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Technology options for feeding 10 billion people

Options for sustainable food processing

State of the art report

Science and Technology Options Assessment

STOA

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State of the art report

IC STOA 2013/122

November 2013

PE 513.533

The STOA state of the art report 'Options for sustainable food processing' as part of the project 'Technology options for feeding 10 billion people' was carried out by the Wageningen UR Food & Biobased Research and the Wageningen University Food Process Engineering.

AUTHORS

H.C. Langelaan, F. Pereira da Silva, U. Thoden van Velzen, J. Broeze, A.M. Matser, M. Vollebregt
Wageningen UR Food & Biobased Research

K. Schroën,
Wageningen University Food Process Engineering

Bornse Weilanden 9
6708 WG Wageningen
The Netherlands

STOA RESEARCH ADMINISTRATOR

Lieve Van Woensel
Science and Technology Options Assessment (STOA)
Directorate for Impact Assessment and European Added Value
Directorate General for Parliamentary Research Services, European Parliament
Rue Wiertz 60 - RMD 00J012
B-1047 Brussels
E-mail: lieve.vanwoensel@ep.europa.eu

LINGUISTIC VERSION

Original: EN

ABOUT THE PUBLISHER

To contact STOA please write to STOA@ep.europa.eu
This document is available on the Internet at: http://www.europarl.europa.eu/stoa/

Manuscript completed in October 2013

DISCLAIMER

CAT BA-04-13-048-EN-C
DOI 10.2861/4330
ISBN 978-92-823-5122-2

Abstract

Innovations in food processing techniques can significantly contribute to meeting the needs of the future 10 billion world inhabitants with respect to quality, quantity and sustainability of their food intake. The present study provides an expert judgment for the potential of new and emerging technologies to enhance sustainability in the food processing sector. It includes the following technologies: sensor technology, sustainable packaging and refrigeration climate control, non-thermal pasteurisation and sterilisation, nano- and micro technology, innovative processes for utilisation of by-products, alternative processes requiring less energy or water, plant-based meat alternatives and information and knowledge transfer.

For each technology the direct impact (reduced losses, energy and water use) as well as the indirect impact (food losses, suboptimal utilisation and unnecessary quality decay within the supply chain) are described, as well as their contribution to the areas of improvement of the European food processing industry (new and better food products, resource efficient manufacturing processes, integrated and transparent supply chains and enhanced innovation capacity).

CONTENTS

1 MANAGEMENT SUMMARY

Science and Technology Options Assessment (STOA) initiated a project that investigates and assesses the technology options for providing food of sufficient quality and quantity to meet the needs of the future 10 billion world inhabitants. In general, these needs can be summarized as: "the availability of sufficient food that is safe, tasty, nutritious, varied, convenient (i.e., easy accessible, easy to prepare) and affordable". This report focuses on '*Technology options for optimizing processes in the food industry*', and gives an overview of the current status and trends in the technologies for sustainable food processing.

Food processing can be defined as the transformation of raw ingredients and intermediates into products intended for human consumption, with the purpose to improve the digestibility, bio-availability of nutrients and energy, taste, appearance, safety, storability and distribution. In essence, the modern food processing techniques have the following three major aims:

1. To make a sufficiently stable food product, that is safe (microbiologically and chemically) for human consumption.
2. To give the product the required intrinsic quality aspects, e.g. digestibility, nutrient content, flavour, colour and texture.
3. To add value to the product on other aspects, e.g. convenience, lifestyle and marketing.

Food processing in its earliest form may have already started about 1.9 million years ago when our ancestors got control of the use of fire in the preparation of their food. Science-based food production only started in the 18th and 19th century, when the scientific progress in the fields of chemistry and physics found their application in the different stages of food production, storage and distribution. Traditional and artisanal production methods were slowly substituted by more modern and reproducible techniques that helped to increase the availability and safety of food. The growth of the world population, the abundant availability of agro raw materials and energy and the integration of knowledge from other scientific disciplines (e.g., engineering, physics, nutrition, toxicology and biotechnology) further boosted the growth of the food and drink industry to a robust industrial sector that:

- Produces food that is generally meeting the safety and quality requirements, and is responsive towards adapting quality parameters to meet changing consumer expectations which respect to, e.g., nutritional value, health aspects and taste.
- Guarantees the year-round availability of food and continuously improves its distribution with the use of modern logistical concepts.
- Produces affordable food products: until 1800 European people spent 70-80% of their income on food. This percentage decreased to 25% around 1860, while the current figure is about 14.5%.

Within the European context, the food and drink industry is a leading manufacturing sector. It is EU's largest manufacturing sector in terms of turnover (2011: €1.017 billion) and employment (2011: 4.25 million people). Even in the current period of economic downturn the food and drink industry remains to be a stable, non-cyclical and robust sector with a steady growth in turnover and profitability. The popularity and sales of processed foods are still increasing, not only in the high-income countries but even more in developing countries.

The main challenge for the Agro-Food industry in the coming decades is to guarantee the availability of safe and healthy food for a growing global population, against the background of increasing consumer demands, sustainability concerns as well as resource demands for biobased (non-food) applications. Climate change, the intensified competition for energy, fresh water raw materials and land, as well as the shift in dietary patterns (increasing consumption per capita, growing meat consumption) across the world are expected to have a major impact on the food supply chains of current times. Next to this future challenge, the European food and drink industry should act against a number of more short-term, interdependent, challenges:

- Price competition and rising/more volatile raw material prices put pressure on small businesses
- The growing distance between production and consumer, food contamination scandals and outbreaks of food borne illnesses undermine the trust of consumers in the current system of food supply
- The European industry is losing ground in the global export market, while the low population growth in the internal market requires action towards other ways to increase industry's profitability
- The food industry is being asked to play a more prominent role in the prevention of food/lifestyle related diseases as well the more efficient use of water, energy and raw materials (i.e., reduction of food waste)

In the short-term, increased resource efficiency can bring both cost reductions and sustainability gains. However, to remain competitive on the longer term the European food and drink industry must focus on technological innovations in food processing that support the development of:

1. ***New and better food products*** to:
   a. Meet the growing food demand (growing world population, increased standard of living)
   b. Alleviate the food security gap (starvation, nutritional deficiencies)
   c. Account for demographic changes (urbanization, ageing population)
   d. Prevent lifestyle-related diseases
   e. Meet consumer demand for personalization with respect to pleasure, health, convenience and ethics

2. ***Resource efficient manufacturing processes*** that:
   a. Minimize the dependency on valuable crops
   b. Consume less water and energy and preserve local balances
   c. Prevent the generation of waste (*zero waste concept*) and allow for high-value (food) application of by-products
   d. Produce high quality and high functionality products with an extended and predictable shelf life
   e. Allow for diversification with respect to specific consumer demands

3. ***Integrated and transparent supply chains*** that:
   a. Provide food security in developed and developing countries
   b. Connect local food production and demand with the globalization of the food industry and retail (e.g., regional production, 3d printing at home)
   c. Generate less losses and waste and operate in a synergistic way with other sectors of the upcoming bioeconomy
   d. Increase the consumer trust in food production on aspects like food safety, sustainability and ethics through certification and chain agreement
   e. Provide objective information, e.g., with respect to food-health relationships, ingredients, claims and technologies
   f. Allow for transparency and traceability of raw materials and intermediates in all parts of the supply chain (sourcing, food manufacturing, retail)

Sufficient competitiveness can only be realized if the EU food and drink industry speeds up the pace of innovation. Given the highly fragmented character of this sector (287.000 companies, of which 285.000 are SME's) special attention should be paid to increase the capacity of SME's to realize a faster translation of scientific results into industrial implementations as well to utilize scientific advances from other disciplines.

This report discusses a number of technology options that can contribute to more sustainability in the food processing sector. Given the fact that sustainability as such is not within the day-to-day focus of many food processing companies, the technology options will be linked to the 4 areas of improvement (better products, efficient manufacturing processes, integrated and transparent supply chains, increased innovation power), thereby identifying the opportunities for innovation.

Food processing industries contribute to eco-sustainable development of the food system through direct savings (reduction of energy and water use) and indirect savings (contribution to reduction of losses and improved valorisation of the biomass resources).

The following technological developments help to reduce the *direct* impact of food processing:

- more sustainable refrigeration technologies combined with more effective climate control strategies, insight into steering options for product quality and innovative packaging will reduce the energy use of refrigeration/cooling;
- dry processing as alternative to wet processing routes will reduce the energy costs of drying processes;
- innovative food microsystems will reduce the required energy in fractionation processes and in the production of advanced food structures like emulsions;
- Advanced process control to manage variation in the process.

An even larger impact on sustainability can be expected from improvements in resource valorisation (*indirect effects*).The main inefficiencies within the food processing sector are food losses (food manufacturing accounts for ~5% of the total food waste), suboptimal utilisation of by-products/processing residues and unnecessary quality decay within the supply chain. Food processing technologies can contribute to reducing such inefficiencies on the following aspects:

- Cooling, stabilisation / preservation processes and packaging technologies contribute to increasing the shelf life of products, thereby reducing losses in the chain. Technological advances with respect to innovative sensor technologies and packaging solutions support these developments.
- Creation of more added value through higher value applications of by-products. This report presents a number of practical examples where industries are generating new food ingredients from former waste streams or low-value by-products.
- The application of smart sensors and RFID tags allow for quality control over the entire supply chain. Application of such sensors enables the use of guaranteed quality statements, the supply of consumption-ready products to the supermarket as well as logistical concepts such as FEFO (first expired first out).
- The implementation of novel technologies for mild preservation, e.g. non-thermal pasteurization or sterilization techniques. Application of such technologies could help to reduce food losses over the supply chain by prolonging the shelf life of the (semi-) fresh products.
- Mild separation technologies for the creation of functional fractions (instead of pure ingredients): next to maintaining the nutritional value of the original plant material, the application of functional fractions could lead to significant savings in water and energy consumption, especially when drying and subsequent rehydration steps in the manufacturing process could be omitted.
- The development of plant-based meat alternatives: Technological developments initiated by the food processing industry can help to increase the consumer acceptance of such products.

Policy recommendations to support the implementation of sustainable process technologies are:

- Stimulate the implementation of novel preservation technologies that are ready for use (e.g. high pressure pasteurization, advanced heating) via knowledge transfer and feasibility studies, specifically aimed at SME's.
- Stimulate the knowledge basis for technologies that are currently not ready for application, like cold plasma processing.
- Stimulate the development of industrial equipment for technologies that are proven to be interesting but for which industrial equipment is not yet available, like high pressure sterilization and pulsed electric field processing (as equipment manufacturers are hesitating to invest in the development of novel equipment).
- An active role of regulatory bodies in promoting novel technologies for food manufacturing. Similar to the pharmaceutical industry, a one-sided focus on excluding food safety risks will lead to a standstill in innovation. A promising route may be to allow industry more regulatory freedom in, e.g., the implementation of new technologies or the use of side streams in food applications, provided thorough understanding of the manufacturing processes and the associated risks is demonstrated.
- Publish eco-efficiency manuals or stimulate sharing of best-practices to help companies to identify areas of improvement.
- The active promotion of operational excellence programmes like Lean Manufacturing or Six Sigma as modern methods for Quality Risk Management, similar to what has been done in the pharmaceutical industry. These programmes have already proven their success in other sectors of the industry and could potentially lead to reductions of 80% in the costs of poor quality.
- The further deployment of Industrial Symbiosis programmes to stimulate new partnerships between suppliers and potential users of side- and waste-streams.

2 INTRODUCTION AND SCOPE LIMITATION

2.1 Introduction

The main challenge for the Agro-Food industry in the coming decades is to guarantee the availability of safe and healthy food for a growing global population with increasing welfare standards, against the background of increasing consumer demands, sustainability concerns as well as resource demands for bio-based applications. Climate change, the intensified competition for fresh water and land, as well as the shift in dietary patterns (increasing consumption per capita, growing meat consumption) across the world are expected to have a major impact on the food supply chains of current times.

The UN Food and Agriculture Organisation (FAO) defines food security as follows: "Food security exists when all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". Currently, over one billion people in low-income countries are malnourished (FAO/OECD, 2011) with 60% of deaths in the under-five-year-olds resulting from a lack of protein, vitamins and minerals. It is predicted that the situation of food insecurity will further deteriorate due to the global population growth[1], climate change combined with a decreasing availability of necessary resources like water, energy and minerals (Rockström et al., 2009) and an increasing demand for food. For the latter, it is predicted this increase may be up to 60-70% in 2050 (Topsector Agro & Food, 2011; FAO 2011, 2012), not only because of the population growth, but also because of the increasing wealth (in 2030 the global economy will have 3 billion more middle-class consumers (McKinsey, 2011). When taking into account that each kilo Joule (kJ) caloric content of a food product is estimated to require 20 to 25 kJ of energy earlier in the food chain (originating from both biomass and fossil resources (Bos-Brouwers et al., 2012)), it becomes clear that the current agro-production will not be sufficient to meet this demand, let alone provide sufficient biomass to sustain or develop other applications in the emerging biobased economy (e.g., biobased materials, chemicals and bio-energy). This makes an inquiry into the options to make food production more sustainable more urgent than ever.

2.2 Scope limitation of this study

Science and Technology Options Assessment (STOA) initiated a project that investigates and assesses the technology options for feeding 10 billion people. The project has been divided into the following 5 areas:

1. The interactions between climate change & agriculture and between biodiversity & agriculture
2. Technology options for plant breeding and for innovative agriculture
3. Technology options for optimizing processes in the food industry
4. Options for cutting food waste
5. Technology options for recycling crop and food residues for sustainable bio-energy and biomaterials

This report is linked to the area 3 and gives an overview of the current status and trends in the technologies for sustainable food processing, with the aim to provide food of sufficient quality and quantity to meet the needs of the future 10 billion world inhabitants. In general, these needs can be summarized as: "the availability of sufficient food that is safe, tasty, nutritious, varied, convenient (i.e., easy accessible, easy to prepare) and affordable".

[1] Estimated to rise from 7 billion in 2011, to 9.3 billion in 2050, and 10 billion at the end of this century (UNDESA, 2011)

The set-up of this report was meant to serve as a state-of-the-art report providing an overview of the main drivers and issues related to sustainable food processing as well as an expert judgement for the potential of new and emerging technologies for optimizing the food production and (partially) the retail chain. For this purpose, experts from Wageningen UR have provided input to review the current status and trends in the technologies for sustainable food processing.

The scope of this study is limited in two ways:

- *Scope limitation in time*: This study will primarily focus on the technological status and developments which are expected to have an impact on food processing **within the next 5 years**.
- *Scope limitation within the food system*: Within the food production-to-consumption chain, the following steps can be discerned:
  - Primary production:
    - Purpose: the stable supply of (plant or animal derived) raw materials
    - Activities: agricultural crop production and harvesting, cattle-breeding, fisheries and aquaculture, pre-processing, storage of raw materials and intermediates
  - Food processing:
    - Purpose: the transformation of raw materials into stable, edible food products
    - Activities: ingredient production (separation), formulation, conversion, structure formation, stabilization and packaging
  - Distribution and consumption of the food products:
    - Purpose: to supply the consumer with the desired food products (according to the Preference/Acceptance/Needs criteria)
    - Activities: supply chain management, transport and quality monitoring of food products to the different outlets (e.g., retail, supermarkets, out-of-home services), preparation and consumption.

This report will focus on the second step: food processing, i.e., the conversion of agro-raw materials into (packed) food products with the desired quality and functional properties.

Following this introduction, Chapter 3 will give an overview of the historical context of food processing and the technologies that are currently applied in the subsequent steps of food manufacturing processes (*unit operations*). Chapter 4 describes into more detail the different issues which are relevant for the food production system in general and the European food and drink industry in particular. These issues will be summarized into a number of challenges that the European food manufacturing sector needs to overcome to maintain its competitiveness. In the last section of Chapter 4 these challenges will be translated into opportunities for innovation that promote more sustainable food processing. Chapter 5 then provides a description of the different technology options that could be introduced in the food manufacturing industry. Per technology option the current state of the art is explained, examples of successful applications (*success stories*) are given, as well as an outlook for the expected developments in the near future. The description of the technology options also includes the possibilities to improve the knowledge transfer in the food manufacturing industry as well as the role of the regulatory bodies. Through combining the industry drivers with the technology options the potential topics for improvement and innovation projects in the food processing industry are identified.

Chapter 6 assesses the expected impact of the different technology options, both for their *direct* effect (reduced water, energy use) as well as their *indirect* effect (more efficient use of resources over the entire chain). This chapters ends with a number of policy recommendations that could help to stimulate the innovation power of the food processing industry.

Wageningen, 22 October 2013
Ben Langelaan, Jan Broeze
Wageningen UR Food & Biobased Research

3 FOOD PROCESSING: HISTORY AND TECHNOLOGIES

3.1 Food processing in an historical context

Food processing can be defined as the transformation of raw ingredients and intermediates into products intended for human consumption, with the purpose to improve the digestibility, bio-availability of nutrients and energy, taste, appearance, safety, storability and distribution. As hypothesized by Wrangham (Wrangham, 2009), food processing in its earliest form may have already started about 1.9 million years ago when our ancestors got control of the use of fire in the preparation of their food. The impact of this invention on our physiological as well as social development was enormous. First, the evolutionary benefits associated with adapting to cooked food may have induced the transition from habilines ("*the missing link*") to *Homo Erectus*. These benefits mainly concern the energy efficiency of digestion, and are associated with an increase in the brain volume as well as a decrease in the size of the jaws and intestinal tract. As a consequence, human beings have now become dependent on food processing to ensure the uptake of sufficient nutrients after chewing and digestion. Second, the time that was saved by eating cooked meals instead of chewing and digesting raw foods (on a daily basis: 2 hours for humans versus 17 hours for primates) allowed mankind to specialize, e.g. in hunting, and to build the social structures which are still dominant worldwide.

Following the invention of cooking, other primitive forms of food processing techniques were developed, e.g., to convert raw materials into a more acceptable form (through fermenting) and to preserve and store food products (through drying and salting). These developments increased the food security for our ancestors. A major step in securing the supply of food year-round, however, was made when people gave up their nomadic lifestyle and started to live in larger communities (about 10,000 years ago). In these communities the first agricultural activities were deployed, e.g. through the cultivation of grains and the domestication of animals. By trial and error new types of food and new processing techniques were developed, all somehow linked to increasing the digestibility of food and ensuring its availability, quality and safety.

Science-based food production only started in the 18th and 19th century, when the scientific progress in the fields of chemistry and physics found their application in the different aspects of food production, storage and distribution. Traditional and artisanal food production methods were slowly substituted by more modern and reproducible techniques to increase the availability and safety of food. The growth of the world population that started around 1750 as well as the military activities at that time were the main drivers for the increased need for safe, stable and nutritious food. With respect to the latter: after the French army realised that they were losing more men to malnutrition and food poisoning than to war activities at the end of the 18th century, a contest was organised for the development of a method to safely preserve food (Featherstone, 2012). This price was finally awarded to Nicolas Appert for his hermetic glass bottling and heat sterilization technique, which later was further developed into the canning process by Peter Durand in 1810. It was, however, not until the year 1862 that Louis Pasteur provided the scientific substantiation for this process by demonstrating that micro-organisms are responsible for spoiling food products, and that they can be inactivated by heating.

The industrialization of agro production and food manufacturing was further boosted by the replacement of manual production methods by machines during the Industrial Revolution period. The impact of the use of steam power was enormous, as exemplified by the sugar refinery plants in Amsterdam. In 1830 the total annual sugar production of the 65 hand-labor based refineries in Amsterdam was 13 million kilogram. When one of these refineries changed over in 1843 to the use of steam power, the sugar production of this single refinery increased up to 20 million kg/year (Bakas, 2012). In the years following, the advantages of "economy of scale" and relatively low transportation costs were the main drivers for further productivity increase as well as concentration of activities: at this moment The Netherlands only has 2 sugar refinery plants which produce about 6 times more sugar than the 35 factories did in 1900 (Bruins, 2013).

Just like in other manufacturing industries, the abundant availability of cheap fossil energy supported the implementation of many technological innovations in the food industry. Together with the increased field productivity through the use of fertilizers, these technological innovations are the main reason why food production could keep pace with the growing world population in the developed countries in the 20th century, even though the number of people involved in the agricultural production decreased (Floros, 2010). Advances in refinery technologies, drying, (chemical) preservation, canning, packaging, refrigeration and transport led to an increase of the food production volume and the reliability of the food distribution system. Further developments in food processing were stimulated by integrating knowledge from disciplines like engineering, chemistry, physics, nutrition, toxicology and, more recently, biotechnology, genomics, ICT and nanotechnology. The impact of this successful integration is visible in today's food supply, where:

- The year-round availability of food is guaranteed and its distribution is continuously further improved with the use of modern logistical concepts.
- Food is generally meeting the safety requirements, and further improvements are realized without affecting the nutritional and sensorial quality.
- Food is affordable: until 1800 European people spent 70-80% of their income on food. This percentage decreased to 25% around 1860, while the current figure is about 14.5% (Bakas, 2012; FoodDrinkEurope, 2012).
- Food is of sufficient quality, and the food system is responsive in adapting quality parameters to meet changing consumer expectations which respect to, e.g., nutritional value, health aspects and taste.
- Popularity/sales of processed foods are still increasing, not only in the high-income countries but even more in developing countries (Kearney, 2010).

Despite these positive features, a number of recent social, economic and sustainability issues have clearly revealed the limitations of the current system for food supply. These will be further elaborated in Chapter 4, which discusses the issues and challenges for the European food and drink industry.

3.2 Food processing technologies

Raw food constituents undergo many changes in size, chemical composition, structure and colour before they are consumed as a final food product (**Figure 1**). This is the essence of food processing.

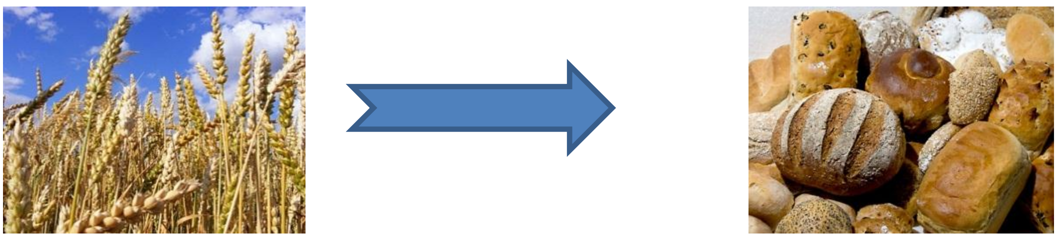

Figure 1: *Raw food materials undergo many changes before they are consumed as a final food product.*

This report uses the following definition for food processing: "the transformation of raw ingredients and intermediates into products intended for human consumption, with the purpose to improve the digestibility, bio-availability of nutrients and energy, taste, appearance, safety, storability and distribution". In essence, the modern food processing techniques have the following three major aims:

1. To make a sufficiently stable food product, that is safe (microbiologically and chemically) for human consumption.
2. To give the product the required intrinsic quality aspects, e.g. digestibility, nutrient content, flavour, colour and texture.
3. To add value to the product on other aspects, e.g. convenience, lifestyle and marketing.

Food production processes usually consist of the execution of a number of basic steps, the so-called *unit operations*. In this report the classification as derived from the EU-project HighTech Europe[2] is used to describe and classify these different unit operations[3]:

1. Pretreatment and Separation

a. The purpose of this step is to obtain the raw materials in the desired purity, as well as chemical and physical state to allow for proper handling in the next steps of the food manufacturing process. Separation processes make use of differences in chemical or physical properties (e.g., size, mass density, dielectric properties, chemical affinity) between the constituents of a mixture to obtain two or more distinct fractions, at least one of which is enriched in one or more of the constituents.

b. Examples of pre-treatments are: washing, milling, cutting, melting and dissolving.

c. Examples of separation technologies are: air classification to separate husks from beans, membrane filtration for sediment removal from beer, extraction of flavor components from hops.

2. Conversion

a. The purpose of this step is to process one or more components of a mixture into a desired intermediate or final product that contains one or more chemically different components. Conversion processes can, e.g., result in the desired color or flavor of a food product (after baking), but are also used to tenderize meat or to modify fats. The class of conversion processes also includes the formation of undesired components (e.g., acryl-amide formation during frying).

b. Examples of conversion processes are: alcohol production through fermentation, flavor development during ripening of cheese or meat, enzymatic treatment and chemical reactions.

3. Structure formation

a. The purpose of this step is to change the physical properties of a food product, including its appearance. Ideally, structure formation processes do not affect the chemical composition of the intermediate or final products. In practice, however, in most structure formation processes also conversion processes are involved.

b. Examples of structure formation processes are: cooking (e.g., to soften plant tissues in vegetables, or to solidify egg white and yolk) and baking (e.g., to reorganise gluten and starch to give a solid bread product).

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[2] www.hightecheurope.eu

[3] In literature other classifications for food processing unit operations can be found, e.g., based on whether or not heat is applied (Fellows, 2009)), the driving force for the operation (e.g., mechanical, electrical, heat) or the underlying principle (physical, chemical, biological).

4. Stabilizing

a. The purpose of this step is to increase the shelf life of the processed product by fixing its biological, physical or chemical state. Stabilizing processes can, e.g., focus on the prevention of oxidation (by removing oxygen or deactivating specific enzymes) or the reduction of enzymatic or microbiological activity (either through reducing the microbiological count or by slowing down the growth rate).

b. Examples of stabilizing processes are: drying, freezing, heat pasteurization and sterilization, high pressure pasteurization, pulsed electric fields.

5. Packaging processes

a. The purpose of this step is to protect the final product against harmful influences from the outside world (e.g., oxygen or other chemical substances, moisture, micro-organisms), to maintain its physical integrity and/or to bring about gas conditions that reduce microbial growth but increase the products' shelf life. In packaging processes usually a material which is commonly not part of the food product, is brought around the product. Packaging also plays an essential role in the marketing of products and can be used as a means for informing consumers.

b. Examples of packaging processes are: bottling, foil wrapping, blistering, canning and modified atmosphere gas packaging.

Annex 1 gives an overview of the different techniques which are part of the 5 above-mentioned classes.

In many common food manufacturing processes the order of the unit operations is similar to the order of the classification described above (**Figure 2**). As an example, the process of bread baking contains the following steps:

1. Pretreatment and separation: milling of the grains to obtain bran on the one hand and flour with the desired specifications on the other hand.
2. Conversion: during the proofing step, yeast converts part of the starch into CO_2 to allow the dough to rise.
3. Structure forming: during kneading, proofing and baking, respectively, the gluten and starch structures are formed that determine the physical structure of bread.
4. Stabilizing: during baking water is removed by evaporation which has a stabilizing effect on the final product.
5. Packaging: the baked bread is packed into a paper sack or plastic bag.

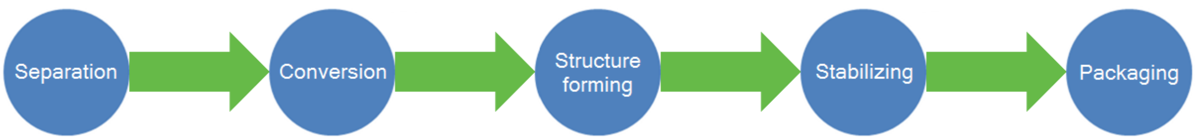

***Figure 2**: Order of unit operations as applied in many common food manufacturing processes*

A considerable part of the food manufacturing processes, however, relies on a different order of the unit operations or omitting one or more steps. For example, processing of canned foods or the application of the more innovative process of high pressure pasteurization, requires a packaging unit operation before the stabilizing process (**Figure 3**). The structure formation step (e.g., softening of the plant tissue through heating) then also takes place after the product has been packed. For semi-processed products (e.g., sausages, cut vegetables) usually only a few of the 5 processing types are applied at the industrial level; structure formation processes (such as cooking) are performed at household level by the consumer.

Figure 3: *Order of unit operations in food manufacturing processes which require a packaging step before stabilizing (e.g., canned food and high pressure processing).*

Next to the 5 classes of technologies that can be applied during food processing, technologies for process/quality monitoring and control should be included into this study too, given their importance for assessing the quality evolution and traceability of raw materials, intermediates and final products throughout the entire food production-to-consumption chain. These technologies have not been included in HighTech Europe's classification, but nevertheless are an essential part of process development as well as quality control during routine manufacturing. Better control results in more effective (meeting requirements, both in terms of quality as well as quantity) and efficient (less waste, better use of resources) processes and supply chains.

The current status of quality monitoring and control in the food processing industry has recently been reviewed (Van den Berg et al., 2013). **Figure 4** is derived from this publication and gives a schematic overview of process control strategies in (food) manufacturing.

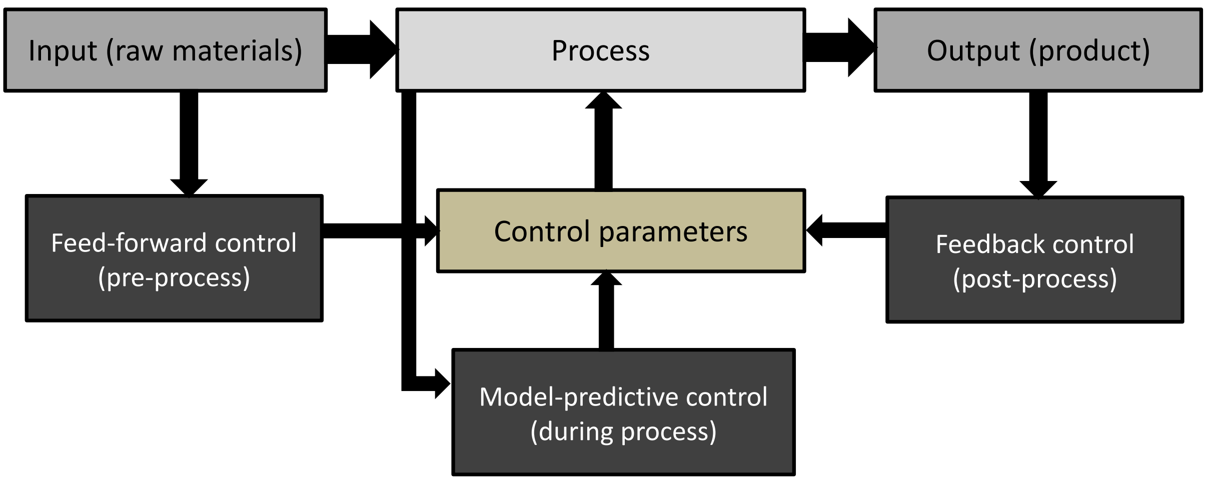

Figure 4: *Schematic representation of process control strategies in manufacturing processes (derived from Van den Berg et al., 2013).*

In the early days of quality control, most emphasis was put on testing of the output, i.e. sorting out final products into good and bad samples. This control strategy, however, has long feed-back loops and does not allow for adjusting the manufacturing process to avoid products failing to meet the specifications. This leads to the generation of a lot of waste as well as an inefficient use of personnel resources.

In modern control strategies the settings of the manufacturing process are derived from the specifications of the desired final product. Usually this is done by first defining the *critical product attributes* (CPA's), which are the most essential features of the product. During process development *critical process parameters* (CPP's) are identified which have a direct effect on the CPA's. When a process is implemented for routine manufacturing, sufficient knowledge should be generated on the process settings and the allowable variation (*the process window*). During processing, active control of the CPP's through feed-forward and feedback control loops, results in a consistent output of products with the desired specifications.

Current developments in process control are focused on:

- The replacement of monitoring and control of inferential parameters (i.e., process parameters describing the processing state, like temperature, pH, pressure) by monitoring and control of core parameters (direct indicators for product quality, e.g., concentrations, uniformity, conversion rate). For this, new sensors as well as analytical technologies are required.
- The possibilities to obtain *real-time* information from the process, to enable faster feed-forward and feedback loops. Recent advances in ICT are an enabling factor for this development.
- The development of quality models to enable predictive control, e.g., on the relation between raw materials quality and processing on the one hand and the final product quality on the other hand.

4 THE EUROPEAN FOOD AND DRINK INDUSTRY – CHALLENGES AND OPPORTUNITIES

4.1 The European food and drink industry - introduction

The food and drink industry is a leading manufacturing sector in the EU. It is EU's largest manufacturing sector in terms of turnover (2011: €1.017 billion) and employment (2011: 4.25 million people[4]). Even in the current period of economic downturn the food and drink industry remains to be a stable, non-cyclical and robust sector with a steady growth in turnover and profitability. The €1.107 billion turnover in 2011 means a growth of 6.8% compared to 2010 and 32% compared to 2006. Despite the existence of a number of multinationals (e.g., Nestle, Kraft, Danone, Unilever), the food and drink industry is highly fragmented with 287.000 companies, of which 285.000 are SME's. These SME's generate about half of the turnover of the sector and account for 63.4% of the employment (FoodDrink Europe, 2012).

4.2 Challenges for the European food and drink industry

The positive figures in the previous section do not reveal that the leading position of the European food and drink industry is under pressure. The main concerns for this industry are (FoodDrink Europe, 2012; Wijnands et al., 2008):

- Europe's share in the global export market is steadily falling, from 24% in 1997 to 16.5% in 2011. This declining trend holds for all traditional food exporters (Australia, Canada, US) and is counterbalanced by an increasing global market share for countries in Asia (China, Thailand, Malaysia, Indonesia) and South-America (Brazil, Argentina). Globalisation of markets resulting in competition on cost alone will further undermine the competitiveness of the European food industry.
- Compared to other manufacturing sectors, the product and process innovations in the food and drink industry are lagging behind. Food production is still largely based on traditional recipes, products and processes. In addition, the industry is weak in economies of scale and labour productivity. The latter is substantiated by the figure for the value added per employee, which is much lower (< 50%) in the food and drinks industry than in manufacturing sectors like the chemicals and automotive industry.
- The food and drink industry is underrepresented in R&D expenditures compared to other manufacturing sectors. In 2009 the R&D investments for the whole sector were 0.53% of the annual turnover, which leads to the classification "low intensity R&D sector" on the European industrial R&D investment scoreboard (JRD/DG RTD, 2012). The big food producing companies are responsible for the major part of the R&D expenditures of the sector. The innovative power of SME's in the European food sector is only very limited, despite their large number. This distinguishes the food industry from other sectors like pharmaceuticals, ICT or biotechnology, where SME's are the driving force behind growth and innovation. The Novel Food Regulation[5] is sometimes mentioned as an impeding factor for innovation in the food sector, e.g., given the resources required for the substantiation of health-related claims on food products. It must be realised, however, that the regulatory framework in the

[4] The employment in the entire food chain is about 5 times higher

[5] EC Directive 258/97 of 27 January 1997 concerning the placing on the market of novel foods and novel foods ingredients

pharmaceuticals sector is even more strict while R&D expenditures as well as innovative power of SME's are much higher in this sector compared to the food and drinks industry.

- The low population growth in the internal market forces industry to find other ways to increase its profitability. Demographics-related changes like the increase of single households, ageing population and lifestyle-related diseases offer ample opportunities for new product development. This requires continuous efforts in innovation from the food manufacturers and their technology suppliers. At this moment, only 5 to 15% of new product developments are commercially successful. This low success rate makes it difficult for SME's to innovate, also given the legislative restrictions on raw material production and approval procedures for new products (following, e.g., from the Novel Food Legislation). Especially for the larger firms, stagnation on the home markets forces them to expand to foreign countries to realize growth. This can be done through export of processed goods, provided the products are sufficiently stable and special requirements with respect to the supply chain can be fulfilled (e.g., cold or refrigerated conditions). It needs to be realised, however, that mostly trade tariffs are higher on processed products than on their commodity form. Manufacturing of processed food products closer to their consumer market may then be the preferred option, also because technology and capital are mobile in the world food economy (Winger and Wall, 2006).

The low score of the European food industry on the different innovation parameters is even more remarkable, given the excellent quality of food science and education at the European universities and knowledge institutes. The inability to transform the results of technological research and skills into (industrial) innovations and competitive advantages is also known as the European Innovation Paradox (European Commission, 1995).

Next to the above-mentioned weaknesses which are more or less specific for the European food and drink industry, the entire (global) system of food supply is reaching its limitations as revealed by a number of recent social, economic and sustainability issues:

- Food scares: the recent food scandals about contamination (e.g., melamine in infant formula, horse-meat) and outbreaks of foodborne illness (e.g., EHEC, salmonella) undermine the consumer trust and affect its food choosing behaviour, but also result in huge incidental food wastages. Chain transparency and traceability of raw materials and ingredients become more and more important. The narrow focus on economic efficiency in the food processing, as well as the lack of reflexive change and a continued reliance on technological fixes to systemic problems may lead to even greater problems in the future (Stuart and Woroosz, 2013).
- Estrangement: the increasing complexity and globalization of the current food production and sourcing system leads to a growing distance between consumer and food production. Despite the clear advantages of processed foods (Van Boekel et al., 2010), loss of control/visibility is considered a major problem by many consumers and may even lead to a negative attitude against "industrial food", being considered as of low quality. The complexity of the worldwide linked supply chains with its limited transparency with respect to origin, processing and social aspects calls for improvements in its operations.
- Malnutrition and food/lifestyle related diseases: although the current food system is assumed to generate enough food for the world population, large groups lack access to sufficient, safe and nutritious food, predominantly in the developing countries. This is ascribed to a lack of proper handling, processing, preservation, packaging and distribution technologies. For the developed and developing countries the link between abundance of food, poor eating habits, inadequate exercise and diseases such as diabetes, cardiovascular diseases, cancer, osteoporosis and dental diseases attracts an increasing attention from many governments, mainly driven by the increasing healthcare costs.

- Food losses: worldwide about one third of the food produced is lost somewhere in the production and distribution chain (Gustavson et al., 2011). In developing countries more than 40% of the food losses occur at post-harvest and processing levels, while in industrialized countries more than 40% of the food losses occur at retail and consumer levels. Within the European context, food manufacturing on average accounts for about 5% of the total food losses that are generated[6]. Although this figure is relatively low, large variations are observed between the different countries (1-21%) as well as between the different product categories. Cereals show the highest waste level in European countries with 400 million ton/yr, followed by dairy (~250 million ton/yr) and fruit/vegetables products (~200 million ton/yr).
- Volatility of the prices for raw materials (**Figure 5**): over the last years food manufactures have been confronted with increasing costs for the supply of raw materials (Van der Veen et al., 2013; Commodity Price Dashboard, 2013). From the side of the retail and out-of-home sector pressure is exerted on the food processing sector to deliver their products at the lowest possible price. Due to this squeeze, food manufacturers are forced to cut their own costs to remain in business. This effect was clearly visible in 2011, where the food producer (ex-factory) prices rose at a lower rate than the agricultural commodity prices, while food consumer (i.e., retail) prices rose in line with the inflation (FoodDrinkEurope, 2012).

***Figure 5**: Evolution of global commodity prices. The sharp price increase starting in 2000 has balanced the decline in prices generated by the increased productivity and efficiency since 1900 (McKinsey Global Institute, 2011).*

[6] Source: Preparatory study on food waste across EU 27, Contract #: 07.0307/2009/540024/SER/G4; October 2010

- The economic crisis: the current period of economic downturn not only limits the consumers' disposable income, but also limits the financial means for investments to upgrade the technological status (and, thereby, the efficiency) of the food processing sector.

- The availability of raw materials. Europe is a major net food commodities importer and depends on outside supplies for its food security. Europe's reliance on imports of plant-derived biomass and products is increasing and will face growing competition from the growing world population, their changing consumption pattern as well as the effects of climate change. The recent food-versus-fuel discussion clearly indicates that the upcoming Bio-economy (i.e., non-food applications for biomass) will put extra stress on the availability of raw materials. The future environmental challenge for the agro-food domain is to fulfil the increasing demand for both food and biobased products (including biofuels and bioenergy) under the natural restrictions of the system (e.g., space, emissions, scarcity of water, energy, nutrients and minerals). One of the potential solutions for the food sector is to explore the potential of raw materials which are currently hardly or not utilised in food production. This route, however, is regulated by the New Food Regulation.

To summarize, the European food processing industry is facing a number of (interdependent) challenges with a potential sizable impact on its future activities and competitiveness (see **Figure 6**). It should be realized, however, that for many companies these challenges are not within the focus of the day-to-day business, and thus will not automatically lead to the start of innovation projects. It is, therefore, essential to link these challenges to the appropriate business-drivers of the European food companies. The next section will address this point.

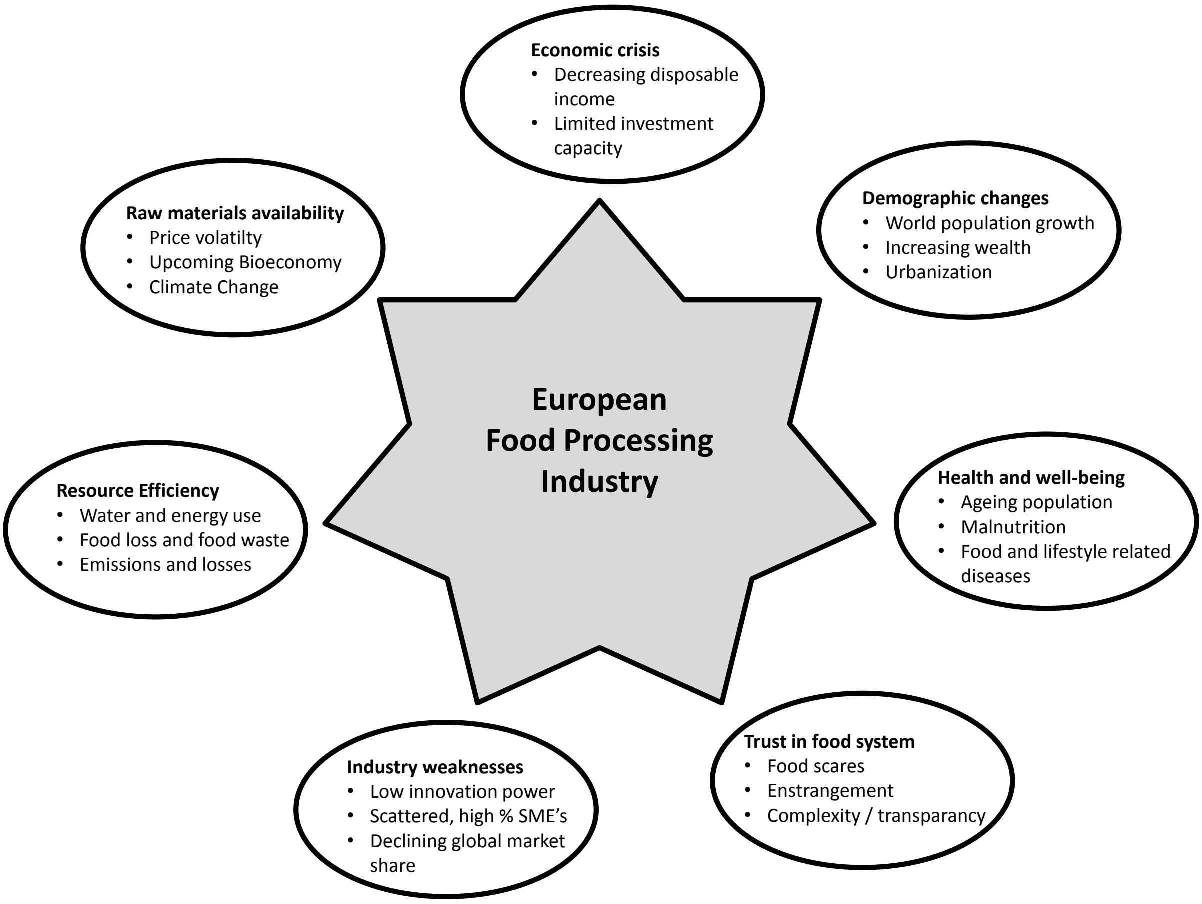

Figure 6*: Overview of the major challenges for the European food processing industry.*

4.3 Business drivers for R&D projects

The previous section ended with an overview of the challenges which may have an impact on the further development of the food processing sector in general, and the European food and drinks industry in particular. As argued before, these challenges will not automatically lead to the start of innovation projects, even though the research goals and priorities for the food industry sector as a whole have been clearly identified in the updated Strategic Research and Innovation Agenda of the ETP Food for Life (ETP, 2013). Given the scattered landscape of the European food and drink industry and the large quantity of SME's, it is questionable whether all industries will actively participate in realizing this agenda. Therefore, it may be interesting to have a look at how innovation is organized "bottom-up" (i.e., on the level of individual companies).

To ensure the most efficient use, R&D-resources in a company are usually focused where they are expected to have the largest impact. In practice this means that industries will only start R&D-projects when they are closely linked to the strategy and business drivers of the company. According to the well-known model of Porter (Porter, 1980) companies have the choice between 3 generic strategies:

1. Cost Leadership: products are similar to those of competitors; the company strives for the lowest cost price.
2. Differentiation: the company discerns itself from its competitors by delivering superior quality or additional services, usually in a broad market segment
3. Focus: the company delivers products and services to a specific niche in the market

Next to this, manufacturers of food products have to comply to the standards, regulations and other requirements within the regulatory framework to guarantee that products they put on the market are safe for human consumption. Compliance in the food manufacturing sector, therefore, has the highest priority.

When translated to the role of technology (being the subject of this report), compliance and the three business strategies can be summarized to the following drivers for R&D investments in the food industry:

1. Compliance
2. Operational Excellence
3. New products/new technologies

These 3 categories and the link to the underlying trends and drivers will be further worked out in the next sub-sections.

Compliance

In the strict definition, compliance involves the way that companies adhere to legislation, standards and other requirements. Without going into the details of the regulatory framework that is imposed on food processing[7], it is clear that both national governments and European authorities apply strict regulations and standards to ensure food safety, animal health and welfare, plant health as well as the effective functioning of the internal market. New insights, e.g. in food safety, nutrition and health, are reasons for the EU to regularly review its food policy to ensure that rules are respected, but also to improve production methods. As stated by the DG for Enterprise and Industry, its aim is to guarantee coherence between food safety and competitiveness principles by promoting a standardized, transparent and reliable legal framework that is not overly burdensome for companies.

[7] Refer, e.g., to DG Health and Consumers (http://ec.europa.eu/food/index_en.htm), DG Enterprise and Industry (http://ec.europa.eu/enterprise/sectors/food/eu-market/regulatory-aspects/) and European Food Safety Authority EFSA (http://www.efsa.europa.eu/)

This approach fits very well in the model developed by the Dutch Association on Sustainable Food DUVO (Dutilh, 2012). In this model, the government allows companies to enter the market via a so called *License to Produce*. If companies fail to comply with the regulations, they can be fined or ultimately lose their *License to Produce*. Regulations as such are not static, but may change, e.g., as a consequence of newly acquired scientific insights but also to force industry to reduce the use of certain less-desired ingredients (e.g., salt reduction).

In the same model the interaction between consumers and companies ultimately leads to the consumers' decision to either buy or not buy the offered product: the *License to Sell*. In this domain the sometimes rapidly changing consumer preferences are leading. As a consequence, companies can gain or lose their market share within days, e.g., in case of a food crisis like EHEC.

The same model also describes the interaction between companies and citizens, in most cases represented through NGO's or pressure groups. In this interaction, issues like health, environment, animal welfare, sustainability and safety are dominant. Companies more and more respond to the demand for openness on these themes to ensure that they will not lose their *License to Operate*, i.e., their societal acceptance. A well-known example of a company losing its license to operate was Shell at the time of the Brent Spar crisis.

To summarize the above: Because compliance to standards and regulations is a *must* for companies to stay in the market, legislation can be a driver for innovations in the food industry. Changing standards, e.g., as a consequence of new scientific insights on the relationship between food and health, can drive the development of healthier products. Recent examples of this are products with a reduced salt content or containing less sugar. The novel food legislation challenges the industry and may be either a burden for innovation or providing a competitive advantage especially for SMEs. Anticipation on changing consumer preferences can even be a stronger driver for innovation in the food industry. The growing market share of meat replacing products, for example, clearly indicates that consumer insights with respect to impacts of meat production are changing. As a consequence, this changing attitude gives companies an opportunity to develop new and better meat replacing products.

For the majority of the companies topics like sustainability and animal welfare as such are not the drivers for innovation. However, these topics can be closely linked to the reputation of a company, thereby posing a (financial) risk in case of not complying to their own standards or the standards of their stakeholders. Examples are multinationals like Unilever (Sustainable Living Plan) and players on (niche-)markets like organic food, ethical production and sustainable sourcing. For such companies proper risk management requires an active approach to maintain their reputation and, thereby, their *License to Operate*.

Operational excellence

As previously explained, the volatility of the prices of raw materials on the one hand, and the pressure exerted by retail and out-of-home to reduce cost prices on the other hand, puts the food manufacturing sector into the squeeze of cutting costs. Indeed, an analysis of the Dutch food industry (Van der Veen et al., 2013) concluded that competition on price and cost leadership is the main topic for the Dutch food processing industry; this even holds for the companies that follow a differentiation strategy.

Many companies have started operational excellence programs with the aim to reduce the cost basis for production. Companies that succeed in developing a structural cost advantage are also expected to improve their ability to capture new growth opportunities and to reduce their exposure to resource- and environment-related interruptions (McKinsey, 2011). Operational excellence programs can be built around philosophies on continuous improvement of existing processes, e.g., to avoid waste (Lean Manufacturing) or to reduce variation in the output of the (sub-) processes (Six Sigma). With respect to sustainable processing, eco-efficiency is a way for companies to become more efficient and profitable. Eco-efficiency does not only ensure efficient use of resources (water, energy) and reduction in waste, but it will also lead to cost reductions and reduced vulnerability to future scarcity and price increases.

An interesting example of how eco-efficiency for a sector can be organized is given by the Australian dairy sector (Dairy Australia, 2004). They developed an eco-efficiency manual that provides benchmark data on water and energy use that enables dairy companies to evaluate their individual performance. Furthermore, detailed improvement options are described for each unit operation that is used in dairy manufacturing, e.g., to reduce the use of detergents, energy and water. Similar manuals have been written for other sectors of the Australian food processing industry as well as for the US food industry within the Energy Star program[8].

New products, new technologies

For most companies the development of new products and new technologies is essential to remain competitive and to grow. Failure to develop new products or to implement new technologies puts companies in the "commodity spiral", where price is the main (and sometimes the only) feature for competition. In terms of strategy, many food processing companies would like to follow the differentiation or focus strategy.

Product innovations in the EU are focused on frozen products, dairy products, ready-made meals, poultry/meat and soft drinks (*FoodDrinkEurope*, 2012). In most cases, new product development is dominated by incremental change (*me-too* products, alternative flavorings, etc.); a relatively small part is related to technological innovations. The failure rate for new product introductions is very high.

As indicated in **Section 4.2**, R&D expenditures in the food processing sector are lagging behind compared to other sectors, being the most plausible reason for the low number of product and technological innovations. Nevertheless, demographic changes as well as sustainability concerns offer plenty of chances to the food sector for innovation. The markets in the US, EU and Japan account for over 60% of total retailed processed food sales in the world (Winger and Wall, 2006). Growth in this market mainly comes from added value products, for example labor-saving products, organic products, products that are perceived to be safer or healthier or products that take animal welfare and equitable labor concerns into consideration.

4.4 Opportunities for improving sustainability in food processing

The previous sections have described the complexity of the food processing industry as well as the prominent linkages to many of the current and future societal challenges related to sustainability. It should be realized that the drivers for R&D and innovations in food processing are also closely linked to the position of the food processing industry with respect to the chain and various other stakeholders (**Figure 7**), e.g,. :

- resources: scarcity and increasing prices for biomaterials, energy , water and emissions drive optimization, differentiation and added value creation along the production chain (from sourcing of materials to the consumer product)
- society: demographic changes, food crises etc. require anticipation or fast reactions on (changing) demands from society (legislation, sustainability issues, etc.)
- market/consumers: trust, price competition;
- technology suppliers: novel solutions that facilitate novel practices.

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[8] www.energystar.gov

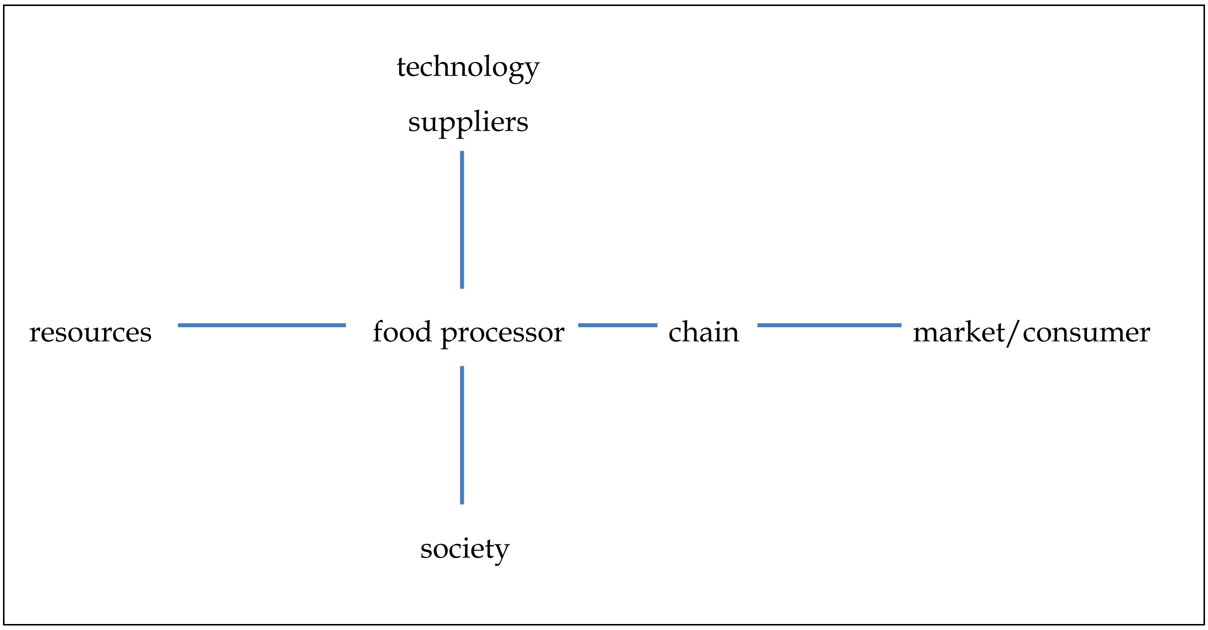

Figure 7: *Stakeholder mapping for food processing research & technology development*

In this time of economic crisis it is expected that cost reduction will be the dominant driver for the near future. The concept of eco-efficiency links cost reductions to sustainability gains, and is therefore a viable improvement strategy to reduce the current impact of food processing.

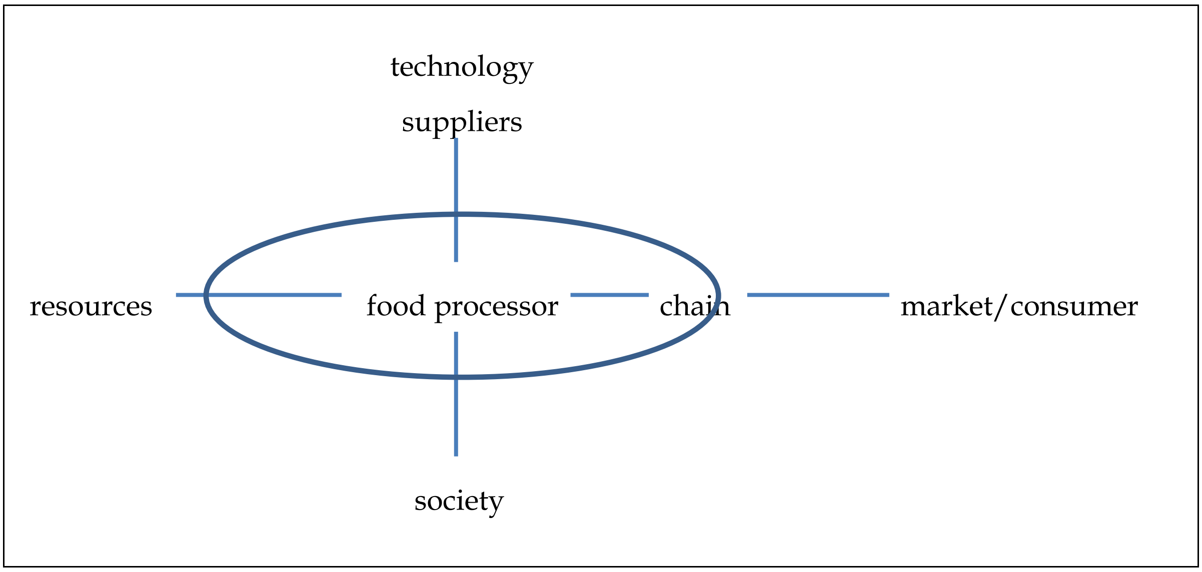

Figure 8: *Focus for short-term development: eco-efficiency in the production chain.*

Cost reduction as such is not a viable strategy for the longer term, since scarcity of resources and the concomitant increase in cost prices can only be overcome through alternatives for the current use and ways of production of, e.g., water, fossil energy, meat proteins and phosphorus. Climate change and the upcoming bioeconomy are expected to further enhance the problem of resource scarcity on the raw materials level.

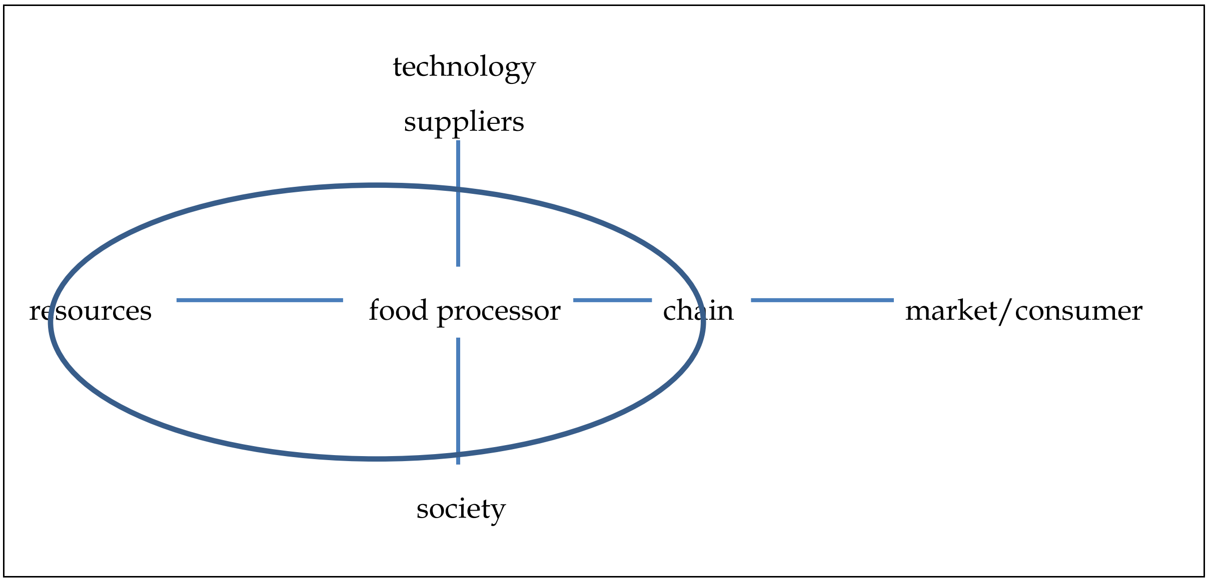

Figure 9: Medium term development: innovative approaches addressing problems of resource scarcity, also driven by social concerns

New product development as well as diversification to different markets may be a driver for growth of the EU food processing industry for the longer term. For the short term, this growth can be realized in the new emerging markets. Given the low level of development in these markets, however, this growth can be realized using established technologies.

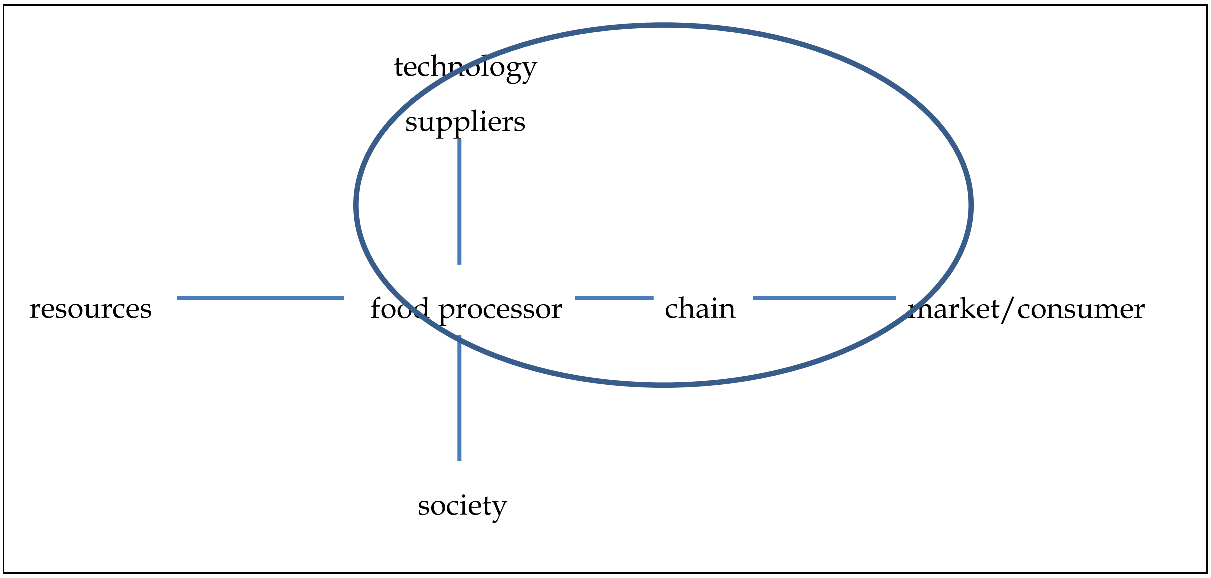

Figure 11: Medium to long term development: novel product development aiming at new markets or creating added value on existing markets (using novel technologies).

In view of the above, most of the short-term innovations in the food processing industry will have an incremental character. However, to remain competitive on the longer term, more radical innovations are required. To be more specific, technological innovations in food processing should support the development of:

1. ***New and better food products*** to:
   a. Meet the growing food demand (growing world population, increased standard of living)
   b. Alleviate the food security gap (starvation, nutritional deficiencies)
   c. Account for demographic changes (urbanization, ageing population)
   d. Prevent lifestyle-related diseases
   e. Meet consumer demand for personalization with respect to:
      i. Pleasure (sophistication, exoticism, variety of senses, fun)
      ii. Health (natural, medical, vegetal)
      iii. Physical (slimness, energy well-being, cosmetics)
      iv. Convenience (easy to handle, time saving, nomadism)
      v. Ethical (ecology, animal welfare, solidarity)

2. ***Resource efficient manufacturing processes*** that:
   a. Minimize dependency on valuable crops (for example through assessing alternative sourcing from by-products)
   b. Consume less water and energy
   c. Prevent the generation of waste (*zero waste concept*) and make high-value (food) application of by-products possible
   d. Preserve local balances (e.g., minerals)
   e. Produce high quality products with an extended and predictable shelf life
   f. Retain the functionality of micro- and macronutrients
   g. Allow for diversification with respect to specific consumer demands (e.g., allergy and intolerance, health-promoting ingredients)

3. ***Integrated and transparent supply chains*** that:
   a. Provide food security in developed and developing countries
   b. Connect local food production and demand with the globalization of the food industry and retail (e.g., regional production, 3d printing at home)
   c. Generate less losses and waste and operate in a synergistic way with other sectors of the upcoming bioeconomy
   d. Increase the consumer trust in food production on aspects like food safety, sustainability and ethics through certification and chain agreement
   e. Provide objective information, e.g., with respect to food-health relationships, ingredients, claims and technologies
   f. Allow for transparency and traceability of raw materials and intermediates in all parts of the supply chain (sourcing, food manufacturing, retail)

4. ***Increased innovation power of the food industry*** by:
   a. Faster translation of scientific results into industrial implementations
   b. Inclusion of scientific advances from other disciplines (e.g., nanotechnology and ICT)
   c. Implementation of new processing technologies

The next chapter will provide examples of technological innovations areas which will support these developments.

5 TRENDS IN FOOD PROCESSING TECHNOLOGY – FUTURE OUTLOOK

In the previous chapter drivers and innovation directions for sustainable food processing were described. This chapter gives an overview of the technology options, with focus on technology areas with potential application in the coming 5 years. Per technology option the current state of the art is explained, examples of successful applications (*success stories*) are given, as well as an outlook for the expected developments in the near future. The choice for the different topics and technologies has been discussed and agreed upon with the sponsor of this project. It should be considered as an expert opinion for the relevant developments in the field of sustainable food processing, rather than considering it as a complete overview of all available technological options.

In **Table 1** the different topics that will discussed in this chapter are summarized. The possible fields of innovation for the (European) food manufacturing industry as described in the previous chapter are indicated in the columns. The different technology options that will be elaborated in the sub-sections of this chapter are summarized in the rows of **Table 1**. Trough combining the information on the rows and in the columns, the intersections list the potential topics for improvement and innovation projects that could be started to promote sustainability in the food processing industry.

Table 1. *Summary of (sustainable) innovations related to drivers for R&D investments (as presented in previous chapters)*

TECHNOLOGY OPTIONS	**OBJECTIVES FOR INNOVATION**			
	New and better food products	**Resource efficient manufacturing**	**Integrated and transparent chain**	**Increased innovation power**
sensor technology	increase control on quality & safety issues	reduce product losses: decision making based on measured product properties	advanced management and control of food quality & safety	increased product quality control and differentiation
sustainable packaging and refrigeration climate control	high quality semi-prepared convenient food	reduce food losses through increased shelf life; work on sustainable packages	smart packaging	
non thermal pasteurisation and sterilisation	shelf-stable (semi-)fresh products	reduce losses through increased shelf life		new processing technologies result in products with improved properties
nano- and micro technology	advanced product development	reduction of energy use; detection of contaminants and spoilage micro-flora		new processing technologies result in products with improved properties
innovative processes for utilisation of rest and by-products	generate natural and health-beneficial ingredients from by-products	generation of food ingredients from by-products; valuable application instead of waste		alternative thinking results in new concepts and products; continuous improvement related to avoidance of waste
alternative processes requiring less energy or water	less intensive processing for less refined products	reduction of energy and water use	less refined food ingredients: more specific relation between ingredient supplier and food producer	exploration of new routes for alternative food processing chain design
product development: plant-based meat alternatives	develop more attractive meat replacers	production efficiency of plant-based is higher than animal-based		broader spectrum of raw materials speeds up product innovation process
information and knowledge transfer	improve quality control along the chain	improve production planning based on shared information along the chain	improve knowledge sharing along the chain; make chain transparent for consumer.	faster translations of R&D results into industrial implementations

5.1 Sensor technology and quality monitoring

Introduction

Main applications of sensor technologies in food processing are

- quality control of raw materials, intermediate products and food products, including detection of defects, chemical residues, etc.;
- process control: measuring relevant process parameters or (intermediate) product attributes as a basis for process control actions.

Both types of applications contribute to improving the sustainability of food production.

Quality control

One of the challenges for food producers and supply chain is to enhance consumer trust in safety and quality. In the past years several scandals occurred in the agro-food supply chain, such as the use of horse meat for beef, uncertainties with respect to the origin of biological eggs, melamine in infant formula powder, etc. The complexity of *worldwide* linked supply chains, with limited transparency with respect to origin, processing and social aspects, calls for improvements in quality control. New sensor technology is foreseen to measure critical product attributes at the level of consumer product manufacturing.

Sensors are essential to achieve an optimal food processing chain not only in terms of final product quality, but sensors can also contribute to the efficient use of resources during the storage, processing and distribution of food products. Through objective classification of materials/products, different qualities can be valorized in most suitable applications. Such approaches result in efficient use of raw materials.

Given the broad range of potential applications, the impact of applying sensor technology to increase the sustainability of food production is, therefore, expected on different levels. This development is enabled by rapid developments in the ICT domain.

Sensors for process control

Sensors are crucial in process control (food processing as well as storage). Based on measuring relevant attributes of raw materials, intermediate or end products as well as critical physical conditions, adequate control actions are taken. Automated process control systems as well as process operator-controlled actions are very commonly applied. This operation contributes to food chain sustainability through

- optimization of product quality, including reduction of quality losses and defects;
- decrease of energy and water consumption;
- optimized protection strategies (e.g., pesticides application, use of additives during production).

State of the art

Currently available analytical and sensor technologies are able to measure most relevant product, process and environment parameters. However, the application of these technologies to optimize the food production and distribution chain are limited due to a number of drawbacks:

- sensitivity
- speed of detection
- size/portability
- robustness
- signal communication

Most of the future development will be focused on removing or reducing these limitations. The possibilities of nanotechnology open the door for enhanced sensor technology. **Table 2** presents a number of possible applications of the technology in the food production and distribution area.

***Table 2**: Nano-enabled sensor technology applications in food processing (source: ObservatoryNano Agrifood, Briefing No 28, March 2012)*

Technology	Description	Target
Uni-molecular sensors	Single biomolecule enclosed or attached to nanomaterials (liposomes, nanoparticles, nanorods, or carbon nanotubes).	Pesticides, gases such as CO_2.
Bioarrays (including electronic noses or tongues)	Multiple biomolecules enclosed or attached to nanostructured materials.	Multiple chemicals & microbes.
Solid state sensors	Thin film or nanowire (carbon nanotube, silicon, metal oxide, metal alloy or conducting polymer) sensors.	Gases.
Optical & spectrographic sensors	CCD, lasers and spectrometers.	Plant growth, presence of different chemicals.
Radio Frequency Identification (RFID) tags	Elaborated in text.	Monitoring of produce condition during transit.
Sensor networks	Individual sensor nodes that can be dispersed over an area, measure local variables, and report to a central processing unit.	All aspects of crop and livestock monitoring for precision farming.

Another important trend on sensors and sensing systems are the wireless technologies. The application of these technologies offers flexibility, fast signal communication and the possibility to combine sensing systems in sensor networks. A number of applications are already in place in the agricultural and food processing industry, as for instance use on conditions monitoring in cold chain monitoring and for identification related to traceability. A set of sensors detect, identify, log and communicate the transport and handling of food products in the chain enabling in this way the optimisation of the supply chain. There are still challenges, however, to be overcome in this technology (Ruiz-Garcia et al., 2009). Particularly signal losses due to ambient conditions are an issue, both in outdoor and indoor applications.

The quality (and safety) of perishables (e.g. shelf-life) can be determined more precisely if viable information exists about the actual conditions under which the particular product has been stored. If monitoring equipment is attached to the device that uniquely identifies the product one would have a complete solution for traceability and quality of this product. This is achievable if a monitoring device (with all the required sensors) is combined with a radio frequency identification (RFID) chip. On the one hand this technology will improve cold-chain distribution quality and record-keeping, on the other hand it will also assist in pinpointing problems, assigning liability and ensuring earlier provision of preventive measures.

The shelf life of many fresh food products depends on the ambient conditions (such as temperature and relative humidity) as well as the initial product quality. The combination of these two aspects will deliver a strong control of the product quality in the whole chain and ultimately contribute to decrease food waste in different parts of the supply chain. The measurement of strict ambient conditions has largely been developed in the last decades. On the side of the product related parameters there is still need for development and optimization. Knowledge on the relationship between the optical and mechanical properties of fruits and vegetables and their physiological and quality parameters needs to be generated. The same applies to other types of food products. In addition, the development of cost effective, nondestructive sensors and sensing systems to measure and monitor the quality would be of great value.

In process control most common are single-input-single-output control systems: one process parameter is controlled based on one signal. With advancing processing knowledge and levels of automation, more advanced systems are getting more common: information about processing status and (intermediate) product quality is derived from combined information from multiple sensors based on advanced product models. The example Quest shows options to reduce energy consumption during refrigerated transport and storage of food products. These savings are not directly based on the applied sensor technology, but the complete system was based on recent knowledge of product behavior.

Reducing losses in the food chain: the Dynamic Control System DCS^T

In the postharvest field the use of specific sensor based technology can lead to enormously advantages. The Dynamic Control System (DCS™) can be used in the storage of fruit, particularly fruits that are stored for a long period such as apples and peers. In the current technology these fruits are kept under low oxygen levels in order to decrease the metabolism of the fruits, hence keeping the quality. However, if the level of oxygen decreases under a certain limit, anaerobic respiration will be induced and the quality of the fruit will decay rapidly. This specific limit depends on a number of factors and it is not fixed. The current technology is, therefore, not optimal. The DCS™ method measures the amount of oxygen, carbon dioxide and ethanol during storage. Ethanol is one of the products of anaerobic respiration. The principle of this dynamic sensor technology is to control the level of oxygen based on the measured ethanol amount (Veltman et al., 2003). Very sensitive sensors, that are able to measure low amounts of ethanol, are necessary to apply this concept. With the DCS™ technology the fruit will be more firm and of better quality than the current Ultra Low Oxygen technology. In addition the application of this technology leads to less scald and skin spots on the fruit (Montsma, 2012). These are disorders that reduce the product value considerably. DCS™ will therefore contribute to reducing losses in the supply chain.

Quest – more quality, less energy in refrigerated container transport

Quest, which stands for "QUality and Energy in Storage and Transport", is a methodology that controls the refrigerated container unit based on the real climate control requirements of the cargo. Quest II saves energy by improving control of two important components: internal air circulation and the compressor. Internal air circulation is adjusted to heat load. Air circulation will run at full capacity when necessary, but at lower heat load the air circulation rate may reduce to about 10% of its maximum capacity. Apart from that, Quest II reduces energy consumption by controlling the operation of the compressor, depending on the required refrigeration capacity to maintain cargo at the precise temperature. The effect of Quest II on produce quality was thoroughly researched and tested for a range of products, both in labscale tests and in hundreds of field trial shipments, with no adverse results. Labscale testing was performed with bananas, pineapple, kiwifruit, grapes, iceberg lettuce, lily bulbs and lamb meat. The shipments included more than 15 different commodities, including apples, bananas, garlic and potted plants. Quest II is easy to implement in containers, because only the refrigeration unit's software needs to be updated.

Refrigeration in storage and transport based on the Quest II methodology leads to 65% less CO_2 emission. A yearly reduction of CO_2 emission of 350,000 tons is comparable to the CO_2 emission of cars driving 2 billion kilometers.

For more information, please follow:

http://www.wageningenur.nl/en/show/Energy-use-of-refrigerated-containers-further-reduced.htm

Radio frequency identification (RFID)

The state-of-art in the field of sensor based RFID tags are devices whose sensing capability is mainly limited to ambient temperature monitoring. In Europe some companies provide flexible RFID tags with integrated temperature sensors: for example KSW Microtec AG and Schreiner MediPharm GmbH. The US-based company InfraTab provides a RFID tag with a temperature sensor for controlling the temperature along the cold chain for perishable goods. Some companies, mainly in USA (e.g., Alien Technology, Savi Technology), present on their websites additional functionalities, such as humidity and shock sensors. In practice, however, these products are still in the development stage and in any way designed for stationary applications. Typical prices range from €10 for simple temperature monitors to €100 or more for highly advanced systems. The price development trend of RFID tags is illustrated in **Figure 12**.

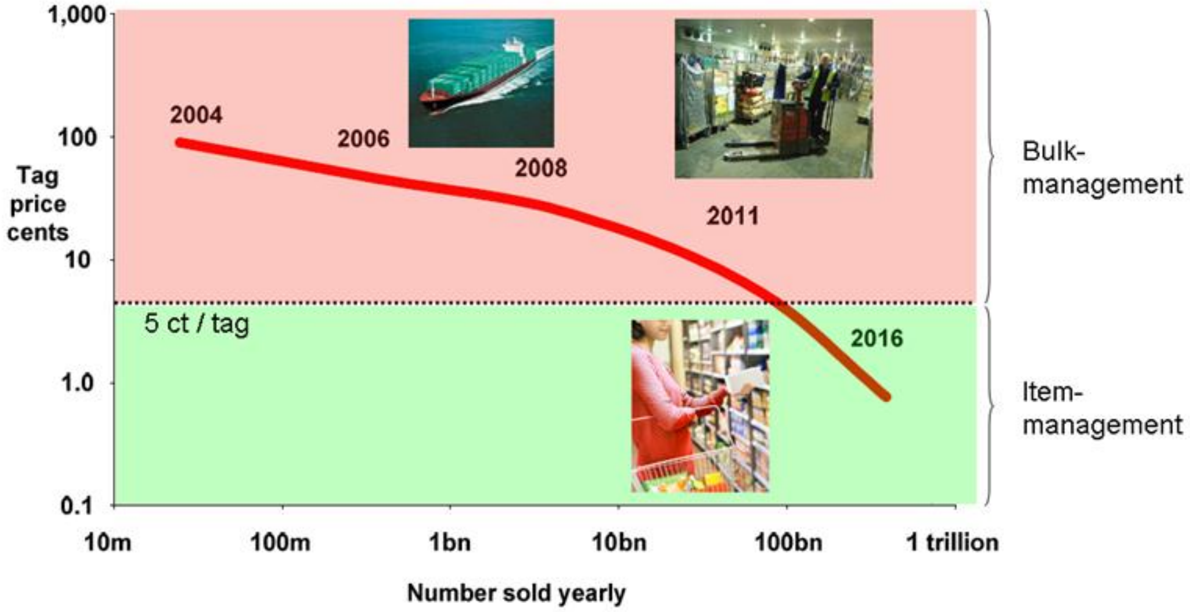

***Figure 12**: Price development in the past and future prognoses of RFID tags.*

When tags contain a microcontroller this enables possibilities to interpret the environmental data on-chip. Besides process control on the applied storage and transport conditions of the perishables the chip facilitates prediction of the product quality. Upon reading the chip the actual status of the goods is immediately available. The expected future status can be described by quality models which predict the status of the quality of the product depending on the experienced environmental conditions. The quality models can have different complexity, ranging from statistical process control on environmental conditions, through shelf life predictions based on single or multiple inputs, to development of specific quality attributes based on single or multiple inputs. The Pasteur RFID-chip is a good example of such a functional monitoring device.

Smart tags: The Pasteur RFID chip

In the PASTEUR project (CATRENE programme, CT204) a multi-disciplinary consortium of partners worked on breakthroughs in further development of smart tags (Hoofman *et al.*, 2013). Partners originated from the high-tech industry and the agro-food sector. The project focused on technology solutions for multi-market use with focus on the low-end (e.g. fruit, vegetables) cold supply chain (cooled transport of goods), which enable eventually item management. For this to be realized, breakthrough developments are needed in power consumption, cost, physical shape and multi-sensor functionality. This project focused on the technological step from bulk to multi-item (box, crates etc.) monitoring applications.

The main achievements of the project were: low energy consumption to enable use of small batteries; a small form factor, including RFID antenna; reduction of costs to about 1$ per chip; multiple sensor functionalities integrated in a single sensor chip; and a high integration level with all functionalities integrated on the tag. In addition, several improvements in sensing materials, efficient material use, power efficient ADCs, and product quality models were realised.

In the project two main application areas were defined:

a) Fruit case, monitoring temperature and different gas fractions;

b) Meat case, monitoring temperature and pH.

These cases resulted in two prototype demonstrators: 1) Wireless smart sensor tag (with temperature, humidity and possibly CO_2 sensor capability) for fruit, vegetables and ornamentals; 2) Smart sensor package (with temperature and pH sensor) for meat.

The prototype wireless sensor tag is based on a multi-sensor chip which is interfaced to an RFID chip and a low power microcontroller. The prototype was realised as a flexible tag, including the possibility to integrate battery and antenna, and as a printed circuit board. The form is comparable to a credit card. The multi-sensor chip monitors temperature, relative humidity and CO_2. The microcontroller contains embedded software to store product information and measurements data and for on-chip data analysis and product quality calculations. The RFID chip facilitates the communication with the outside world.

The prototype pH-sensor consists of a moulded stick (containing the sensitive pH sensor device) connected to a small custom printed circuit board which contains an microcontroller for data storage, a battery and communication components. The package was designed to withstand the conditions during processing of carcasses in a slaughterhouse. Both demonstrators have successfully been tested in field trials, namely in a mimicked cold chain and in carcasses in a slaughter house. An illustrative video for fruit chain monitoring was made by KU Leuven (2012).

Outlook

With the use of smart sensors the need to fulfil consumers and government demands for transparency comes within reach. The possibilities for better assurance of the production and distribution chain and prediction of the product quality bring added value and options to improve one's position compared to competitors by risk reduction and delivery of products with guaranteed quality. With the information obtained from the smart sensors, decision support for supply chain stake holders becomes available on various topics: decisions on post-harvest processing, matching product quality and customer demand, logistics and order management of supermarkets, more precise quality estimates, etc. (**Figure 13**). This enables the use of guaranteed quality statements as well as the supply of consumption-ready products to the supermarket. Furthermore, logistical concepts such as FEFO (first expired first out) can be realised.

The quality of the sensors will further be improved, as a further development of the underlying analytical techniques is expected. A number of technologies have been studied and applied to measure product quality, such as optical and vision techniques, electrical techniques, acoustic vibration, nuclear magnetic resonance, electronic noses and computed tomography. Spectroscopic methods seem to have potential for future developments since this technology is a.o. characterized by high-sensitivity detection and nondestructive measurements (Omar and Matjafri, 2013; Alander et al., 2013).

Biosensors might be applied to envisage the presence of chemical contaminants and food-borne pathogens. The development of this type of sensors can play an important role in assuring food safety in the future. The current detection methods based for instance on culture and colony counting, polymerase chain reaction, Elisa-methods are tedious, time consuming and require high skilled personal. The development in the biosensors field is therefore focused on high performance sensors, capable of rapid detection with minimally skilled personal. Enzyme-based biosensors have been thoroughly investigated and seem to be a promising tool for the detection of chemical threat agents and food contaminants (Simonian and Chin, 2010). Despite this promising outlook, the developments in the field of biosensors are not expected to lead to relevant commercial applications the coming years. The necessary investments will be only feasible on a medium-long term. A similar forecast is expected for the application of nanotechnology in sensors. The high technology requirements and costs hinder a fast development and application of nanotechnology in this field.

Policy measures to directly regulate, stimulate and improve the application of sensors are not obvious. Rather, the application of sensors and sensing systems will be the natural consequence of regulation on the safe and sustainable production and distribution of food products.

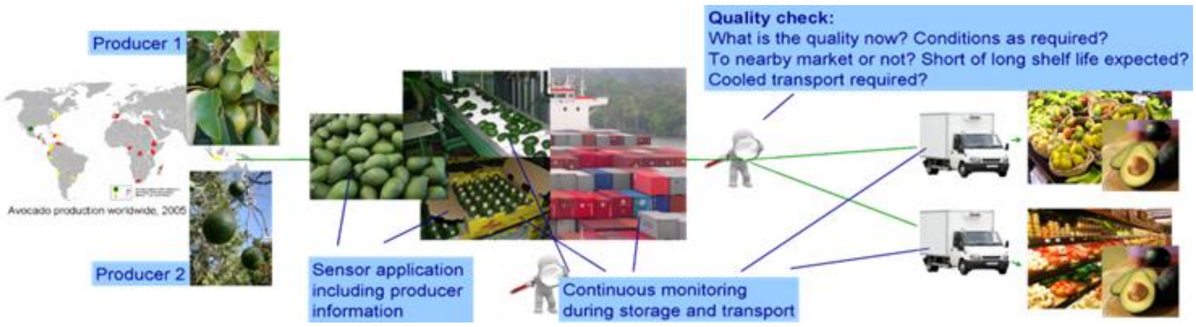

***Figure 13**: Use of smart sensors in avocado distribution chain.*

5.2 Sustainable packaging and refrigeration climate control to enhance shelf life

The causes of food losses and waste in medium/high-income countries are mainly due to consumer behaviour and lack of coordination within the supply chain. In addition, the quality standards set by retailers on the grading and appearance of particularly fruits and vegetables also contribute to a large extend to the generation of food waste. Next to the size and appearance, loss of quality is an important cause of waste in this group of products. The quality of vegetables or fruits decreases fast, starting directly after harvesting of the products and involving a number of biochemical and physiological changes. As the product senescence depends on several factors different strategies can be applied and combined to keep the quality as long and high as possible. In addition, in the current global market, fruits and vegetables are very often subjected to long storage and distribution chains. An integrated chain approach is, therefore, essential to achieve optimal product quality and extend shelf life, hence reducing postharvest losses.

Most relevant control strategies:

- (controlled atmosphere) packaging
- Temperature control
- Control of relative humidity and ethylene
- Controlled and modified atmosphere
- Phytosanitary and anti-mould treatments

Sustainable packaging

The Sustainable Packaging Coalition has published one of the more comprehensive definitions of sustainable packaging (Sustainable Packaging Coalition, 2006):

A. Is beneficial, safe & healthy for individuals and communities throughout its life cycle,

B. Meets market criteria for performance and costs,

C. Is sourced, manufactured, transported and recycled using renewable energy,

D. Maximizes the use of renewable or recycled source materials,

E. Is manufactured using clean production technologies and best practices,

F. Is made from materials healthy in all probably end-of-life scenarios,

G. Is physically designed to optimize materials and energy,

H. Is effectively recovered and utilized in biological and / or industrial cradle to cradle cycles.

From a historical perspective, the aspects A and B have been the main drivers for the development of new food packaging concepts. The major part of the recent developments have made a contribution to minimize food losses for the lowest possible costs, while simultaneously boosting the sales in the retail and fulfilling all relevant criteria related to health and logistics, etc. The other aspects of the above definition (C – H) have gained more and more importance over the last years and the environmental impact of the package itself has received much more attention from manufacturers, media and governments.

Only a few new food packaging technologies, with the intention to prolong the shelf life and to reduce the food losses have been successfully introduced on the European market in the last decades. These market introductions tend to take many years in Europe but do result in large environmental impact reductions. For example, the first experiments with modified atmosphere packaging (MAP) for fresh meat were conducted in 1964 in the Netherlands. The first early adopter Hanskamp BV implemented this technology for fresh red meat products in 1975 and the mass adaptation followed after 1999 in the wake of the BSE crisis (Thoden van Velzen, and Linnemann, 2008). Similarly, the first crude E-MAP technology for freshly cut curly kale and cut carrots was introduced in 1975 but the mass-adaptation followed between 1985 and 2007 and was driven by the profits retailers commanded with MA-packed freshly cut fruits and vegetables. (Thoden van Velzen, 2008). Besides tests with oxygen absorbing packages that are currently performed on organic cakes, no other entirely new packaging technologies are expected to be introduced in the Netherlands in the coming 5 years.

The slow pace of market introductions for new food packaging technologies in Europe results from:

- The complex nature of the modern food industry which results in a general conservative attitude towards innovation,
- Often the packaging industries are contract-operators for retailers and need to pay for the additional packaging costs, while the benefits (logistical cost reductions, added sales, etc.) are for the retailer,
- Food packaging technology is not a prime topic in the board rooms of food manufacturers. Many food companies have either no packaging engineer or have a packaging technologist working as a trouble shooter.

Nevertheless, the old vacuum packaging technology is starting to make a comeback in the form of the modern more attractive appearance of skin-packaging. Modern skin-packages for fresh pieces of meat with a flat tray at the side offer the retailers many potential advantages: longer shelf lives, better display options (vertically hung packages) and more chilled stock per square meter in the display cabinets. The only downside is the purple colour that red meats develop under vacuum and hence the retailer needs to explain that although the product has coloured purple, it is still fresh. This type of packaging is already common for game meat and some sausages and we expect a gradual expansion towards the more common whole muscle meat products in the coming years.

Another contemporary development are cardboard based barrier trays which enable various food products to be packed under modified atmospheres inside a cardboard package. Various companies tried to create top-sealed barrier trays from cardboard and plastic film, but most did not succeed in creating barrier package in a reliable manner. Packable BV, however, succeeded and is performing pilot tests with launching customers. The first aim is to prolong the shelf life of food products (deli products and bakery products) that are currently packed in card-board boxes under air and suffer from a short shelf life.

More market introductions are related to packages of which the environmental impacts of production and end-of-life handling are reduced. These innovations come in many different forms and several trends are discerned:

Material reduction

Most packages from beverage cans, candy wraps to pallet wrap have become lighter during the last decades. These weight reductions are significant; in the 10-30% range and are primarily driven by a reduction of operational cost, but simultaneously represent a reduction in environmental impact per packaging unit. All major food producers in Europe have their own success stories in relation to packaging material reduction. Companies like Unilever sell for example their dried food products in paper-thin aluminium paper laminate structures, rendering a long shelf life and minimum packaging material use.

Bio-based material input

More than twenty years of research and development towards bio-based plastic packaging has resulted in many different types of packaging, of which the most common are: PLA trays and cups, PLA film, starch-blend films, bio-based PE and bio-based PEF (polyethylene furanoate, a bio-based PET analogue). In the coming years we continue to observe many different developments in this field, which will become most apparent in the markets for organic foods and in the beverage market. No large market penetration is expected for these materials, since the prices for these materials are expected to remain relatively high as compared to fossil-based materials and the technical performance is not much better. The major benefit is currently marketing and hence, these materials will be predominantly applied in the sectors which are vulnerable to ecological sceptics.

Packages made from recycled materials

The EU directive 282/2008 regulates the approval process for producing recycled plastics for food packaging. Hitherto only processes for post-consumer plastics have been approved that are based on PET. Due to the chemical nature of PE and PP it is unlikely that a recycling process will be developed for these more common types of plastic packaging waste that will receive an approval and are economic. Hence, for the coming years the focus of recycled plastic packaging will be on PET only and especially on soda bottles and meat trays.

Refrigeration climate control

Several studies have clearly shown that temperature control and a well-designed cold chain is by far the most important strategy to keep quality. Cooling demands high energy uses, and hence is a less sustainable technology. This energy use, however, should be put into perspective by the fact that without the application of refrigeration the product losses would be enormous. Since cooling cannot be avoided, the challenge in this area to develop and implement energy-saving refrigeration systems for both storage and transportation. The need for further development is clear for all stakeholders and focus on this area is expected in the future (Green Blue, 2006; Thoden van Velzen, and Linnemann, 2008). Energy-saving refrigeration systems will be further addressed later in this report.

Relative humidity and ethylene

Control over relative humidity and the amount of ethylene in the chain are also important strategies to preserve the quality of fruits and vegetables, thereby avoiding food losses. Relative humidity issues have been reasonably approached with the application of the right packaging technology and a suitable climate control.

Ethylene is a plant hormone that plays an important role in the ripening mechanism of several fruits and vegetables. The ripening process contributes to a faster decay of the quality and thus exposure to ethylene should be controlled. This is a commercially exploited technology that has been in place for some years. Ethylene-control technology can either by based on blocking the production of the hormone or by removing the produced ethylene with scavengers. Knowledge on the optimal application procedure, however, is still lacking. Sometimes products treated with ethylene blockers will not ripe at all and/or the quality of the individual fruits will be very different (high batch heterogeneity). Unripe produce are not acceptable for consumption and thereby contribute to the generation of food losses in the chain. It needs to be realised that ethylene treatments are also temperature, variety and harvesting moment dependent (Montsma, 2012). In summary further efforts and knowledge is required to optimise the use of ethylene-controlling strategies in the chain.

Likewise the control of the relative humidity – to a great extend determined by packaging properties and climate control – still requires additional efforts to overcome the current drawbacks. Particularly in distribution chains with poor temperature control, the presently available packing materials do not perform enough. The water vapour transmission rate of packaging films is temperature dependent but this dependency is not enough to coop with large moisture production in the case of product transpiration or in the case of condensation. A too high water vapour transmission rate is also not required since it leads to drying out of the product, resulting in loss of quality. Packaging material developments are still necessary to improve the current possibilities.

Controlled and Modified Atmosphere

Fruits and vegetables are a challenging group of food products since they continue to respire after harvesting resulting in a complex quality development. Continued respiration gives off carbon dioxide, moisture, and heat, while at the same time oxygen is consumed. Further activities include changes in carbohydrates, pectins and organic acids. Often these are related to the ripening or ageing (post-harvest senescence) of the products.

Reducing the amount of oxygen and increasing the amount of carbon dioxide in the environment of the product (in a container, storage room or package) will slow down these mechanisms. This technology – controlled atmosphere storage (CA) and modified atmosphere packaging (MAP) – has been successfully applied for some time. The CA technology is widely applied within Europe to prolong the shelf life of commodities as apples, pears and several types of soft fruits. The application of CA technology for apples enables year-round sales.

The current MAP technology is suitable for already a large range of fruits and vegetables. Maximum shelf life of 2 – 3 weeks have been achieved under retail conditions. However, the MAP technology is based on a delicate balance in gas exchange between the product's respiration and the packaging's permeability and changes in both parameters can cause the shelf life to be less long than what is optimally possible. Hence, most products in E-MAP will have a shelf life of maximally 10 days.

Additionally, the current MAP technology serves fruit and vegetable products the best that benefit from a headspace with reduced oxygen levels and raised carbon dioxide levels. Some commodities, however, require reduced oxygen and carbon dioxide levels to obtain an extended shelf life. This is, however, not possible with the current industrial standard of micro-perforated OPP film-based packages. It is expected that the application of this technology will grow in the future as the costs of these systems are expected to decrease . In order to be feasible and sustainable this technology needs to be applied together with a good temperature control in the chain. Moreover the change in the atmosphere gas composition should be implemented soon after harvest and not be interrupted during the distribution. This requires an integral chain approach which is in real life still a challenge to be realized.

Phytosanitary and anti-mould treatments

Another important source of food losses are plant infections, as for instance the growth of moulds. There are both chemical and non-chemical strategies possible: warm water treatment, UV radiation, use of Fludioxonil, etc. Food safety and costs are important issues in the implementation of these strategies. Hence the use of these technologies is very limited. However as a supporting measure, the development of effective, safe and cheap possibilities could have added value in the production and distribution chain and further research on this area is expected.

Not only for fruits and vegetables but for all food products, an extension of shelf life due to the application of packaging technology, or temperature control or a preservation technology, will contribute to reduce food waste. According to the opinion of an experienced retailer, one day extra shelf life can lead to 15% less shrinkage on the retailer level.

Policy options

Food waste in European countries can be reduced by raising awareness among food industries, retailers and consumers. Food waste at consumer level in Europe is estimate at 95-115 kg/year the per capita. In addition, an integral chain approach, directed to an efficient coordination of the different actors in the chain is necessary to decrease the level of food wasted in Europe. Current and future technology can facilitate this chain cooperation. Although the European policy should be focussed on avoiding food waste, sustainable and beneficial solutions for safe food that is presently wasted ought to be found and stimulated.

5.3 Non-thermal pasteurization and sterilization techniques to enhance shelf life and quality

State of the art

Traditional preservation technologies like heat pasteurization or sterilization, enhance food safety and shelf life, but often negatively affect product quality attributes such as taste, color, texture and nutrients. Mild processing technologies can therefore be an interesting option for both chilled and ambient stable products, thereby meeting consumers' growing demand for fresh-like and nutritious foods that are safe and shelf-stable. Moreover, they are also interesting for improving the sustainability of food processing. The main mild processing technologies are:

High pressure processing: Pressures up to 700 MPa can be applied for food preservation and preparation. High pressure is applied in industry for pasteurization of packed food products at room temperature and is also potentially interesting for sterilization.

Pulsed electric field processing: Preservation of bulk products by electrical impulses can be applied homogeneously through the product for pasteurization of liquid foods at reduced temperatures. The first implementations of these technology are currently being made.

Cold plasma treatment: Cold plasma gas is suitable for decontamination of surfaces without affecting the quality of the product or packaging. Produced by electric discharges in inert gases that carry exited molecules, cold plasma gas offers the potential to inactivate micro-organisms on surfaces at temperatures below 40 °C. For disinfection in food industry, this technology is not used at the moment.

Advanced heating technologies: microwave, radio frequency heating and ohmic heating are examples of technologies that use electromagnetic energy for rapid and homogeneous heating of products. Contrary to some of the technologies above, these are not non-thermal technologies, however, due to the much faster process improved quality is achieved compared to conventional processing. Several industrial lines are currently being used in food industry.

Table 3 gives an overview of these technologies and the current status of these technologies. High pressure, microwave heating, ohmic heating and radio frequency heating are currently being used in food industry, mainly for pasteurization of food products. These technologies enhance the shelf life compared to untreated products with improved quality compared to conventional treated products.

Table 3: *Overview of novel processing technologies*

	HP pasteurisation	HP sterilisation	PEF	Plasma	Advanced heating
Description	Batch process in which a packaged product is put under high pressure (600 MPa)	Batch process in which pre-heated packaged product is put under high pressure (700 MPa)	Low thermal pasteurisation using short electric pulses to electroporate membranes of bacteria	Surface processing by gas at 40°C to inactivate micro organisms	Homogeneous heating with electric (magnetic) energy
Phase	Commercially in use	Technology proven	First implementations for juice (1500 l/h)	Test facilities available	Commercially in use
Estimated costs (€/kg)	0.10-0.20	0.20-0.50	0.02-0.04	-	0.02-0.05
Shelf life	4-6 weeks cooled	1 year ambient	2-3 weeks Cooled	-	Depending on conditions used
Taste like	Fresh (texture maybe altered)	Freshly cooked	Fresh	Fresh	Freshly cooked

These technologies are interesting for improving the sustainability of food processing via:

Reduced energy and water impact of food processing

As these mild processing technologies can be applied at much lower temperatures compared to conventional processing, less energy is necessary for heating and cooling of the product. High pressure pasteurization is, therefore, more energy efficient compared to heat pasteurization. It is hereby essential to consider the entire life cycle of the product. Davis et al. (2009) showed that high pressure processing uses indeed less energy compared to heat treatment, however, especially transport and choice of packaging are important point to be considered.

Reduced energy impact in product storage

Mild processing technologies can be used for sterilization of food products with improved quality compared to retort processing. Potentially it is possible to obtain ready-to-eat meals with the quality of fresh chilled meals but the shelf life and storage conditions of retorted meals. In this way, chilled or frozen storage of products can be changed to ambient storage, with consequently less energy use. As Sonesson et al. (2010) pointed out, this might reduce the energy impact of storage. However, when application of the new method is used for longer storage times in the retail, this advantage can be smaller when considering the entire life cycle of a product.

Reduction of food waste through extending the shelf life: see success story.

Efficient use of packaging material and avoidance of re-packing.

High pressure, microwave and radio frequency processing are mild processing technologies where products are packed in the consumer package before processing. Therefore, re-packing is not necessary. This avoids the risk on recontamination of the product and significantly reduces the volume of packaging material. Davis et al. (2009) showed that large differences in environmental impact between products are caused by the type of packaging and the composition of the packaging materials. Plastic pouches as used for high pressure processing are environmentally preferable and also lightweight and therefore reducing the impact of transport on the sustainability of the product.

Success story: Enhanced shelf life resulting in reduction of food waste

Improving the shelf life of fruit juices by pulsed electric field treatment without compromising on fresh quality is an example of a successful application of mild processing. A Dutch fruit juice company using this technology explains that this technology can change the shelf life from 8-9 days to 3 weeks resulting in less product losses in the entire production chain. Especially in retail, this substantially reduced the number of products that has to be thrown away (Irving, 2012).

Success story: pulsed power cooking

Following the development of pulsed electric field treatment for cold pasteurization of juices, it was recently discovered that pulsed electric fields can also be used as a mild cooking method (Nutri-Pulse, IXL). Nutri-Pulse cooks by applying pulsed electric fields of 1000 to 4000 volts per centimeter, which has two effects on the food product: cell disruption and (ohmic) heating of the food product. As a consequence, the cooking occurs rapidly and nutrients are better preserved, while the formation of unhealthy compounds is suppressed. The process itself can be easily controlled and as such, the Nutri-Pulse can contribute to the reduction of water and energy use, as well as avoiding food waste.

5.4 Nano- and microtechnology

Nano/microtechnology is considered a key future technology in pharmaceuticals, food and nutrition, enabling the development of targeted production and delivery systems (e.g., Weiss et al., 2006), as well as advanced food processing technologies. Examples of potential further advancements in the food industry using nano- and microtechnology are:

1. Sensors for detection of pathogens, toxins, chemicals or other contaminants enabling advanced process control and quality monitoring.
2. Advanced food processing tools and equipment for mixing & homogenisation, separation, fractionation and structure forming. Examples will follow below.
3. Encapsulation/emulsification and delivery systems that carry, protect, and deliver functional food ingredients to their specific site of action in the food matrix.
4. The use of nano- and micromaterials in food packaging, e.g., microclay to enhance barrier properties or nanosilver particles to inhibit the growth of micro-organisms.

This chapter will focus on developments related to option 2, advanced food processing tools.

Microfluidic techniques for food applications

The mechanisms for formation of structure in many foods take place at micrometer scale and mostly at very short time scales. Standard tools don't allow for observations at these scales, and this is where microtechnology has large added value when combined with high speed imaging. Besides, based on the findings that were generated, new process technologies are being developed that are intrinsically more energy efficient, and make better use of available raw materials. Some of these sustainable processes are already applied in practice. Two nice examples are emulsification and fractionation that are both discussed below. Furthermore, there are emerging applications in the field of analysis, and these are also described. Besides this, microstructured systems can be used very efficiently in packaging (use of microparticles to increase the diffusion length of components) and also in sensors that can indicate e.g. food spoilage early on in the process, as described in other sections of this report.

Emulsions and related products

An emulsion is a mixture of oil and water. Energy needs to be supplied as well as components that stabilize the formed interfaces, so called emulsifiers. When looking at the energy needed to make the interfaces, it becomes clear that the supplied energy in classic process technology is very high; typically only 5% of the supplied energy is not used for the physical/chemical structure, the 95% is either dissipated as heat, or lost because the interfaces are not stabilized fast enough.

At the Technical University of Karlsruhe in Germany an illustrative graph was made that compares energy uses by different emulsification technologies. It shows big differences between traditional techniques such as high pressure homogenizers, and colloid mills with orders of magnitude higher energy usage as compared to relatively new techniques such as membrane emulsification.

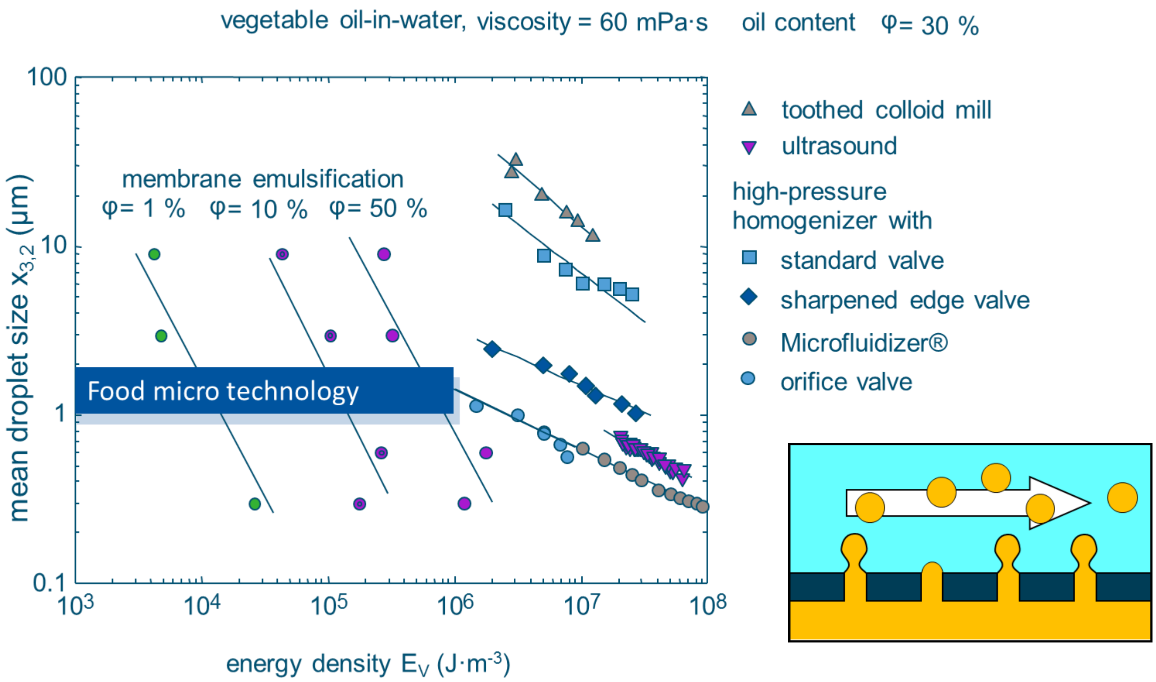

Figure 14: *Comparison energy efficiencies of various emulsification technologies. The graph is adapted from: Schroeder, 1999, PhD thesis, TU Karlsruhe. Right bottom insert: principle of cross-flow membrane emulsification; the to-be-dispersed phase is pushed through the membrane and the droplets are sheared of by the cross-flowing continuous phase.*

The differences are mainly related to the process of droplet formation. Classic emulsification techniques start with a mixture of all emulsion ingredients that are subsequently pushed through a narrow gap, which results in the formation of droplets. In the process of membrane emulsification, droplets are formed one by one. The to-be-dispersed phase is pushed through a membrane (a sieve with very small pores) and the droplets formed on top of the membrane are sheared off by the cross-flowing continuous phase. In membrane emulsification the required energy also depends on the volume density of the droplets (indicated in the graph, going from 1 to 50% droplets).

For membrane emulsification various scaling relations have been suggested. In order to discriminate between all the supposedly relevant parameters, microfluidic channels are ideal tools that allow observation at relevant scales, both in regard of time and size. Based on these insights new emulsification technology has been developed, for example within the company Nanomi (www.nanomi.com), that specializes in medical applications, but the principles that are used can also be applied to food.

Fouling of microstructured systems is still a challenge. New microstructured systems are being developed that don't suffer from fouling as was the case in membrane emulsification, e.g. glass beads can be heaped upon a carrier sieve and act as an in-situ membrane that easily can be cleaned (Nazir et al., 2013). This latter application is still in development, but shows great potential.

These technologies can be applied for manufacturing of a broad set products, such as capsules, foams and particles, and in all cases the process will be more energy efficient compared to the current processes.

Ingredient fractionation and filtration

Membrane filtration is an accepted technology to separate milk components, although not for fat separation which is known to give many issues. Basically the fat droplets are carried toward the membrane that retains them, and because of that forms a thick layer that hinders/prevents separation. Also here observations on micrometre scale, have led to new insights for novel process technology, and successful separation.

Recently it was found that typical flow patterns in channels/pipes can be used for fractionation/separation. In a closed channel, the position of fluorescent particles of different sizes was monitored, and it was found that larger particles predominantly move to the centre, while the small particles move towards the outer regions of the channel. In the process of membrane filtration this phenomenon can be used to avoid accumulation of particles on the filter. The expected energy reduction compared to regular filtration is around 50%; this saving is due to the relatively low cross-flow velocities that need to be applied, which can be considerably lower compared to regular filtration (van Dinther et al., 2013).

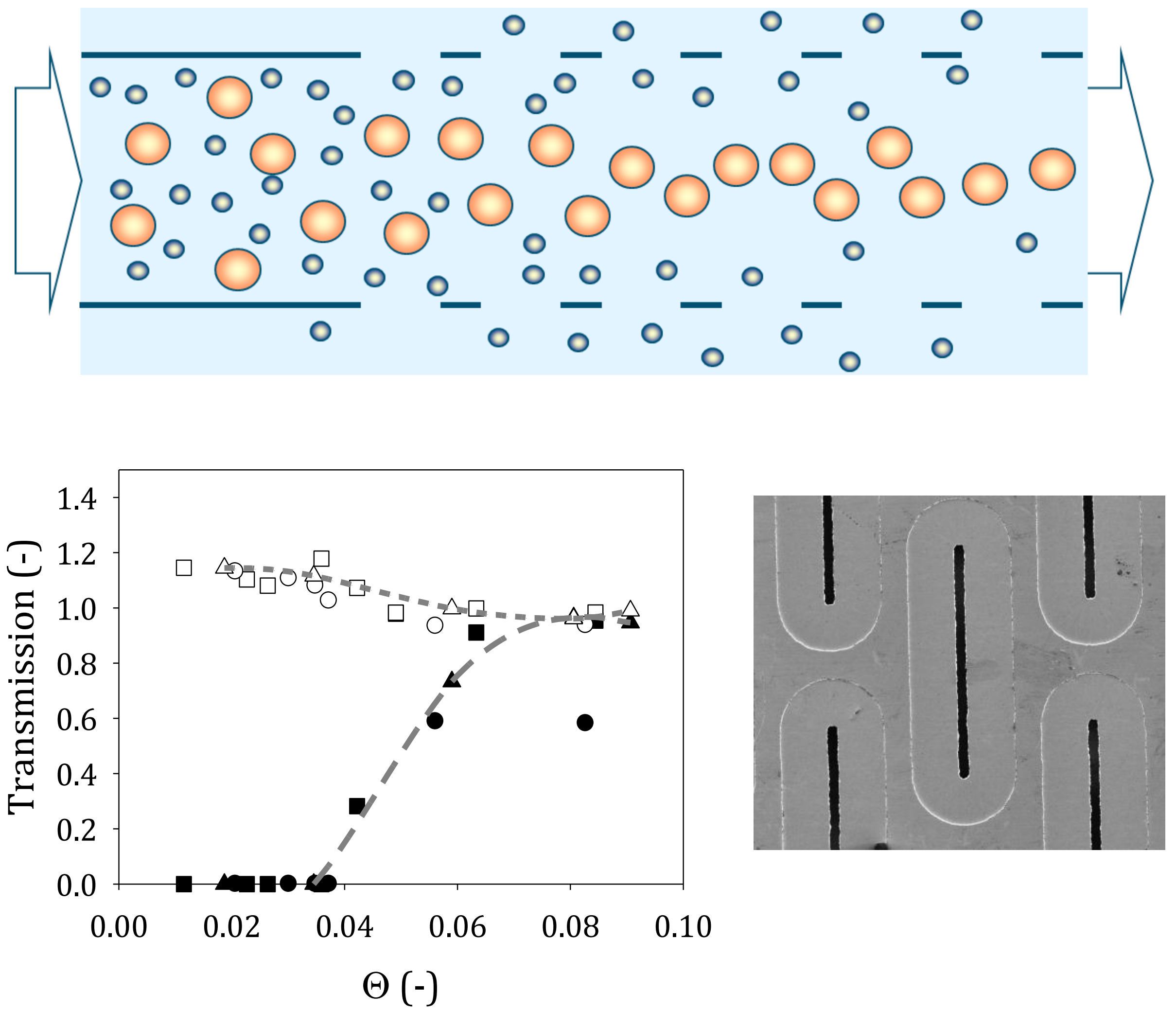

***Figure 15**: Top: Schematic representation of particle migration in closed channels, with the larger particle moving to the central part and the small ones expelled to the outer regions. Bottom: Transmission of small (open symbols) and large particles (closed symbols) as function of the dimensionless time (Θ), corresponding to the ratio of trans-membrane velocity, and the cross-membrane velocity. The insert shows one of the Stork Veco membranes with uniform pores that were used in the filtrations experiments (van Dinther et al., 2013).*

Besides for fractionation, microstructured sieves, in this case so called microsieves (see **figure 16**; van Rijn, 2004) have been used to reduce the number of bacteria in liquids. When compared to the other entries in **Table 4**, it is clear that the microbial count that can be achieved is much higher for these well-defined sieves as compared to regular membranes, that all suffer from pore size distributions, and because of that higher transmission of bacteria. Besides, the flow resistance of the microsieve is so low that the fluxes that can be achieved are much higher (decades) than for classic membranes.

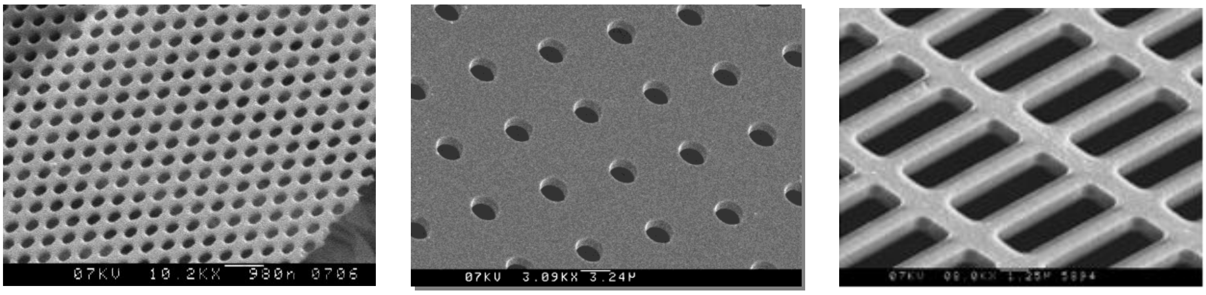

Figure 16*. Various microsieve designs; left image contains microorganisms that were filtered from a liquid medium (images courtesy of Aquamarijn Microfiltration B.V.)*

Table 4*. Comparison of cold sterilization results from various sources (table from Peinemann et al, 2010)*

Membrane type and flux	*Process conditions cross flow / pressure, UTP, back pulsing*	*Log reduction*
Ceramic 1.4 µm; 1.4•10^{-4} m/s	50 kPa, 7.2 m/s UTP	above 3.5
Reversed asymmetric 0.87 µm; 1.4•10^{-4} m/s	0.5-1 m/s; back pulsing 0.2-1 s^{-1}	between 4 and 5
Microsieve 0.5 µm	dead-end filtration of spiked SMUF	6.6
Bactocatch: ceramic membranes	6 to 8 m/s	

Application of microtechnology to analyze phenomena relevant to food

Since microfluidics allow observation at very small scale and at very short time scales, dynamic interfacial phenomena can also be investigated, which would otherwise not be possible, at least not at relevant time scales. A nice example of this is the determination of the dynamic interfacial tension at microsecond level (Steegmans et al., 2009), and droplet coalescence also observed at the same time scales (Krebs et al., 2012). The tools that were developed are expected to be very useful, and will become accepted technology within the food industry in the near future.

General background on microfluidics including references to food:

Encyclopedia of Microfluidics and Nanofluidics (second edition to be published 2013), edited by Dongqing Li, Springer Verlag, Germany.

5.5 Innovative processes for utilization of rest and by-products

In food processing relatively large streams of by-products are generated (by-products: not being the chain's primary product, mostly valorised other than food applications). Many of these can be utilised at higher value than in the current situation.

Valorisation of by-products

Within the food processing sector, substantial parts of the raw materials that enter the factory are ultimately traded as by-products (**Table 5**). Direct utilising of these streams for food would require alternative (and generally technically more complex) processing than the chains' primary product. Hence, a large part of these side streams is only poorly valorised: for animal feed, technical applications and fertiliser production (through composting). Higher value applications (**Figure 17**), however, can increase total value generation of the food processing chain.

Table 5: *Food processing side streams (mass-% of crop) (source: ec.europa.eu/Eurostat)*

Type of food	*Production process*	*% of input*
Fish	canning	30-65%
	filleting + smoking	50-75%
Meat	beef slaughtering	40-52%
	pig slaughtering	30-40%
	poultry slaughtering	30-40%
Dairy products	milk, butter, cream	0%
	yoghurt production	2-6%
	cheese production	85-90%
Fruits & vegetables	juice production	30-50%
	vegetable oil	40-70%
Commodities	corn starch	40-45%
	potato starch	80%
	wheat starch	50%
	beet sugar production	86%

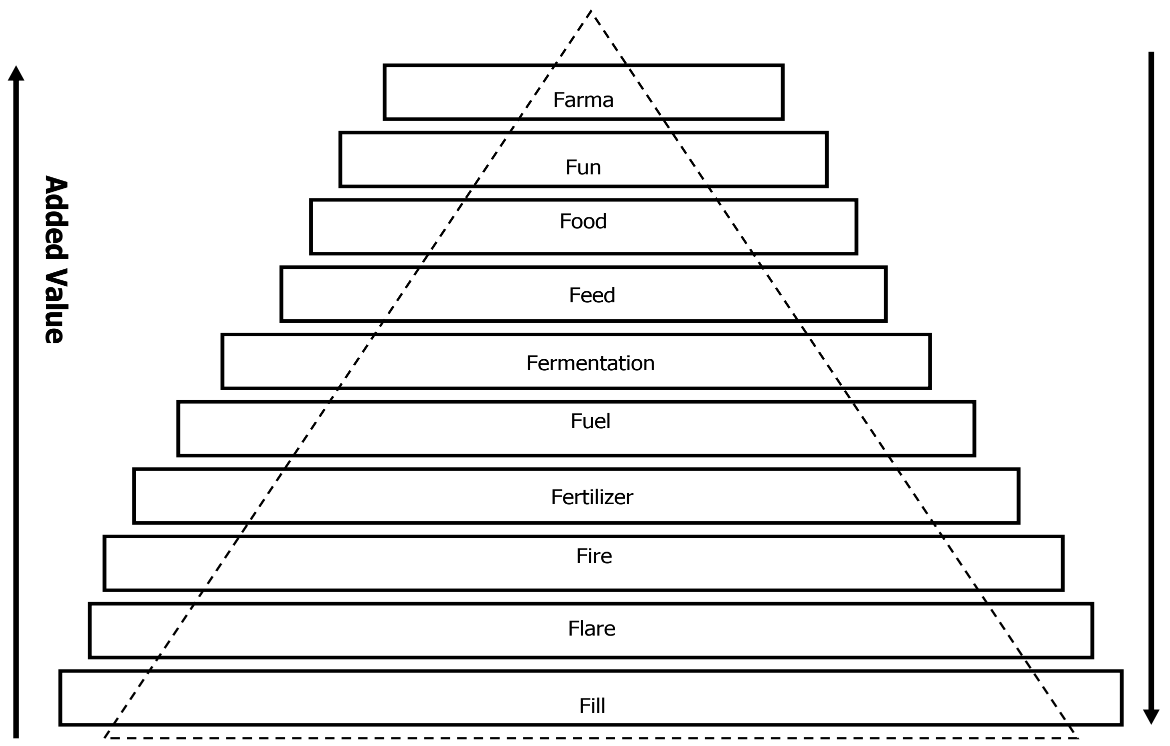

***Figure 17**. Valorisation pyramid: from low to high valorisation opportunities*

Converting by-products to food products or ingredients demands for technological and non-technological developments. specifically
(1) generating valuable materials from the by-products, and
(2) developing a market-oriented (or rather demand driven) market system:

- development of separation/extraction technologies (pre-treatment, fractionation, isolation technologies, etc.);
- conversion technologies for producing valuable molecules (fermentations, enzymes, etc.);
- stabilisation processes to prevent rapid quality losses of the by-products (which are generally susceptible to microbial decay, oxidation and other processes);
- drying processes for structure formation and stabilisation (specifically relevant because of high water contents of by-products);
- development of new quality standards for intermediate products derived from by-products (existing quality standards match well with traditional feedstocks, but do not fit well for by-products derived ingredients); this may serve food, feed and non-food markets;
- demonstrating practical potential of by-products based ingredients and products;
- demonstrate how traditional ingredients can be replaced by by-products-derived ingredients;
- setting up databases for by-products (which would reduce threshold for end-users to integrate by-product based ingredients in their products);
- development of sustainability assessment protocols and essential databases on composition, extraction processes, yields and quality of components that can be generated per by-product.

In their efforts to maximise (economic) production value, especially large-scale industries last decades have made major steps in increasing valorisation of by-products. Especially animal by-products (e.g. from dairy and meat processing) made a transition from relatively elementary feed applications (e.g.

meat meal, whey) to high-value food ingredients (specialty proteins, fermented products, pharmaceuticals, etc.). These developments were successful because of specific strengths and opportunities:

- large scale size of dairy and meat processing factories
- necessity of processing because of legislation/costs of waste processing
- relatively high economic value of proteins

With increasing food prices (including other components than proteins) and with on-going consolidation/scaling up of food various food processing industries, within 5 years this practice is expected to be followed in other sectors as well (think of fisheries by-products, fruit and vegetable by-products, etc).

Waste stream valorization: Alternative sourcing of gelatin

Confidence in traditional sources of gelatin (amongst others bovine hides and bones) was seriously damaged by BSE breakout. Increase of gelatin prices has been a trailblazer for alternative production processes. A successful example is the Dutch company Ten Kate Vetten; their production process (primarily aiming at extracting fats from pig slaughter by-products) was innovated so that high-quality gelatin can be isolated from their processing water. The (mild) fat extraction process furthermore enabled valorization of other protein products in pet feed.

Key success factor: development of a patented innovative process that enabled valorisation of high quality gelatin.

External factor: market-demand for gelatin from a safe source due to BSE breakout.

Waste stream valorization:
production of potato protein from potato processing waste water

Recently the Dutch potato starch processing company AVEBE started recovering proteins from what was previously considered waste water (in a new company called Solanic). Based on the average annual throughput (2.5 million tons potatoes, grown on 55,000 hectares, delivering 700,000 tons starch) the AVEBE/Solanic production potential is estimated at 25 to 30,000 tons high quality potato proteins (FoodChain, 2009). This new, by-product based, source can replace 15,000 protein crop cultivation (average protein productivity is about 2 tons/hectares (Vereijken and Linnemann, 2006).

Waste stream valorization: production of vegetable juices from cutting residues

Based on a novel separation process (Nell and Kosters, 2010), a high-quality tomato juice can be produced out of low-quality tomatoes. This reduces the market need for fresh tomato production.

For the middle-term, new solutions are expected to come from RTD. Typically, valuable molecules like polyphenols, currently generated from green tea leaves, can also be extracted from by-products like olive and citrus by-products. Fava et al. (2013) (Namaste-EU project) even show co-generation of multiple other food-valuable ingredients (fibres, pectins) from one by-product stream. Economic feasibility, however, does not only depend on the food ingredients extraction techniques, but also on market development for food ingredients and consumer products. Food ingredients obtained through innovative processing or from alternative sources mostly differ from traditional food ingredients. Either intensive – cost adding – processing is required (for instance to remove a specific flavour), or alternative applications have to be developed for alternatively sourced ingredients.

It was concluded from the Namaste-EU research that after a product valorisation research (resulting in suggestions for product development per by-product) a product valorisation initiative should be started. This should focus on product development where specific characteristics of the by-product based ingredients are used for additional value (or cost savings) in existing or new food products.

Successful development of high-value products from the by-products reduces dependency of traditional sources for the ingredients are reduced (including agricultural land use).

5.6 Alternative processes requiring less energy or water

The most energy-consuming processes in the food industry are: process heating (evaporation, pasteurisation, boiling, drying), process cooling/refrigeration, processing machinery (e.g., fans, pumps, ventilation, compressed air) and transport (Kaminski and Leduc, 2010). Water use is mostly related to washing, dilution and separation processes.

For drying often mild (relatively energy inefficient) processes are chosen for reasons of product quality, for instance dairy. Main purposes of drying are stabilisation, transport efficiency and product homogeneity. Technological developments that may reduce energy use for drying:

- using residual heat (spatial clustering with other industry that has surplus waste heat)
- process intensification: combining/integrating energy intensive processes can be more efficient. Challenges lie in process control and preventing undesirable quality defects.
- reducing need of drying processes through alternative chain layout and processing.

Refrigerated storage is highly relevant for sustainable food supply since it contributes to minimization of food losses (see previous sections). Sufficiently long shelf life helps reducing product losses and is necessary to optimise logistics/transport efficiency. Increasing shelf life (resulting in longer storage, thus increased refrigeration energy usage) is mostly considered sustainable development since it contributes to reducing losses (taking into account the embedded energy in the product from production to consumption). However, because of the high impact on energy use and greenhouse gas emissions, technological developments are highly relevant, such as:

- more sustainable refrigeration technology (new refrigerants and equipment with higher energetic efficiency and lower greenhouse emissions);
- more advanced control systems that enable large energy savings, even with existing hardware (like the QUEST example presented before);
- direct application of fresh streams (when the process that supplies the ingredients and the food production process are geographically clustered, ingredients can be supplied directly; in this context, drying for reasons of stabilisation and transport efficiency is not needed).
- alternative options to cooling: mild technologies that maintain fresh quality of the product but enable storage at ambient temperature (as presented in a previous section).

Dry fractionation for dry materials

Through dry fractionation for dry materials (replacing wet fractionation) addition and need of removing water are prevented (Schutyser and Van der Goot, 2011). Dry fractionation will result in less purified components, but in many food applications high purity of the ingredients is not fundamentally necessary (however, in the current system, based on commodity ingredients, often preferred by the food industries).

The approach of adding water, drying and re-wetting results in high water and energy use (about ¾ of energy use in food processing is related to drying). In addition, biomass valorisation efficiency is not optimal due to the by-products generated in the refinery processes, which are not used efficiently. The question now is whether complete purification of raw materials is really necessary, or that new food products can benefit from partly fractionated materials.

Redesigning the chain with milder separation processes will have several advantages:

- fractionation can be focussed on production of functional fractions (rather than the pure components), preserving the natural structure of the plant materials, with improved nutritional quality,
- functional fractions may still contain combinations of proteins, starches, fibres, etc. as a basis for high-quality foods but at lower costs compared to the situation where individual refined ingredients are recombined,
- applying mild separation processes (e.g. dry fractionation) largely reduces the energy consumption of food processing,
- applying mild separation processes can contribute to improved ingredient quality (e.g. protein functionality),
- declaration of "plant extracts" goes without the need of E-numbers.

Mild and application-oriented fractionation of plant materials is oriented on the production of functional fractions rather than pure components. Functional fractions can be obtained through a mild fractionation process that aims as preserving the natural structure of the plant material as much as possible. The functional fractions can then be dried for storage and transportation purposes.

However, it becomes even more interesting to apply these functional fractions into food products without the prior drying step. This concept requires logistic innovations in addition to process innovations. A direct connection of the final application and the separation process might be a route towards more efficient use of raw materials, with the ultimate aim of total use. In the proposed concept water that has not been added does not have to be removed. Research (e.g. Schutyser and Van der Goot, 2011) on wheat dough and particle dispersions showed that a new separation principle (defined as "shear-induced separation", based on specific properties of the concentrated system) enables producing existing types of food products at much lower water and energy use.

5.7 New product development: plant-based meat alternatives

The increase in world population as well as standards of living in particularly developing countries are expected to result in a high demand for animal-derived proteins by 2050 (Boland et al., 2013). For instance, the FAO expects that in the period 2000-2050 the demand for meat will rise from 235 to 463 million tonnes (FAO, 2006). Because the environmental impact of animal-derived proteins is very high (Steinfeld et al., 2006), it will be hard to meet this increasing demand in a sustainable way. One way of doing so, is by developing plant-based meat alternatives. Such alternatives based on pea protein need for instance 3-4 times less land and 30-40 less fresh water than pig meat (Aiking et al., 2006). In the last decade, much attention has been given to improve the existing processing technologies to produce such alternatives in order to better meet consumer demands with respect to e.g. texture and juiciness.

Examples of such improved alternatives include the American products Beyond Meat and Match and the Dutch product Plenti (Zorpette, 2013). Also new technologies to produce meat alternatives are being explored. At Wageningen University a shear induced structuring technology is being developed that is aimed at better mimicking the fibrous nature of meat (Manski et al., 2007).

Another way of meeting the increase in protein demand is to develop new, sustainable sources of proteins. Such sources can be used to meet the increasing need of protein for feed stocks but also for direct human consumption. An example of such a source are insects (Van Huis, 2013). The environmental impact of insect protein is much lower; the feed-to-meat conversion of cricket is lower than that of cattle, pig and poultry chicken protein by respectively a factor 12, 4 and 2 (Van Huis, 2013). Insects can be eaten directly or in a more hidden way, for example in the form of mixed products like burgers and sausages containing insect and meat protein. It is expected that these mixed products are more acceptable to Western consumers than direct consumption of insects.

Other very interesting potential sources for sustainable protein supply are aquatic ones such as duckweed and algae (Hasan and Chakbari, 2009). These sources can be very rich in protein, for instance micro-alga can have a protein content as high as 50 %, depending amongst others on species and growing conditions (Becker, 2007); soy beans, a well know protein source, have a protein content of about 40%. Aquatic sources have as a premium that their land use is low. The same holds for agricultural produce such as leaves from vegetables, that is not being used except for fertilisation of the land. The exploitation of such new protein sources will require the development of new, mild processing technologies for disentanglement and extraction of the protein. The implementation of the biorefinery concept (i.e., maximum valorisation of sub-fractions into food and non-food applications) in this exploitation will strongly support the commercialization of these sources. The commercialisation is however hampered by present regulation and legislation concerning the use of novel protein sources.

Third generation meat alternatives: Plenti and Beyond Meat

(Source: IEE Spectrum, 2013 http://spectrum.ieee.org/energy/environment/the-better-meat-substitute)

Consumer acceptance is still a limiting factor for plant-based meat alternatives to make a real contribution to the transition to a more sustainable protein supply. Recent advances in process technology, however, allow for the production of so-called third generation meat replacers which really mimic the taste and feel of (animal-derived) meat.

Looking back into the history of meat replacing products, three generations can be discerned. The first is a “tofu generation,” based on the curd of the soya bean. These products don’t taste much like meat but have reasonably high levels of protein. The key ingredient for the second generation meat replacing products is texturized vegetable protein. It is produced by extrusion of a low-moisture precursor and then dried into flakes or granules. These are rehydrated and incorporated into the final, ready-to-use products (like sausages, meatballs, hamburger patties) which are sold frozen or chilled.

The third generation, which includes products like Plenti and Beyond Meat, are a special category known in the food industry as high-moisture meat analogues, or HMMAs. They are designed to have the taste and mouth feel of genuine muscle meats— chunks of chicken breast, a piece of smoked eel, or shredded pork. The new analogues are meat like enough to be sold in much the same way as meat—refrigerated and intended for use in soups, sandwiches, chilies, burritos, and other dishes where sauces and seasonings will help enhance the meaty illusion.

The third generation products include Beyond Meat and Match in the United States and Plenti in the Netherlands. All are produced with technology or advice from university laboratories: Beyond Meat from the University of Missouri; Plenti from Wageningen University & Research Centre in the Netherlands; and Match Meat from the University of Illinois at Urbana-Champaign.

5.8 Systems for knowledge transfer and information

As explained in **Chapter 4**, its weak innovation power is one of the main reasons why the European food and drink industry is losing ground in the global markets. The excellence scientific research that is conducted in the field of food and nutrition is insufficiently translated into industrial implementations of either new technologies or new food products (*the European innovation paradox*). This European Innovation Paradox is at least partly due to a lack of knowledge transfer, especially between science and industry, but also within the industry and between regions or cross-border. For the food processing sector it is evident that the process of research and development (R&D), implementation and application of high-tech food processing technologies requires tailor-made multidisciplinary solutions. Capacity building at SME's will provide a major gain, given their share in the European food processing sector. Collaboration of SMEs with academia, knowledge institutes and other companies is usually not part of their daily business. Besides the lack of resources (both financially and personnel) speaking the right language (by SMEs as well as scientists) is also a major bottleneck. For most of the medium-sized and large food processing companies collaboration with business parties usually has a higher priority. A higher qualified staff in combination with a larger R&D budget makes is easier to establish links with academia and knowledge institutions.

To stimulate knowledge transfer within the food industry a spectrum of tools and instruments is available. To name a few:

- Financial incentives (subsidies) for collaborations between industry and academia/knowledge institutions, e.g. in the form of Public Private Partnerships on a European, national or regional level. Examples are:
    - European: Bridge / PPP Bioeconomy (www.bridge2020.eu)
    - National: Dutch Topsector Policy (www.topsectoren.nl)
    - Regional: Food Future programme to stimulate cross-border collaboration between The Netherlands and Germany (www.food-future.eu)
- Formation of new networks, e.g. on the basis of :
    - Geographical region: e.g., Öresund region in Denmark, Food Valley in Wageningen, Agropolis in France
    - Shared interest: EHEDG (Hygienic design, www.ehedg.org), EFFOST (European Federation for Food Science and Technology, www.effost.org), Waste streams (Industrial Symbiosis Programme (www.nispnetwork.com)
- Sharing best practices within the food processing industry:
    - Stimulation of operational excellence by publishing manuals on potential water and energy savings in factories or benchmark numbers for the sector. Examples of eco-efficiency manuals are given in **Chapter 4.3**
    - Stimulation of the implementation of mild preservation technologies in food processing through short feasibility studies and workshops (see, e.g., www.novelq.org)
    - The Food Technology Innovation Portal (www.hightecheurope.eu) – see separate box
- Other instruments, e.g., staff-exchange between industry and academia, awards for implementation of new technologies and knowledge auctions (see www.hightecheurope.eu)

Although many systems and instruments have been developed and tested in practice, a widely applicable *best practice* for knowledge transfer in the food processing industry has not been identified yet. The highly fragmented character of this industrial sector may be the most plausible explanation for this. In an evaluation of the success factors for technology platforms (Raldow, 2006) the following key factors were identified:

- Industry-driven, competitiveness-focused process
- Wide stakeholder involvement
- Bottom-up approach
- Private / public collaboration
- Coherence in the RTD work conducted at different levels across Europe
- Education and training programme
- Communication / dissemination actions

Besides the above-mentioned instruments, regulatory bodies can also play an active role in impeding or promoting innovation in an industrial sector. This will be discussed in the next chapter.

Knowledge Dissemination: HighTech Europe's Food Technology Innovation Portal (Food TIP)

(source: Lienemann et al., 2010)

One of the goals of the European Network of Excellence HighTech Europe is to explore the facilitation of innovations in different regions of Europe, adapted to the needs of local SMEs. For this purpose an *interactive technology portal* has been developed, which is open to the public since May 2013 under the name Food Technology Innovation Portal (abbr.: Food TIP, see www.hightecheurope.eu).

The Food Tech Innovation Portal intends to provide a central address with bundled information for people interested in 'open innovation' and networking related to food processing technologies. Through this portal the implementation of new technologies in the food sector could be stimulated, thereby enhancing the competitiveness especially of small and medium-sized companies without R&D departments.

The Food TIP is created in Wikipedia style, allowing a continuous update and extension of entries. Scientists from the project HighTech Europe have written about 150 datasheets, with information on new technological developments in the food processing area. Content quality is guaranteed by a review process organized by the portal developers.

The portal is accessible free of charge. Certain functions, however, are available only after free registration for the Associated Membership Platform of HighTech Europe (*amp@hightecheurope.eu*). Associated members are able to enter their own contact data, technologies, and infrastructure to use the portal as a networking platform and to generate new business contacts. Furthermore, also personal contact data are only available for registered users. Thus, not only new technologies but also suitable partners for new developments and collaborative projects can be found. The content of the portal can be divided into the following categories:

- **Technologies**: Information about technologies from latest research results to machineries already implemented in the market; including: where and how to apply them in industry, limitations and advantages, additional sources of information, institutes or companies with expertise in the respective field, related infrastructures.

- **Profiles**: information about research institutes, companies or associations, completed with personal contact information and expertise.
- **Infrastructures**: information about open accessible infrastructure (machineries, laboratories, services etc.) e.g., for development or pilot studies, including details of the persons to be contacted.
- **Innovation Guide**: information and support for the whole innovation process from pre-feasibility to market launch, including technical, legal, financial, management, and marketing aspects at European level.

The advantages of the Food TIP are:

- Open editable portal: Since the portal is MediaWiki based, any kind of information can be uploaded, changed, commented or revised at any time from any place. A special function will ensure that your profile cannot be changed by a third person.
- Intelligent search: An ontology database has been implemented together with a thesaurus-based full text search application. This allows you to find the information you need at one click.

5.9 Food Safety Regulations

Food safety regulations

Quality control and assurance is an essential part of the entire food production chain. Food chain integrity covers all aspects of the entire food chain, including microbial and chemical food safety, authenticity of origin, fraud and quality. It is expected that this will be expanded in the near future with aspects like sustainability, minimisation of carbon foot print, free of child labour, favours trade with developing countries and animal welfare (Hoorfar et al., 2011).

The food sector is the third most regulated market in the European Union (after automobiles and chemicals (Van der Meulen, 2009)). Food standards are being developed and applied at a national, European and global level (WTO, FAO, WHO, Codex Alimentarius), but also by private parties. Many of these standards are of a technical nature and focus on food safety, food quality, consumer protection and consumer information. The Codex Alimentarius Commission, established by FAO and WHO in 1963 develops harmonised international food standards, guidelines and codes of practice to protect the health of the consumers and ensure fair practices in the food trade.

Regulatory acceptance of novel technologies for sustainable food products is essential for the introduction of these technologies. Traditional food processing methods are accepted because of a long history of safe use. When applying a traditional method, risk management, HACCP and hygiene are important for ensuring a high quality and safe product. Adequate procedures are described by e.g. Lelieveld et al. (2003) and Shapton et al. (1993).

Novel technologies require a science-based demonstration of safety before they can be applied. Understanding the working mechanism of these technologies and their impact on microbial and chemical safety is crucial to ensure safe introduction of these technologies. From a regulatory point, the main concern is whether the process is safe, which means that the risks are assessed and acceptable (Smith, 2007).

Foods that are treated by a technology that does not have a significant history in Europe fall within the scope of the Novel Food Regulation. Article 1 of Regulation 258/97 specifies the scope of the novel food regulation for novel technologies:

This regulation shall apply to the placing on the market within the Community of foods and food ingredients which have not hitherto been used for human consumption to a significant degree within the Community and which fall under the following categories:

(f) foods and ingredients to which has been applied a production process not currently used, where that process gives rise to significant changes in the composition or structure of the foods or food ingredients which affect their nutritional value, metabolism or level of undesirable substances.

When application of a novel processes indeed results in significant changes in the product, this product must be subjected to a risk assessment before the new technology is approved for application. For many novel processes, however, it should be possible to prove that the process does not result in significant changes in the food. This should lead to the conclusion that the new process is as safe as an existing process. Smith (2007) describes that this is probably the case for the application of pulsed electric field processing for pasteurisation of fruit juices.

Based on a study among food producers in Europe, Van der Meulen (2009) describes that for many producers the regulation is not clear, especially in specifying what is a *significant change*. Clarification can help to stimulate the implementation of these novel technologies. Besides food safety regulations in relation to the introduction of novel technologies, these regulations also play an essential role in preventing waste and the re-use of food by-products. For re-use it is essential that the food is not considered as waste, but as a by-product that can be re-used. Food safety is of course crucial for this. Proper monitoring of food safety attributes might enable more re-use than is currently allowed due to safety regulations. A similar situation holds for the re-use of process water, which is an interesting option for reducing the use of water ánd energy in food processing. However, regulatory restrictions are sometimes hindering this as disinfection of process water is not feasible.

Regulations are necessary to guarantee the safety of food products. It is, however, important to monitor if these regulations don't hinder the innovation and application of novel options in food industry for sustainable food processing. The DG for Enterprise and Industry acknowledges this fact, by stating that it wants to promote a standardized, transparent and reliable legal framework that is not overly burdensome for companies[9]. In the pharmaceutical manufacturing sectors regulatory authorities have acknowledged their impeding role on innovations in manufacturing technologies. This has led to the start of the "science-based manufacturing" initiative where companies are allowed more freedom in (changes in) their operations, provided they can sufficiently prove real understanding of their manufacturing processes[10] (see separate box).

Regulatory bodies support the implementation of improvement programs in the pharmaceutical industry

An analysis of the FDA in 2001 revealed the following weakness in the pharmaceutical industry:

- Lack of science behind the product formulations and manufacturing processes
- Low efficiency and high costs related to the production of pharmaceutical products
- Reluctance towards the implementation of new technologies

The overall conclusion was that in terms of *operational excellence* the pharmaceutical manufacturing industry is lagging behind to other industrial sectors, as evidenced by a number of performance indicators.

[9] http://ec.europa.eu/enterprise/sectors/food/eu-market/regulatory-aspects/
[10] See, e.g., http://www.fda.gov/downloads/AboutFDA/CentersOffices/CDER/UCM174306.pdf

Indicator	Farma Norm	Farma Best	World Class
Stock Turn	3 to 5	14	50
Order time in full delivery	60 to 80 %	97.4 %	99.6 %
Right First Time	85 to 95 %	96.0 %	99.4 %
Process Capability (CpK)	1 to 2	3.5	3.2
Overall Equipment Efficiency	30 %	74.0 %	92.0 %
Cycle Time	720 hrs	48 hrs	8 hrs
Safety per 100.000 hrs	0.100	0.050	0.001

(data from: ABB Eutech Process Solutions)

Following this analysis, the FDA launched in 2002 the "Pharmaceutical current GMP's for the 21st Century – a Science and Risk-based approach to product quality regulation". Central within this initiative is an integral quality systems approach, which includes the implementation of modern scientific concepts for risk management and stimulates innovations and continuous improvement. The latter can be realized through implementation of concepts like Lean Manufacturing and Six Sigma, which already have proven their applicability and success in other sectors of the manufacturing industry, like the automotive and semi-conductor industry. The potential costs savings in manufacturing and quality are estimated to be 25-30% if the pharmaceutical industry would be able to reach the so called 6 sigma level (current level: 2-3 sigma).

Through the ICH (International Committee on Harmonization) the FDA initiative got support from the European and Japanese regulatory bodies. From a regulatory point of view, the pharmaceutical companies are allowed more freedom in their operations, provided they can sufficiently prove real understanding of their manufacturing processes. This means that, next to the potential cost savings due to a better operational performance, pharmaceutical companies can also save money on the approval procedure for changes in their manufacturing processes. Despite this promising outlook, the "Pharmaceutical current GMP's for the 21st Century" initiative has not (yet) led to a breakthrough in innovative manufacturing equipment within the pharmaceutical manufacturing area. Given the timeframe which is required for developing a new pharmaceutical product/process (~10 years) the effects of this initiative may become visible in the coming years.

6 EXPECTED IMPACT AND CONCLUSIONS

The previous chapter has presented a selection of technological developments which will lead to a further enhancement of sustainability in the food processing industry. Since sustainability *as such* is not a direct driver for innovation, smart combinations need to be made with other industrial drivers. In this period of economic downturn the most plausible option appears to be cost savings, e.g. in the form of water and energy savings and reduction of product and material inefficiencies.

Food processing industries contribute to eco-sustainable development of the food system through direct savings (reduction of energy and water use) and indirect savings (contribution to reduction of losses and improved valorisation of the biomass resources). Although the direct eco-impact of food processing is rather small compared to e.g. primary production, still substantial savings can be achieved because many innovative processing technologies give major efficiency improvements compared to traditional technologies. Indirect effects are expected to be even larger. Because of the relatively large impact of primary production, reducing losses in food chains (largely affected by food processing) provides major contributions to sustainability of the food system.

The following technological developments help to reduce the *direct* impact of food processing:

- more sustainable refrigeration technologies combined with more effective climate control strategies and insight into steering options for product quality will reduce the energy use of refrigeration/cooling;
- dry processing as alternative to wet processing routes will reduce the energy costs of drying processes;
- innovative food microsystems will reduce the required energy in fractionation processes and in the production of advanced food structures like emulsions.

Next to reductions in water and energy use, an even larger impact on sustainability can be expected from improvements in resource valorisation (*indirect effects*).The main inefficiencies within the food processing sector are food losses, suboptimal utilisation of by-products/processing residues and unnecessary quality decay within the supply chain. Each of these inefficiencies leads to excessive demands of raw materials. Food processing technologies can contribute to reducing such inefficiencies on the following aspects:

- Food losses along the chain from harvest of the crops up to the stage of consumption are estimated at 30%. Through cooling, stabilisation / preservation processes and packaging technologies food processing industries contribute to increasing the shelf life of products, thereby reducing losses in the chain. Technological advances with respect to innovative sensor technologies and packaging solutions support these developments.
- Suboptimal utilisation of by-products: major fractions of the crops currently end in by-products (with large differences between sectors; varying from 0 to over 80%). In many cases these by-products are discarded as waste with a high negative price. For marketable by-products only a relatively low price is received. However, increasing awareness of (expected) scarcity of resources has resulted in more interest in the by-products. Food processing industries are getting more interested in creating more added value through higher value applications of by-products. In this report a number of practical examples was presented where industries are generating new food ingredients from former waste streams or low-value by-products. In many cases a sound business case can be made for the economic potential of such valorisation. From experience in the practical examples as well as from the R&D projects, however, it is concluded that the practical application in final (food) products deserves more attention and is the major critical success factor.

- Unnecessary quality losses result in reduced shelf life and inferior products (with low prices), ultimately resulting in large losses. Insight into the relationships between food processing and product quality will help to reduce these losses.

Examples of such technological developments described in this report are:

- Improved packaging and product-oriented refrigeration climate control help maximising products shelf life and minimise product spoilage.
- Innovative sensors and control systems will allow for further optimisation of processes directed towards higher effectiveness (i.e., meeting required specifications) and higher efficiency (i.e., using less resources). The application of smart sensors and RFID tags allow for quality control over the entire supply chain. Application of such sensors enables the use of guaranteed quality statements, the supply of consumption-ready products to the supermarket as well as logistical concepts such as FEFO (first expired first out).
- The implementation of novel technologies for mild preservation, e.g. non-thermal pasteurization or sterilization techniques. Application of such technologies could help to reduce food losses over the supply chain by prolonging the shelf life of the (semi-) fresh products.
- Mild separation technologies for the creation of functional fractions (instead of pure ingredients): next to maintaining the nutritional value of the original plant material, the application of functional fractions instead of 100% pure ingredients could lead to significant savings in water and energy consumption, especially when drying and subsequent rehydration steps in the manufacturing process could be omitted.
- The development of plant-based meat alternatives: as consumer acceptance of such products is still hampering a breakthrough, it is clear that the food processing industry alone cannot realize this transition. Nevertheless, technological developments initiated by the food processing industry can help to overcome this bottleneck, as evidenced by the example of the 3rd generation meat replacement products

Future developments that enhance sustainability in food manufacturing can be expected from the further integration of scientific advances from other disciplines into food processing technology. Examples are:

- Genomics: technologies like genomics, proteomics, transcriptomics, etc. can be used to monitor small changes in composition of the food product. For adequate use of the information, it is essential to use expertise in bioinformatics and functional genomics.
- Molecular methods for microbial quantification: molecular methods can be used for typing and quantification of micro-organisms which can be used for addressing the specific steps in the entire productions chain for microbial safety.
- Risk informed decision making: risk assessment tools, decision making tools and improved communication will contribute to food safety and quality control.
- Rapid detection methods in combination with ICT can be used for real-time monitoring of safety and quality of the products, both during and after processing.

Quantification of the sustainability advantages of these technological developments is not straightforward, given their potential impact on the different areas of the current supply chain. Furthermore, the so called *rebound effect* (i.e., the implementation of sustainable technologies is sometimes used for more unsustainable activities) causes the practical sustainability gains to be lower than the theoretical values. For example, a longer shelf life or predictable quality decay of food products could allow for longer (cooled) distribution channels, thereby consuming at least a part of the sustainability advantages.

Nevertheless, some general recommendations can be made on how the implementation of sustainable process technologies could be further enhanced:

- Stimulate the implementation of the novel technologies that are ready for use (e.g. high pressure pasteurization, advanced heating) via:
    - Knowledge transfer from universities and research organizations to food companies
    - Feasibility studies where preferable SMEs can test the possibilities of these technologies for their specific products
- Stimulate the further development of the knowledge of potential interesting technologies (mechanism, effect on food safety and quality, etc.). This is especially interesting for technologies that are at the moment not ready for application, like cold plasma processing.
- Stimulate the development of industrial equipment for technologies that are proven to be interesting but for which industrial equipment is not yet available, like high pressure sterilization and pulsed electric field processing. Especially in the current times of economic downturn, equipment manufacturers are hesitating to invest in the development of novel equipment, even though these technologies are potentially very interesting with respect to sustainable food processing.
- An active role of regulatory bodies in promoting novel technologies for food manufacturing. Similar to the pharmaceutical industry, a one-sided focus on excluding food safety risks will lead to a standstill in innovation. With the implementation of modern risk-management concepts as well as more science-based manufacturing the right balance between ensuring product safety on the one hand and stimulating innovation on the other hand should be found. A promising route for this may be to couple a thorough understanding by the industry of their manufacturing processes to more regulatory freedom in, e.g., the implementation of new technologies or the use of side streams in food applications. A similar approach could be applied in addressing the safety risks associated with the use of novel ingredients (e.g., new protein sources) for food applications.

Although the expected cost savings should in principle be sufficient for an individual or consortium of companies to start an improvement project, for various reasons food industries are rather reluctant with respect to innovation. The following stimulating measures could be considered:

- The publication of eco-efficiency manuals to help companies to identify areas of improvement, e.g., through providing benchmark data on water and energy use or sharing best practices. These kind of manuals could be sector-specific (e.g., for bakeries or the meat processing industry) or be centred around a specific unit operation / type of technology (e.g., drying).
- The active promotion of operational excellence programmes like Lean Manufacturing or Six Sigma as modern methods for Quality Risk Management. These programmes have already proven their success in other sectors of the industry and could potentially lead to reductions of 80% in the costs of poor quality[11]. Similar to the pharmaceutical industry, regulatory bodies could play a central role in such an initiative. Another option could be to provide individual companies with innovation vouchers, small tickets of about 5000 € to hire specified consultancy.
- The further deployment of Industrial Symbiosis programmes to stimulate new partnerships between suppliers and potential users of side- and waste-streams.

[11] Provided the food industry could reach a level of 6 sigma, against a current (estimated) figure of 3-4 sigma.

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ANNEX 1: CLASSIFICATION OF FOOD PROCESSING TECHNIQUES

(Source: HighTech Europe, refer to Chapter 3 of this document)

Table 1: Overview of "essential pretreatment" technologies

Essential pretreatments	
Function	**Processing technique**
Size separation	Crystallisation
	Recrystallization
	Dessication
	Distillation
Density separation	Drying
Gravitational separation	(specified in next table)
Other	Evaporation
	Flocculation
	Fractional freezing
	Pervaporation
	Precipitation
	Rectification (= re-distillation)
	Sublimation
	Zone refining

Table 2: Overview of separation technologies

Separation		
Process / Operation	**Class**	**Specification**
Size separation	Membranes	Micro filtration
		Ultra filtration
		Nano filtration
		Osmosis
		Reverse osmosis
	Sieving	
Solubility separation	Extraction	Crows flow extraction
		Leaching
		Solvent extraction / Liquid-liquid extraction
		Stripping
Hydrodynamic / aerodynamic resistance	Cyclones	Cyclones
		Hydrocyclones
	Air classification	
Mechanical force	Expelling	
	Mechanical pressing	
Di-electric / magnetic properties	Electrostatic separation	
	Electrophoresis	
	Magnetic separation	
Affinnity Separation	Adsorption	
	Absorption	
	Chromatography	
	Solid phase extraction	
Gravitational Separation	Centrifugation	
	Decantation	
	Dissolved air flotation (removal suspended solids by bubbles)	
	Flotation	
	Oil-water separation (gravimetrical separation suspended oil droplets from waste water)	
	Sedimentation	
	Vapor-liquid separation, separates by gravity, based on the Souders-Brown equation	
	Spinning Cone	
Other	Deinking, separating hydrophobic ink particles from hydrophilic paper pulp in paper recycling	
	Demister (vapor), removes liquid droplets from gas streams.	
	Froth flotation (recovers valuable, hydrophobic solids by attachment to air bubbles)	

Table 3: *Overview of conversion processes*

Conversion processes			
Mechanical conversion	**Cutting/ Slicing/ Dicing**	Water jet cutting	
	Mixing	particle-particle	
		liquid-particle	reconstitution
			rehydration
		liquid-liquid	
		liquid-gas	
	Sorting	Size sorting	
		Shape sorting	
Chemical conversion	**Biological conversion**	Fermentation	Bacterial fermentation
			Yeast fermentation
			Mould fermenation
		Biocatalysis/Enzymatic conversion	
	Thermal conversion	Baking	
		Frying	
		Roasting	
		Grilling	
		Gelling 2.2.3	
		Coagulation 2.2.3	
	Washing	Cleaning-in-place/CIP	
	Salting 2.2.2		
	Sugaring 2.2.2		
	Gelling 2.2.3		
	Coagulation 2.2.3		

Table 4: Overview of food structure formation technologies

Structure formation			
Binding	Adsorption	physico-chemical, entropy effects	molecular / nano
	Agglomeration	physico-chemical, entropy effects	molecular / nano
		physico-chemical, entropy effects / mechanical /thermal	micro
			macro
Phase transition	Crystallisation	physico-chemical, entropy effects	molecular / nano
		physico-chemical, entropy effects / mechanical /thermal	micro
			macro
	Freezing	physico-chemical, entropy effects / mechanical /thermal	micro
			macro
	Gelification	physico-chemical, entropy effects /thermal	micro
			macro
Motion	Cutting	mechanical	macro
		thermal	
	Extrusion	physico-chemical, entropy effects / mechanical /thermal	macro
	Kneading	physico-chemical, entropy effects / mechanical	macro
	Pelletising	physico-chemical, entropy effects / mechanical /thermal	macro
	Pressing	physico-chemical, entropy effects / mechanical /thermal	macro
(Two-)phase generation	Emulsification	physico-chemical, entropy effects	molecular / nano
		physico-chemical, entropy effects / mechanical	micro
			macro
	Foaming	physico-chemical, entropy effects / mechanical /thermal	micro
			macro
Other	Encapsulation	physico-chemical, entropy effects	molecular / nano
		physico-chemical, entropy effects / mechanical /thermal	micro
	Homogenisation	physico-chemical, entropy effects / mechanical /thermal	micro
			macro
	Mashing	physico-chemical, entropy effects / mechanical	macro
	Separation by change of structure		

Table 5: Overview of stabilization processes

Stabilizing					
Dehydration	**Dehydration by heat**	Atmospheric hot air drying	Spray drying		
			Rotary drying		
			Tunnel drying		
			Fluidized bed drying		
			….		
		Contact drying			
	Freeze drying				
	Vacuum drying				
Water activity control	Salting				
	Sugaring				
pH control					
Heating	**Heating of moist foods**	Cooking			
		Blanching			
		Pasteurisation	In pack pasteurisation		
			Aseptic pasteurisation	HTST pasteurisation	
		Sterilisation	In pack sterilisation	Batch retorting	Steam retorting
					Steam/air retorting
					Water spray retorting
					Water immersion retorting
					Agitating retorting
				Continuous retorting	
			Aseptic sterilisation		
	Dry heating				
Cooling	Cooling				
	Freezing	Air freezing			
		Plate freezing			
		Liquid-immersion freezing			
		Cryogenic freezing			
Antimicrobials					
Antioxidants					

Table 6: Overview of packaging technologies

Packaging			
liquid packaging	**cold filling**	bottles	
		pouches (tube fill)	
		bag in box	
		cans	
	hot filling	bottles	
		pouches (tube fill)	
		bag in box	
	aseptic filling	bottles	
		bag in box	
		box (multilaybarrier, tetrapak)	
	modified atmosphere	bottles	
		pouches (tube fill)	
solid packaging	**bulk material**	pouch filling	pouch
		tube filling	pouch formed from tube
		box filling	box
		modified atmosphere	protecting gas combined with barrier material
	pieces	blistering	blister
		tube filling	pouch formed from tube
		box filling	box (cartoon, plastic, multilaybarrier)
		modified atmosphere	protecting gas combined with barrier material

This document is the state of the art report on 'Options for sustainable food processing', making part of the STOA study 'Technology options for feeding 10 billion people'.

A summary is also available.

The STOA studies can be found at:
http://www.europarl.europa.eu/stoa/cms/studies
or requested from the STOA Secretariat: STOA@ep.europa.eu

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This is a publication of the
Directorate for Impact Assessment and European Added Value
Directorate General for Parliamentary Research Services, European Parliament

PE 513.533
DOI 10.2861/4330
CAT BA 04-13-048-EN-C
ISBN 978-92-823-5122-2

ISBN 978-92-823-5122-2

16668