identified in previous Missions should be made available as soon as possible. Local self sufficiency can be enhanced by the formation of co-operatives but training in FS&T is at a low level, start up capital is rate limiting, and distribution infrastructure will also need investment. All these are receiving support from the public sector, by state intervention, charitable action and public private partnerships. These supporting inputs should increase if this critical need is to be met. Unfortunately, the previous Global Visions analysis indicated that in many of these regions, national governments show an absence of strategic planning for the future of FS&T.

The Urban Poor and "Hidden Hunger"

"Hidden Hunger" relates more to health and welbeing than starvation and survival. We mentioned previously that food chains have evolved by focussing on a few global animals and crops, and their efficient conversion to foods that are safe and pleasurable to eat. This has been successful, but the cheaper foods tend to be energy dense, because their macronutrient components are produced efficiently and at global scales. Surveys show that for the financially and socially deprived population, these are preferred for their cost, convenience and pleasurable eating, rather than their nutritional quality. This results in unbalanced nutrition .

Nutritional advice on balanced diets and exercise, (which already includes groups such as childbearing mothers , neonates, children, and male and female adults,) is not being adopted by poorer consumers, but there are multiple reasons, leading to a variety of health consequences. Firstly, for some households, other demands on disposible income means that food is unaffordable, as seen by the growth of "Food Banks" even in countries where average income is high. Secondly, where income is available, households, can be "time poor" or inexperienced in the culinary skills to provide healthy diets from cheaper food materials. As a result, cheaper processed foods are consumed, which are energy dense and these unbalanced diets are leading to obesity. This is a general trend in all nations, but is particularly so in poorer sectors of every society.

Rather than the unsuccessful communication and “nudges” toward better individual choice of diets, pressure is now applied to the manufacturing industry to improve the nutritional balance by reducing calories (via smaller portion sizes, less fat, sugars) and salt within individual products, as well as diets. Major advances are underway, but it must be recognised that the total diet should be balanced, and many food types contain fats, sugar and salt as part of their traditional recipes. To provide healthier alternatives with the same acceptability in taste and and safety is a serious technical challenge.

For improved micronutrient content, there are several solutions. One is to fortify foods with beneficial micronutrients, which is relatively straightforward, provided their added cost is not prohibitive, and they are protected during any subsequent processing. Many of these could be extracted from existing side streams ,simultaneously adding value to what are currently low value waste. Since micronutrients are chemically reactive secondary metabolites, likely to be damaged or react during processing, their addition is usually at the later stages of food manufacture. Any novel processing should pay as much attention to micronutrient protection as to the conversion of components and the preservation and shelf life of finished products. However, the list of secondary metabolites with claimed health benefits in monadic feeding tests grows every day. Safe levels are not yet known, neither is their interaction with each other in whole foods. More detailed studies are required to avoid overenthusiastic dietary switches to maximise health.

A competing approach is the “nutraceutical” route where micronutrients are taken in conjunction with food. (see Mission 6) Such products are already available in tablet or liquid form, but are expensive.Whilst these products receive large R&D attention from the pharma industries, their access to the poor will only be by charitable or state intervention.

A third is to preserve micronutrient content and availability of each food type throughout its processing and distribution. This is much more challenging, since as discussed above, secondary metabolites are not stable and prone to damage during processing. This critical need for FS&T requires close collaboration with other disciplines as discussed in Mission 6 below.

Mission 6 - To improve health through diet

The average well fed consumer is increasingly aware that diet has a vital impact on health and well being, including the prevention of non-communicable diseases of both the mind and body. There are major gaps in knowledge of the fate of food and its components during ingestion and digestion, which need urgent attention if causal rather than correlative links are to be established between nutrient availability, their effects on human metabolism and hence their health benefits. This is the greatest scientific challenge, not only to FS&T, but the disciplines of nutrition, medical physics, neuroscience and physiology. Collaborations will be essential.

The critical needs to which all these disciplines must contribute are:-

- ***To measure the release of nutrients from whole foodstuffs both in position and time throughout the alimentary tract.***
- ***To identify and validate dietary biomarkers to objectively reflect food intake among consumers and make use of metabolomics to detect responses to different foods and diets***
- ***To identify feed forward and feedback signaling from nutrients to brain activity and hence the regulation of organ activity and whole-body metabolism.***
- ***To determine the extent to which genotype and metabolic phenotype determines the responses to diet, within existing dietary groups.***
- ***To establish more specific information of the nutrient needs of individuals within established nutritional groups for precise advice on diets.***
- ***To validate the impact of "neutraceuticals"on health, using cohort studies and market data, within realistic diets.***
- ***To identify the combined effects of macro and micronutrients on long term health via diet.***

Nutrient Release by physical processes in the alimentary canal

FS&T has been engaged with how breakdown during chewing provide the sensory stimulus relating to flavour and texture perception. Recent collaborations between FS&T with dental mechanics and mouth physiology has allowed a radical shift in approach, allowing some understanding of the effects of nutrients on the oral microbiome, and more particularly the feedback and feed forward mechanisms of foods components and the chewing process on saliva type, rate of production etc. This is critical to sensory perception, and palatability but also restructures food prior in preparation for digestion. *In vitro* analogue processes are available, which can give first order information on breakdown and nutrient release, but none have the sophisticated feedback of the human mouth. Quantitative models have been proposed by food engineers but none are yet predictive design tools.

The dynamics of chewing have also been measured directly by imaging techniques, where the field is led by oral physiologists studying malformations of the mouth or illness resulting in Dysphasia, which in chronic form can lead to malnutrition. Food scientists are also collaborating with clinicians, studying the effects of food intake on brain responses, which relate to pleasure, pain and possibly appetite regulation. The mouth and nose are the first organs where aromas and textures are recognised, and the corresponding brain responses are being mapped in real time by techniques such as fMRI. All future progress will be made through collaboration of FS&T with the medical physics sector.

In principle, a similar approach can be taken along the digestive tract. The physical action of the stomach, small and large intestines can now be measured in real time in human subjects, and can be regarded as "unit operations" in the engineering sense. In future, food engineers will need to examine the processes of food breakdown in as great a detail as they have studied food assembly processes. An assortment of *in vitro* models for these organs have been proposed which at least give indication of the relative effects of food structures on digestion. Models can always be improved, by incorporation of representative effect of physiology, gastroenterology, and neural feedback signaling. These models should be shared with pharmaceutical and medical practice where targeted drug or nutraceutical release is the primary objective.

Genomics and Phenomics

Sampling from saliva, blood, urine and faeces has been a long-standing tool of nutrition. Recent advances in analytical methods and phenomics techniques such as metabolomics and microbiomics allows the collection of enormous data sets, identifying up and down gene regulation, the molecular composition of the metabolome in real time, and what metabolic pathways are influenced. It is now recognised that the relevant genome is not just that of the human, but also the gut microbiome. It appears that the microbiome, from mouth to colon, produces active metabolites which can act as signaling agents and additional nutrients.

Groups versus Individuals- "Precision Nutrition."

Existing dietary recommendations are based on average needs within age groups, gender, lifestyle etc. but it is already known that within each group, a very broad spectrum of responses are found. Advanced molecular biology now offers the opportunity to tease apart individual responses based on genetic and epigenetic effect of both the human subject and their personal microbiome. Big data sets will emerge and for the first time multivariate correlative models will be built, relating individual genetic and metabolic status to their long term dietary habits and their response to dietary intervention. It is probable that in future, metabolic status will create new groupings (or subsectors within existing groups), relating their common risk status for cardiovascular disease, various cancers etc. For these groupings more accurate dietary advice can then be given (Ordovas et al 2018)

Such models of human metabolic responses do not identify exact causes, but allow hypotheses to be built for beneficial nutrient combinations (ie foods and diets) on health status, both physical and mental. To test these hypotheses and to realise successful precise guidance, FS&T will will have a vital role in the design and manufacture of experimental products whose composition , architecture, breakdown pathways, and sensory appreciation are known.

This research collaboration with biological sciences will form the basis of precision nutritional advice, direct the reformulation of new food types, and has the further benefit of accelerating product manufacture and distribution at the appropriate scale and price.

Health foods

Selective diet design is already visible for elite groups such as in sports nutrition and performance of the military. FS&T is engaged in producing specific formulations and manufactured products for their benefit. In principle, this precision could be delivered to other selected groups, but overall health benefits depend on long term intake rather than short term performance. As explained above, there is missing knowledge and critical needs for a new science base if this is to be achieved.

Industry is already engaged in the production of individual foods products targeted towards health benefits, but because their mechanisms of action are not known, regulations are required to guide the manufacturer and consumer.

Medical foods are defined as those relating to the treatment of a particular disease state, and must be administered by a physician. They are closely regulated by the Food and Drug Administration in the USA, and by the European Food Safety Authority.

"Nutraceuticals". are micronutrients, particularly from plants, with suggested physiological effects on human subjects, and every society has historical systems for food choices related to claimed health effects. Using the fractionation and testing methods developed by pharmaceutical and food ingredients industries, molecular components isolated from edible materials (Nutraceuticals) have been associated with benefits to health via their impact on energy maintenance, protection against infection, stimulation of the immune system, improvement of cognitive performance etc. However it is also known that deleterious components can also be present in the same source materials, inducing addiction, growth repression, lathyrism etc., so advanced separation sciences and safety testing is required.

These new actives have begun to enter the food chain from the pharmacy as additions to ranges of vitamins and micronutrients in tablets or capsules, or as new ingredients for fortification of existing foods. The average consumer is incapable of making independent assessment of these risks and benefits, and relies heavily on expert opinion. It is vital that these ingredients are rigorously assessed in a range of complete food products and diets, where physical and chemical interactions may alter their efficacy.

Functional Foods. According to the British Journal of Nutrition, these products affect beneficially one or more target functions in the body, beyond adequate nutrition ", in a way that improves health and wellbeing or reduce the risk of disease" (Scientific concepts of functional foods in Europe Concensus Document, 1999). They may be similar in appearance to conventional food and consumed as part of a regular diet. Specific health claims need approval in Europe from EFSA. In Japan they are also subjected to a government approval process. (Foods for Specified Health Use, FOSHU). The food industry has seized upon this opportunity, and as one attempt to improve gut metabolism, pre and probiotics have entered daily use, not necessarily with a formal claim, but with advice that health benefits may be delivered. There is still a role for FS&T to create targeted delivery of components to regions of the alimentary tract thereby establishing real benefit. Otherwise, there is a danger that in the absence of comprehensive studies, inferences related to health benefits will be overemphasised.

"Superfoods" have no formal definition, and are not regulated. They are whole products (fruits, berries etc.) containing nutraceuticals such as antioxidants, coloured phytochemicals, fibre and fats which have been shown in separate independent trials to be of some health benefit. As yet, their impact on overall nutritional status has not been quantified, yet because they are promoted as healthy, there is a danger that consumers believe their intake need not be restricted. As a new market sector, their sales growth is dramatic. The whole food chain, including primary production, manufacture and retail, are called upon to produce, preserve and deliver these new foods to the marketplace, but must also question their net benefit.

Both the manufacturing and retail sectors can actively spread the uptake of Nutraceuticals Functional and Superfoods. The scientific challenge to FS&T is to collaborate in monitoring the health benefit of these ingredients and a variety of finished products containing them, over an extended period of *ad libitum* intake.

Mission 7 - To integrate Big Data, Information Technology and Artificial Intelligence throughout the Food Chain.

The ability to capture, store and interrogate digital data is already enormous, and its application will only grow. Its use has been mentioned in several of the Missions previously described above. The proper use of digitisation of food chain information is mandatory, making Information Technology a key element in the future of FS&T. The critical needs are

- ***To use multivariate data to construct self-consistent models for material/process interactions in food manufacture.***
- ***To collaborate with the biological sciences to identify statistical and causal relationships between Diet and Health.***
- ***To provide validated data, and develop secure methods to link information flows between Production, Distribution and Consumption, thereby enhancing traceability, standardising safety, and reducing costs and waste.***

Models for ingredient and product manufacture

We mentioned previously that food conversion from raw material to product needs to move from "copy and upscale" to "design and build". Systematic bench and pilot plant studies, where variables are restricted, will continue to be the major research methodology. However, every production run at large scale represents a multivariate experiment. If performance data can be captured, then an enormous data base for any production process can be created . Interrogation by statistical methods, including self learning artificial intelligence can produce multivariate correlations between raw materials, processability, product quality and cost. Furthermore, even though correlations are statistical rather than causal, these models will accelerate the generation of causal, mechanistic and predictive models by identifying key parameters to be investigated.

Where data is available, statistical models are already used for materials purchasing, process scheduling, advertising costs and sales value, but in future these will be more sophisticated and robust, since higher levels of multivariate parameter interactions can be identified.

If this data is fed into "learning algorithms" (Artificial Intelligence) the the models created are self regulating, since all new information validates or updates the model.

Diet and Health

The same massive multivariate approach can be applied to the development of models of dietary requirements of groups and individuals. Genomics, proteomics and metabolomics already requires modern molecular biology to handle Big Data. To this can be added the composition, processing, product architecture and breakdown of foods during the time course of digestion, to build models of not only nutrient requirements, but their bioavailability, and metabolic effect. Hence more accurate dietary information can be given.

In the limit , every individual can be monitored and advised in real time, but only if advanced personal sensors of intake, activity and metabolic status are available.

Again, the developed models are self regulating if coupled to AI, and provided they are placed into the public domain, they will continue to be subject to scientific peer review and regulatory endorsement.

Food Chain Management

The various operating businesses that make up any food chain, already collect and store copious data. Some of this is a legal requirement to establish safety, but most relates to purchasing materials, line performance, product quality and financial data on sales and profit. The sharing of information along the chain, by the application of Distributed Ledger Technology, (DLT e.g. "Blockchain) could be a disruptive innovation, and claims are made that it could reduce waste; enhance safety (and more importantly accelerate it with reduced costs); deliver traceability: increase raw material availability; etc. etc. Furthermore, this open access might facilitate the growth rate of market innovation, simply by publicising its availability to a wider audience. It is argued that the consumer will be the major beneficiary, since access to a Blockchain, coupled with the option to order on-line from suppliers, make all supply chains more transparent and shorter, by cutting out "the middle man".

The development of software to handle DLT is a growth industry in itself.

However there are inherent problems.

- Data sets from private sector businesses would need to be harmonised. This is far from the case at present.
- Some information is confidential since it relates to operations which give competitive edge. This will never be shared.
- Current chains are based on trusted transactions and the reputation of partners. Open access is totally reliant on the integrity of the data input. Systems for validation, auditing, and prevention of criminal intervention (hacking) will need to be comprehensive and constantly upgraded.
- Massive investment in smart sensors will be required if ingredient and product quality is to be included.

Nonetheless, whilst this technology is far from harmonised, its application within current chains is already beginning, since the potential benefits are obvious. Inclusion in a Blockchain gives benefit to the partners, and exclusion from it represents a threat to business operation.

Summary of Critical Needs of FS&T

Our analysis via a Mission based approach demonstrates that FS&T is a crucial knowledge base that will allow advances in Primary Production to be sustainably converted to better control of Health through Diet.

Through examination of each Mission, the details of new actions and new capabilities along the food chain have been identified which will be necessary to increase sustainability of production along with better health provision; and are necessary if the food chain is to play its part in meeting the Sustainable Development Goals

The first 4 of these Missions identify the needs for development of the traditional role of FS&T.(Farm to Fork). This includes integration of more sustainable crops into the complete food chain; improving the efficiency and flexibility of processing, reducing waste, whilst maintaining safety and consumer acceptability

Missions 5 and 6 identify the need for a new collaborative science base, led by the advances in human and microbial biology. This will need the integration of FS&T with Nutrition and the Medical Sciences to provide healthier food at lower cost, together with much better targeting of diets toward group and individual metabolic requirements

Mission 7 examines the overarching impact of computer based datahandling and Knowledge Management across the entire food chain ("Digitisation"). Its impact will be twofold .Firstly by allowing improved modelling of physical and biological processes of manufacturing, crop production and human metabolism, Secondly, its use in supply chains should improve traceability, safety and overall efficiency of material usage (reduced cost)

The use of this "Mission-based" analysis has allowed detailed recommendations for action.Two types of recommendation have been made, those involving new research studies and greater interdisciplinary collaboration, (Strategic); and those requiring development of new measurement science, (Technical).

The former will require significant R&D investment by governments and the private sector in interdisciplinary research Platforms – including Public /Private Partnerships. The latter represent innovative tools , best sponsored as individual projects possibly within a strategic Platform. All of these recommendations will be of global impact, and best achieved by international collaborations.

Part 3. The Critical Need for Skills -- (Training and Leadership)

All the IAP reports recommend that integration ALONG the Food Chain (horizontal integration) will produce optimal strategies, and that collaborations of all stakeholders, both private and public sector need to be maintained. Our analysis confirms this, and the success of the Missions requires technical education and training of research "Thought Leaders" and a continuous supply of broadly educated and skilled operators of manufacturing processes. Furthermore, food economists and governments engaged in national planning, must be aware of the benefits that advancing technology can bring.

The consumer is probably the most important member of the chain. It is no longer appropriate and they will not accept, change without their involvement and acceptance. This means that they must be provided with balanced arguments, in understandable language, for any innovation that influences their health and wellbeing.

Our analysis highlights that future sustainability of the food supply and improvements in health through diet are likely to succeed only if significant critical needs of the science and technology base are fulfilled. This will require maintenance of high standards of safety and quality, and financial investment in the research base of the supply chain, by both public and private sectors. None of this will yield results without a highly trained skill base, and communication with consumers of the benefits of technological advances.

Education and training for the future

Building the Profession of Food Science and Technology

For food professionals, a thorough knowledge of the core sciences of chemistry, physics and biology are necessary to understand all factors affecting the quality of foods. These subjects should have a prominent place in the curricula in all university studies on food science and technology, as well as in other courses related to the food economy.
This basic knowledge is also necessary for anyone interested in rational nutrition, and our analysis shows how modern molecular biology will revolutionise approaches to human nutrition. A minimal awareness of what such approaches will achieve must be taught at this basic level.

Food technology is based on food physics and food chemistry as well as engineering principles, including process operations and manufacturing systems. Education at the level of a Master's degree is often given by either an agricultural or technical university or faculty. The students from an agricultural background will have their base in food science and technology related to primary production, whereas students from technical background tend to be focused on engineering. We can foresee see that nutrition and engineering for health should be included in curricula for both types of study.

Food Science and Technology departments, are challenged by the need for Universities to prove their excellence in global ranking systems. Only when this is fulfilled, can they expect to use the mobility of skilled students and attract the most qualified. The global challenges to the food supply will need even greater and more sophisticated application of FS&T, since more efficient conversion of raw materials to finished foods will be necessary, probably using raw materials which are novel. Course curricula must be dynamic and robust to incorporate/capture new technologies/knowledge.
Also, areas such as molecular nutrition, human biochemistry and physiology can be connected to traditional FS&T in Ph.D. programs related to health. The advances in measurement techniques, structural and process modelling and process control developed outside the food area will need to be captured and used. Therefore, initiatives such as students taking courses and engaging with faculties outside food science should be encouraged.

The awareness and interest in food science should be introduced in schools and the challenges of food science and technology need to be articulated both from the science community and from the business in order to attract good students that can foresee a challenging career within FS&T

There is a great need for strengthening and improving the educational exposure to food science and technology throughout the food chain. In particular there needs to be an increased emphasis on attracting qualified students to into food science and related areas (undergraduate and graduate) in countries where there is a need by employers. There is a shortage of staff entering the private sector with appropriate qualifications to maintain even the existing requirements of business. The majority of food industries do not need staff with research experience, instead a broad base of sciences and business disciplines are required. Food production is in the hands of private enterprise whether in the home, or in global distribution chains. Industry is interested in innovation and has shown its willingness to collaborate, but it does not expect to be the trainer and provider of all its future staff. This is the same position taken by most public-sector industries. Education and training are the responsibility of the public-sector education system of all nations, from schools to post graduate studies. Industry in turn, must support the long and detailed education of its future stars, as well as the training of best practice to manage its existing and near horizon business.

Many Universities, colleges and institutes around the world provide courses already. With increasing global movement of individuals, some identifiable standards of competence need to be displayed. IUFoST and its adhering bodies recognise Continuing Professional Development (CPD), and are attempting to ratify the competences of their membership. For the sake of the reputation of the professional body, it is hoped that this will be continued, harmonized and strengthened.

Developing "Thought Leaders"

Both Global Visions and the IAP reports identify the need to produce the next "thought leaders" for the science and technological development required to face Challenges. This requires a high level of knowledge, experience and practice in Research and Innovation. We identified above that the new leaders will have to be experts educated in the core disciplines, and be aware of the enormous capabilities that biology and IT now offer, in raw material production and the impact of food on human health. Examination of current leaders indicates that they often come from the high flyers of the basic disciplines, who turn their attention to food after post graduate studies These individuals will necessarily form the elite of the profession and need to be recognised and encouraged from early in their careers. Some of the IAP reports recommend that they will best be fostered by the establishment of real or virtual institutes housing the "Best of the Best". Some countries like Sweden, Germany Holland, Norway, Finland and Denmark. have established Young Academies of Science with the most talented young scientists from a broad range of scientific areas. They are now establishing themselves with a strong voice in society. Since challenges on the global and local plane are strongly connected, mobility programs are a requisite to foster the new generation of thought leaders

External communication and outreach

The consumer needs continuous information and education about healthy and sustainable diets. Without their awareness it will be difficult to achieve health improvements. For the well-nourished population the effect of unhealthy diets needs to be evident to the extent that dietary advices will be followed. Here recent advancements in metabolomics can be of great help to give quantitative measures, but the results must be communicated in an actionable form. For the malnourished and low-income population, it is vital that information concerning the high risks of energy dense cheap food with low nutritional value is provided, together with alternative dietary options.

It is the responsibility of IUFoST and all professional bodies with interests in food to provide unbiased information on FS&T, for both current and possible future practices.

Public interest in the sustainability of food production and health benefits has never been higher. Traceability of material flows, "minimal processing and "clean label" products are in great demand, but judgements concerning overall sustainable benefits require a whole chain view. This is rarely offered or even available, so incorrect conclusions can be drawn. All media channels seize upon headlines but do not search or report quantitative data. This is equally true in reporting results from clinical studies of new foods or their components with apparent specific health benefits, or deleterious effects. Confusion arises since scientific studies focus on a particular benefit or risk to health and can appear contradictory. Furthermore, they are rarely based on population studies in whole diets over long periods. As a result, consumers can engage in novel diets or "food fads" which have no long-term benefit. It is vital that up-to-date reviews are made available and publicized in the popular media channels since consumers cannot be expected to conduct meta analyses of scientific publications.

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APPENDIX 1 Sustainability Goals (https://sustainabledevelopment.un.org)

Sustainable development Goals

Goal 1. End poverty in all its forms everywhere

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal3. Ensure healthy lives and promote well-being for all ages

Goal 4. Ensure inclusive and equitable quality education and promote life long learning opportunities for all

Goal 5. Achieve gender equality and empower all women and girls

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 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 10. Reduce inequalities both within and between countries

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

Goal 12. Ensure sustainable consumption and production patterns

Goal 13. Take urgent action to combat climate change and its impacts

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Goal 15. Protect restore and promote sustainable use of terrestrial ecosystems

Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective accountable and inclusive institutions at all levels

Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for sustainable development

APPENDIX 2 IAP Agriculture and Food Security Reports **(www.interacademies.org)**

The IAP reports are the most extensive surveys on Food and Nutrition security taking an integrative food system approach to strengthen the science agenda. The links between Food and Nutrition security and sustainable development are embedded in the SDGs. The reports are updated and have extensive references latest reports

The **Global report** summarizes the similarities and dissimilarities between the regional reports and takes an global approach to recommendations on an international level. The report demonstrates strong consensus around controversial issues, while acknowledging diversities in agriculture, foods, nutrition systems and in political organization. The broad recommendations call for more coordinated action on priority themes of international relevance among different research funders. It points out that translation of research to innovation requires stronger connections across disciplines and with cutting-edge technologies, linkage to science education, training and outreach.

The report makes recommendations for international scientific priorities under the following headings:

- Developing sustainable food and nutrition systems, taking a systems perspective to deliver health and well-being, linked to transformation in the circular economy and bioeconomy
- Emphasising transformation to a healthy diet. How is it constituted? How is it measured? How is it delivered
- Understanding food production and utilization issues, covering considerations of efficacy, sustainability, climate risk and diversity of resources.

- Capitalising on opportunities in the biosciences and other advancing sciences: choices should be made at the national and regional levels but on the basis of global sharing of evidence.
- Addressing the food–energy–water–health nexus, recognising that boundaries are blurred
- Promoting activity at the science–policy interfaces.
  New international science advisory mechanisms

The report on the **Americas** focussed on the sustainability of primary production and noted *inter alia* that:

- Owing to an exceptional abundance of natural resources, the Americas are a privileged region. The region's wealth in agrobiodiversity, arable land and availability of water, all constitute major advantages for the future.
- There is substantial diversity among national agricultural research systems, infrastructure, investments in human capital, in financing capabilities and in the roles of public and private sectors in the provision of Science Technology and Innovation (STI).
- Malnutrition, food insecurity and obesity coexist to a greater or lesser degree, as well as chronic diseases related to obesity.
- *Progress in the Americas over the last quarter century has been impressive and STI have played a major role in improvements. STI will continue to play a key role in achieving the Sustainable Development Goals (SDGs) by 2030, but progress will depend, in part on greater regional and global cooperation in STI, and partly on the development of more uniform policy frameworks.*

The report from **Asia and Oceania** recommended**:**

- ---- emphasis not be placed on calorie provision alone; rather, the focus should be on diverse diets supplying a balance of food types and dietary nutrients and non-nutrients that are known to influence health, ----
- it is imperative that governments in the region not only maintain support for basic R&D and education related to Food and Nutrition Security (FNS) but also greatly increase, as a matter of urgency, the overall level of funding. There needs to be a considerable resurgence in agri-food R&D, extension and education, and such an emphasis needs to be more cross-disciplinary and systems oriented than in the past.
- ---- to form well-resourced regional centres of research excellence that focus on key opportunity areas. Such virtual centres would be populated by the 'best-of-the-best' relevant scientists from throughout Asia and the Pacific and would pursue clearly conceived research plans with specific objectives.
- Cross-disciplinary cooperative research programmes, mustering the best resource from across the regions, need to be formed and funded to develop knowledge. That knowledge needs to be communicated clearly and to be shared freely and extensively.

- Key S&T areas, seen to have universal and prioritised application across the region, include (1) genomic-based approaches to plant and animal breeding; (2) 'big-data' capture and analysis, precision agriculture and robotics; (3) food technology innovations in harvest, processing and storage to reduce food wastage; (4) sustainable farming practices for land and water use that address wider issues such as biodiversity and climate; (5) aquaculture production and integrated farm production systems.

The report for **Europe** took a whole chain approach. The recommendations specifically relevant to FS&T are: -

<u>Plants and animals in agriculture</u>

• For livestock, determining how to capitalise on genomics research for food production and for animal health.

• Evaluating climate resilience throughout food systems and transforming food systems to mitigate their global warming impact.

<u>Waste</u>

• Committing to the collection of more robust data on the extent of waste in food systems and the effectiveness of interventions to reduce waste at local and regional levels.

• Ensuring the application of food science and technology in novel approaches to processing food and reducing waste, and in informing the intersection between circular economy and bioeconomy policy objectives.

<u>Nutrition, food choices and food safety</u>

• Understanding the drivers of dietary choices, consumer demand and how to inform and change behaviour, including acceptance of innovative foods and innovative diets.

• Tackling the perverse cost incentives to consume high-calorie diets and introducing new incentives for healthy nutrition.

• Clarifying what is a sustainable, healthy diet and how to measure sustainability related to consumption. Efficiency in delivery of a healthy diet should be measured in terms of nutritional outcomes.

• Exploring individual responsiveness to nutrition and the links to health.

• Promoting research interfaces between nutrition, food science and technology, the public sector and industry.

• Evaluating how to make food systems more nutrition-sensitive.

• Characterising sources of food contamination and the opportunities for reducing food safety concerns that may arise from other policy objectives.

• Compiling analytical tests to authenticate food origin and quality.

All of these are multidisciplinary challenges with critical needs for future FS&T. directly or indirectly. In some cases, existing knowledge can be deployed, but in many cases new scientific advances and strategies for multidisciplinary approaches are needed.

The report for **Africa** focusses on the urgent need to implement policies already declared.

In relation to FS&T the following recommendations are very relevant and common with other regional reports.

Food system efficiency, human health and well-being

• Research can find ways to promote product diversification with nutritious foods; processing to extend shelf life and make healthy foods easier to prepare, and improved storage and preservation to retain nutritional value; ensure food safety; extend seasonal availability and reduce post-harvest losses (including aflatoxin) and food waste. These solutions should consider current changes in demand, predict future demand changes and shape the future of the African food system in ways that will provide nutritious food for all.

• Develop processing and packaging technologies to respond to consumer demands for safe and healthy alternative foods and extend the shelf life of foods.The limitations of water and power supplies need to be considered in developing these technologies.

• Increasing funding for more research into the fortification, biofortification and enrichment of foods can increase the nutritional value of commonly consumed foods, improve the bioavailability of nutrients for absorption and metabolism, or decrease the concentration of antinutrient compounds that inhibit the absorption of nutrients (for example phytates and oxalates). A focus on harnessing the inherent properties of indigenous knowledge and foods is needed.

Food safety and waste reduction

• Developing technologies to overcome the shortage of cold storage and refrigeration in Africa is necessary, including innovation in processing and packaging to ensure stable, safe foods, particularly in areas where electrification levels are low. The use of solar energy is one possible area to explore.

Human capacity

• Strengthening the human and infrastructural capacity for agricultural research, innovation and technology will support transformation. African academic institutions must work to develop food security and nutrition capacity at all levels of society and across traditional disciplines. Increased effort is required to ensure a well-trained extension service that is constantly updated.

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