DELIVERABLE 4.2

FOOD MICRO SYSTEMS

ROADMAP SECTOR 1
IMPLEMENTATION OF MICROSYSTEMS IN THE DAIRY SECTOR

Main author : EnablingMNT GmbH // Date of publication : October 2013
The research leading to this publication has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n°287634

Coordinator ACTIA

SEVENTH FRAMEWORK PROGRAMME

Acknowledgement

This report forms part of the deliverables from a project called "FoodMicroSystems" which has received funding from the European Union's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 287634. The Community is not responsible for any use that might be made of the content of this publication.

FoodMicroSystems aims at initiating the implementation of microsystems & smart miniaturised systems in the food sector by improving cooperation between suppliers and users of microsystems for food/beverage quality and safety.

The project runs from September 2011 to November 2013, it involves nine partners and is coordinated by ACTIA (Association de Coordination Technique pour l'Industrie Agro Alimentaire, France). More information on the project can be found at http://www.foodmicrosystems.eu.

Main Authors

Patric Salomon, enablingMNT GmbH
Holsteinische Str. 23, 12161 Berlin, Germany
Phone: +49 30 24357870
E-mail: patric@enablingmnt.com
www.enablingmnt.com

Henne van Heeren, enablingMNT, The Netherlands

We acknowledge the valuable discussions and contributions from all partners of the FoodMicroSystem project as well as participants at FoodMicroSystem workshops, interviewees and other supporters!

Table of content

Executive Summary

This report describes the results of a roadmapping action for microsystems to be applied in the dairy sector, carried out by the EC funded FoodMicroSystems project. The “microsystems for dairy roadmap” is one of a series of three application driven technology roadmaps (dairy, meat, wine&beer) that are intended to lay the foundation for future collaborations between the food and microsystems sectors, support strategy decisions of research organisations and companies, supply investors and funding bodies with guidelines to support their investment decisions.

The economic importance of the dairy sector in Europe is underlined by more than 11.000 enterprises representing a total production value of more than 100 B€. Dairy is not only the largest segment of the food industry; it also represents 17% of the total European food export.

There risks and issues associated with the consumption of dairy products (e.g. contamination, allergies, etc.) can be addressed by the introduction and appropriate use of microsystems throughout the supply chain, starting from milking, transport and dairy processing, to logistics & sales, and further on to consumption at the customer’s site. Both, the potentials and the development needs, are addressed in this report.

From the diversity of opportunities for using microsystems in the dairy sector, the report focuses on areas that stakeholders (dairy companies, consumers and microsystems technology providers) consider being the top most challenges in the dairy industry:

- Guaranteeing product safety by preventing contaminated food reaching the market.
- Improving product quality by introducing more homogenous and optimised production.
- Increasing equipment utilisation by using condition based maintenance methods.
- Increasing process efficiency by using less energy and decreasing product loss.

On the down side to these opportunities, legal adaptations are required to pave the way for miniaturised devices and the associated measuring methods to become officially certified methods. Until this is achieved, newer test methods can often only be considered as screening tools, complemented by official lab based tests.

1 Introduction

This *FoodMicroSystems* report intends to combine the needs of the dairy supply chain with the opportunities that microsystems technologies will be able to offer for this sector within a timeframe of about three to ten years.

The “microsystems for dairy roadmap” is one of a series of three “application driven technology roadmaps” that will lay the foundation for future collaboration between the food and microsystems sectors, support strategy decisions of research organisations and companies, and supply investors and funding bodies with guidelines to support their investment decisions.

The roadmaps are application driven, whereby trends for future application areas and products are identified and their “in-service” dates forecasted. In this context, the underlying microsystems technologies provide the basis of the secondary layers constituting the roadmaps. We have identified significant overlaps in microsystems needs within the three application-driven food roadmaps, thus we decided to integrate this secondary layer of Microsystems roadmaps into a separate report D4.5, jointly for all application roadmaps (dairy, meat, wine & beer).

In essence the roadmaps aim at addressing the following questions:

1. Where are we now? (in terms of microsystems technologies available/used in a specific area of the food sector)
2. Where do we want to go? (to get the most benefits of microsystems technologies for this sector)
3. What are the barriers/constraints to get there?
4. How can we overcome these barriers?

1.1 Relevance of the dairy sector to the EU food supply chain

This chapter addresses the relevance of dairy, dairy products, and dairy processing to the European economy, to human health and to the environment. Furthermore it links to the reports that have been produced by other work packages of the FoodMicroSystems project.

1.1.1 Economical relevance

To Europeans and North Americans, both drinking and eating dairy products is very common, but this is far from the global norm[1].

[1] Global Geography of Milk Consumption and Lactose (In)Tolerance, http://geocurrents.info/cultural-geography/culinary-geography/global-geography-of-milk-consumption-and-lactose-intolerance#ixzz2Yw6y2VSF

The map published at FoodBeast.com[2] (figure 1.1.1.1), illustrates that Nordic countries, such as Finland and Sweden, top the list of milk consumption per capita, with over 350 kg of dairy per person per year.

Much of the dairy consumed in these countries is in the form of milk, though Finland is the leading consumer of ice cream in Europe, with 13.7 litres per person in 2003. The third spot in the list of milk-loving countries is occupied by the Netherlands, which ranks as the 5th top cheese producer, the 3rd top cheese exporter, and the 6th top cheese consumer. Among the other top ten dairy consuming countries are such cheese-loving countries as Greece and Switzerland (ranking 1st and 5th in the list of cheese consumption, respectively).

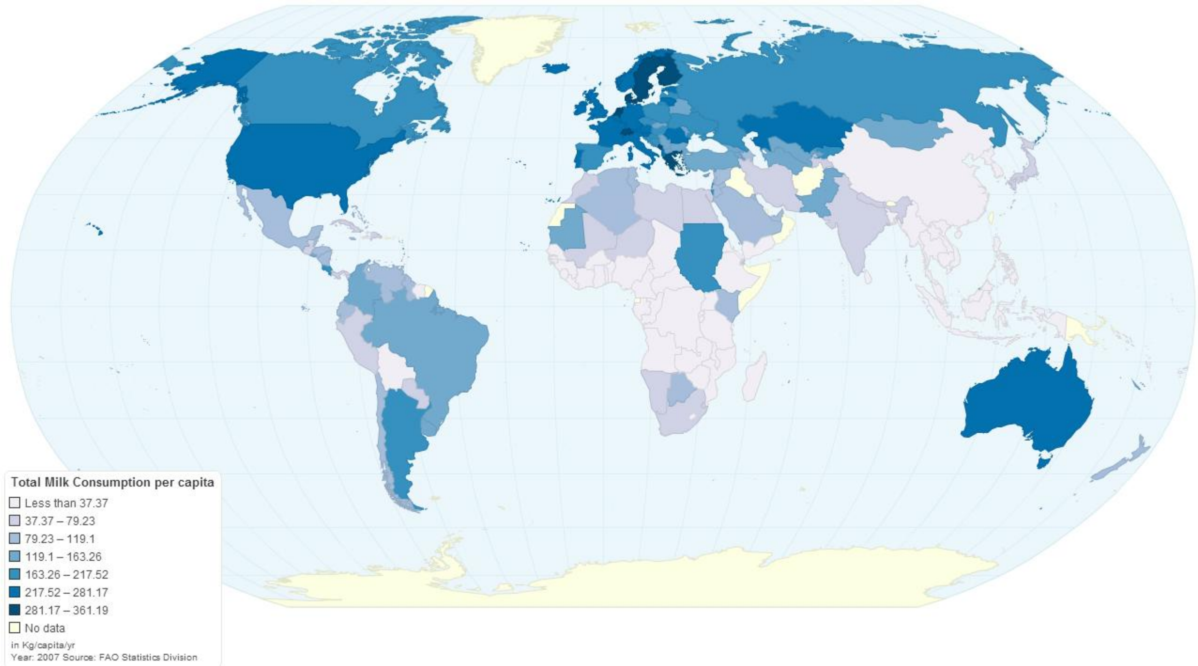


Fig. 1.1.1.1: Global Geography of Milk Consumption per capita (Source: http://*FoodBeast.com*)

Not only from a consumption point of view, also for the economy the dairy sector is one of the most important food markets in Europe:

Milk is the first agricultural product in the EU in terms of value at approximately 15% of the total agricultural output. The EU is a major player in the world dairy market; it represents about 20% of the world wide milk production and accounts for 25% of the world dairy trade.

The main producers are Germany, France, the United Kingdom, the Netherlands, Italy and Poland: they represent more than 70% of the EU production.

[2] From Map of Milk Consumption & Lactose Intolerance Around the World, http://*FoodBeast.com*

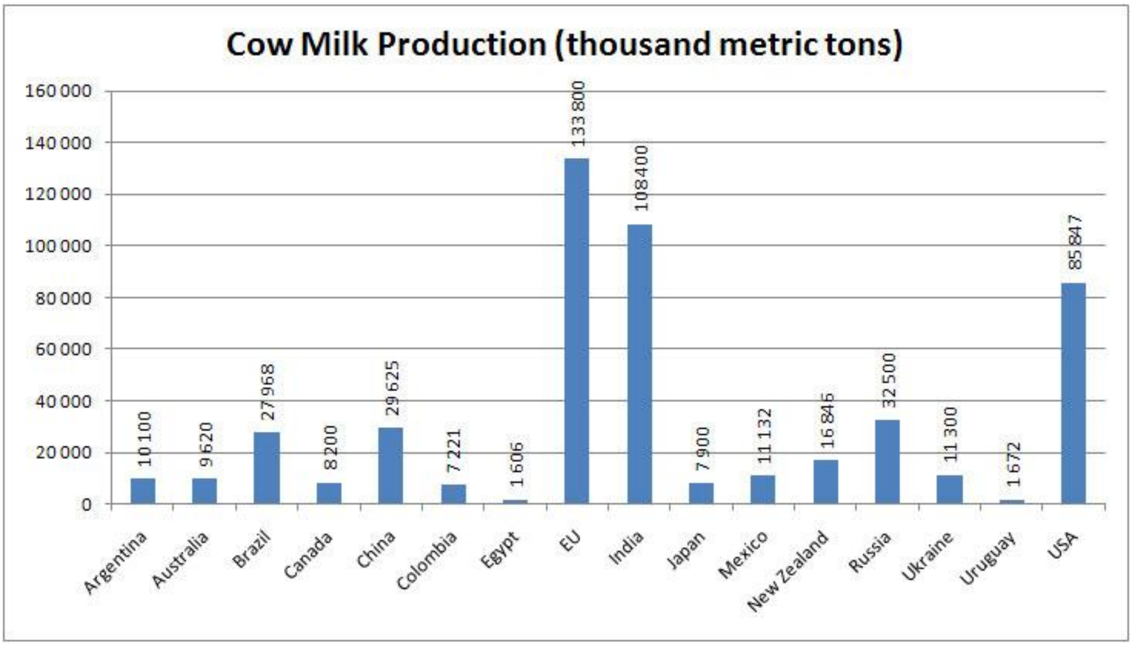


Fig. 1.1.1.2: World Milk Production 2009 (Source: Dairy world - Milkproduction, www.milkproduction.com)

Based on its high production and processing volumes of dairy products, European exports reach nearly 10 times the amount of imports (in tons):

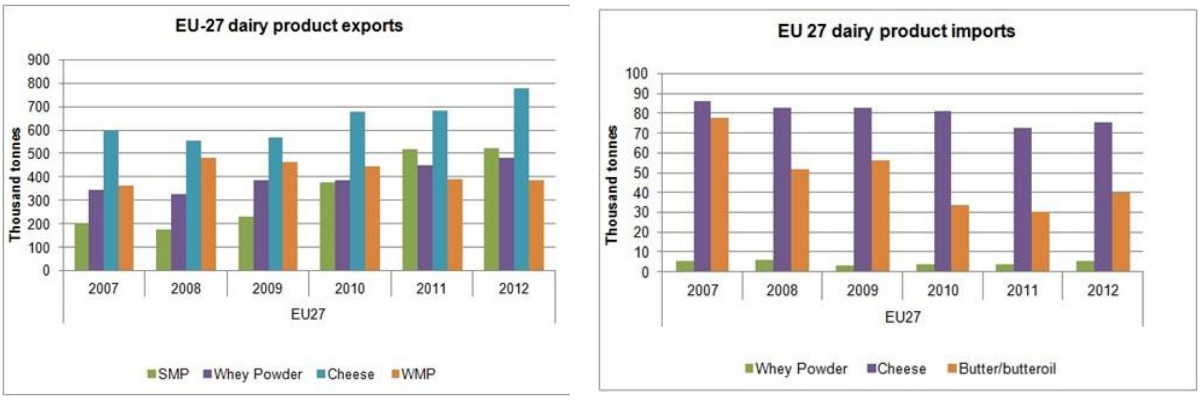


Fig. 1.1.1.3: EU-27 dairy product exports and imports (Source: Eurostat)

The processing side of the dairy sector is characterised by a high level of concentration: the first five key players (*Danone, Unilever, Friesland Campina, Nestlé, Arla*) represent more than 30% of the European dairy market (see annex A1.1, Fig A1.1.1). Those dairy companies collect, process and commercialise milk products. They engage in long-terms partnerships with dairy farms.

There is far less concentration in the primary production side of the dairy industry: in the EU-27, there are more than one million farmers supplying annually close to 150 million tonnes of milk to around 5.000 dairy processors (55% of which are SMEs)[3].

[3] http://ec.europa.eu/agriculture/eval/reports/dairy/

The economic importance of the dairy sector in Europe is underlined by more than 11.000 enterprises representing a total production value of 109 B€[4]. Dairy is not only the largest segment of the food industry; it also represents 17% of the total European food export.

A forecast on the "EU Dairy Supply and Utilisation from 2010 to 2025" is presented in the "FAPRI-ISU 2011 World Agricultural Outlook" (see annex A1.1, figure A1.1.2). From this exhaustive table some conclusion can be drawn:

- There is a pressure on the price and at the same time the productivity is expected to rise.
- The total production is expected to rise thanks to the increase in productivity.
- At the same time, the home consumption will remain stable.
- The increase in production will mainly be in the area of processed dairy products (cheese and others).

It can therefore be assumed that the economic importance of this segment (cheese and other processed dairy products) will further increase. However, the continuous price pressure and the increase of productivity can only be achieved by a continuous increase in production efficiency.

An important question will be on "what" can enable this increase in efficiency? In general terms, efficiency is about higher yields, less manpower and less energy consumptions; this can partly be achieved by more effective processing (e.g.: consumption of energy) and partly by optimizing quality control (higher yields). As in other sectors, the use of microsystems is expected to be a decisive factor.

1.1.2 Relevance to health[5]

Milk is an extremely valuable food for human nutrition as it contains all the basic components required for human life[6]. Dairy products in general are highly nutritious and can play an important part in human diets for both children and adults.

Despite the variation in the composition of milk from different animals, all milk is rich in protein and other nutrients and constitutes a good food for humans, especially children. Caseinogen and lactalbumin, proteins of high biological value, are among the most important constituents of cows' milk. The carbohydrate in cows' milk is the disaccharide lactose. Fat is present in the form very fine globules, which tend to coalesce and rise to the surface. The fat has a rather high content of saturated fatty acids. Milk is a very good source of riboflavin and vitamin A. It is a fair source of thiamine and vitamin C, but it is a poor source of iron and niacin.

[4] Competiviness and innovativeness of the EU Dairy Industry, J.H.M. Wijnands et. Al.
[5] Partly based on: Human nutrition in the developing world, 1997, FAO Food and Nutrition Division
[6] Milk and Diary Product Technology, Spreer & Dekker, 1998

In many countries where cows' milk is a normal item of the diet, it is customary to wean infants from breastmilk on to a diet in which cows' milk also plays an important role. This is a valuable practice, as it helps ensure that the child will receive a balanced diet that provides all the requirements for growth, development and health. Figure 1.1.2.1 presents a summary of consumption of dairy products for Australia to illustrate the importance of milk and the variety of milk products for the diet of people.

This data from the 1995 Australian National Nutrition Survey demonstrates that milk and other liquid milk products are consumed in significant quantities, with 84% of the people consuming an average amount of 347 g/day.

Product	Average no. people surveyed consuming product (%)	Average amount product consumed per day (g)
Milk and other liquid milk products	84	347
All Cheese types	41	34
Very hard cheese	2.3	8
Hard cheese	27.7	32
Semi soft cheese	1.6	23
Soft cheese	5.3	33
Processed cheese	9.4	30
Ice cream	15	112
Butter	14	13
Yoghurt	9	177
Cream	7.7	29
Dairy based dips	1.5	43
Dairy based desserts	4.7	148
Dried milk	1.26	17
Goats milk	1	248
Concentrated milk	<1	57

Fig. 1.1.2.1: Consumption of dairy products for Australia (Source: Australian Bureau of Statistics and Department of Health and Family Services, 1997)[7]

The substantial part dairy products have in the Western diet also has a negative side. Although numbers vary from country to country, in all European countries dairy products are the major source of saturated fats (see annex A1.1, figure A1.1.3). Unfortunately in practically all countries, the total amount of intake exceeds the recommended amount. Cleary here is a challenge for the European dairy industry to provide healthier dairy products with less saturated fats.

There is another negative side to the picture, not all people can consume milk. **Lactose intolerance** is fairly common in the non-western world (but also growing in Europe). The term lactose intolerance refers to any form of allergy to lactose, the form of sugar found in milk, while “lactase persistence” means the continued activity

[7] A Risk Profile of Dairy: Products in Australia, Food Standards Australia New Zealand, 2006

of the enzyme lactase in adulthood. In early humans, as in most mammal species, the activity of the enzyme was dramatically reduced after weaning.

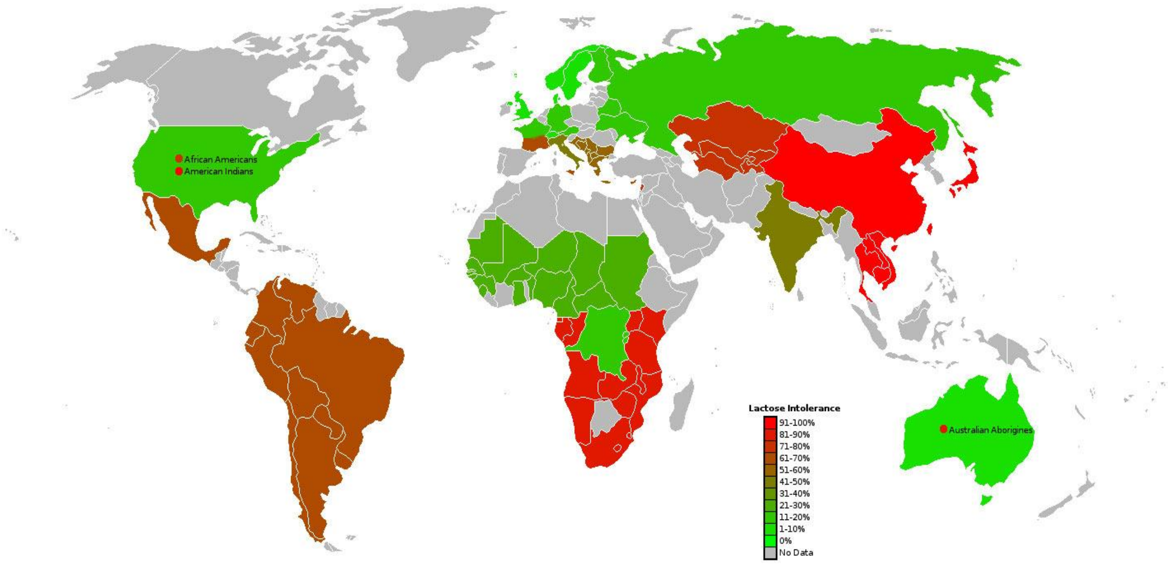


Fig. 1.1.2.2: Worldwide distribution of lactose intolerance (Source: Global Geography of Milk Consumption and Lactose (In)Tolerance, www.GeoCurrents.info)

However, in some populations lactase persistence has evolved as an adaptation to the consumption of non-human milk and other dairy products beyond infancy. The majority of people around the world remain lactase non-persistent, and consequently are affected by varying degrees of lactose intolerance as adults (although the correlation between genetically transmitted lactase persistence and lactose intolerance is not perfect[8]). Countries with high levels of lactose intolerance, especially in sub-Saharan Africa, South and East Asia, are also low in dairy consumption. As can be seen from some of these maps, in the U.S. the levels of lactose (in)tolerance differ by race, with Caucasians being most lactose tolerant, followed by Hispanics and African Americans; Native Americans are said to have the highest levels of lactose intolerance[9].

Thus, measuring the Lactose content in dairy products and/or simple tests for consumers would be beneficial.

Pasteurisation[10] is a process of heating a food, which is usually a liquid, to a specific temperature for a predefined length of time and then immediately cooling it after it is removed from the heat. This process slows spoilage caused by microbial growth in the food. Unlike sterilisation, pasteurisation is not intended to kill all micro-organisms in the food. Instead, it aims to reduce the number of viable pathogens so they are unlikely to cause disease (assuming the pasteurised product is stored as indicated and is consumed before its expiration date). Commercial-scale sterilisation

[8] Lactose Tolerance, KurdishDNA.blogspot.com
[9] Global Geography of Milk Consumption and Lactose (In)Tolerance, http://geocurrents.info/cultural-geography/culinary-geography/global-geography-of-milk-consumption-and-lactose-intolerance#ixzz2Yw6y2VSF
[10] http://en.wikipedia.org/wiki/Pasteurization

of food is not common because it adversely affects the taste and quality of the product. Certain foods, such as dairy products, may be superheated to ensure pathogenic microbes are destroyed.

Milk **homogenisation**[11] is accomplished by mixing massive amounts of harvested milk to create a constant, then forcing the milk at high pressure through small holes. Yet another method of homogenisation uses extruders, hammermills, or colloid mills to mill (grind) solids. Milk homogenisation is an essential tool of the milk food industry to prevent creating various levels of flavour and fat concentration.

Raw milk[12] is milk that has not been pasteurised or homogenised. Health food proponents tout the benefits of raw milk and the ills of pasteurisation and homogenisation, while the medical community warns of the dangers of not pasteurising milk. In particular, there is a worldwide movement[13] that asks for access to raw milk from grass-fed animals.

Research on microbial quality control of raw milk for human consumption has the potential to connect research, industry and society. The technology could support the development of sustainable SMEs, e.g. organic and low food-mile, to deliver high quality dairy products. There is significant potential for Microsystems and micro filtration technology: fast and low-cost methods for pathogen detection and novel filtering/fractionation technologies will be required.

1.1.3 Relevance to environment

In general, the dairy farming in the EU is becoming more intensive and more specialised[14]. This means that production is concentrating on fewer, larger farms (e.g. 40% of EU dairy cows are in herds of at least 50) resulting in a corresponding decrease of dairy farming on many holdings and in some cases abandonment of holdings. For all dairy systems described, largely negative environmental issues increase with increasing intensity of production. Associated with the intensive dairy systems are high stocking rates, high use of chemical fertilisers and pesticides and mechanised methods. These result in problems of direct point source pollution, diffuse pollution and pressure on marginal habitats and landscape features.

Compared to these problems the environmental impact of dairy processing might seemingly be much lower. However, this industry consumes a substantial amount of energy (especially for heating and cooling during the processing), water (cleaning mainly) and chemicals (cleaning). While there is a request from the policy and

---

[11] http://en.wikipedia.org/wiki/Homogenization_(chemistry)
[12] http://en.wikipedia.org/wiki/Raw_milk
[13] see http://www.milkmaps.com/, http://www.realmilk.com/,
http://www.foodstandards.gov.au/code/proposals/pages/proposalp1007primary3953.aspx
[14] THE ENVIRONMENTAL IMPACT OF DAIRY PRODUCTION IN THE EU 2000, European Commission (DGX I), submit ted by CEAS Consultants Ltd, Centre for European Agricultural Studies and The European Forum on Nature Conservation and Pastoralism, http://ec.europa.eu/environment/agriculture/pdf/dairy.pdf

consumer side to address these issues from an environmental view, the main driver for the dairy industry to address the same issues is the economic point of view.

Energy is consumed in a dairy plant mainly in the form of:

- Electricity
- Steam
- Refrigeration
- Compressed Air

Looking at the processing and product stages, the main energy consumer by far is the milk powder production[15] (Fig. 1.1.3.1). New production technologies could generate significant savings.

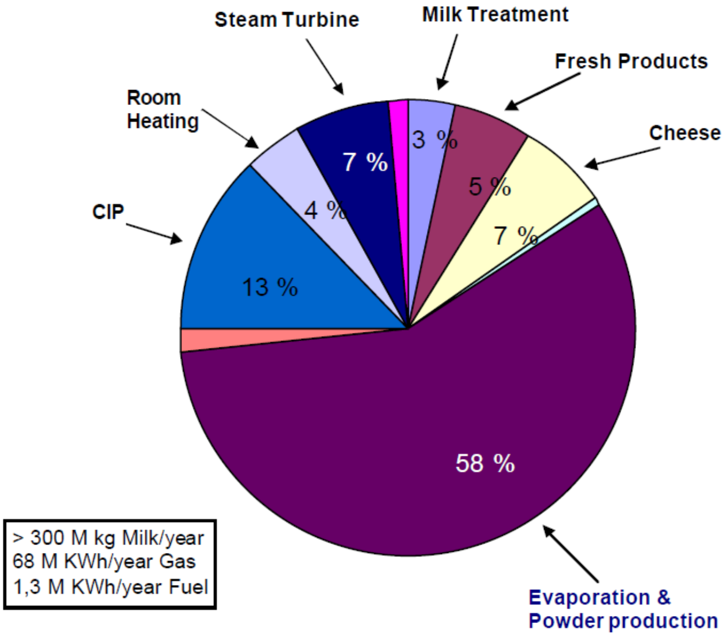


Fig. 1.1.3.1: Thermal energy consumption in a typical German dairy production unit (Source: R. Bertsch, Efficient production of energy in Bulletin of the international dairy federation 2000)

15 R. Bertsch, Efficient production of energy in Bulletin of the international dairy federation 2000

1.2 Roadmapping methodology

The overall objective of the FoodMicroSystems Support Action was to initiate the implementation of microsystems & smart miniaturised systems in the food sector by improving cooperation between suppliers and users of microsystems for food/beverage quality and safety. More specifically, the objective of work package 4 was to develop "application driven technology roadmaps" that can draw the foundations for future collaboration between the food and microsystems sectors, support strategy decisions of research organisations and companies, and supply investors and funding bodies with guidelines to support their investment decisions.
The three roadmaps (deliverables D4.2, D4.3, and D4.4) are application driven, whereby trends for future application areas and products are identified and their "in-service" dates forecasted. In this context, the underlying microsystems technologies provide the basis of the secondary layers constituting the roadmaps; this has been elaborated in more detail in deliverable D4.5. In essence the roadmaps address the following questions:

1. Where are we now? (in terms of microsystems technologies available/used in the food sector)
2. Where do we want to be? (to get the most benefits of microsystems technologies for the food sector)
3. What are the barriers/constraints to get there?
4. How can we overcome these barriers?

It was decided to develop roadmaps for the following areas:

- Microsystems for Dairy
- Microsystems for Meat
- Microsystems for Wine&Beer

The three roadmaps have been prepared through a number of workshops with key stakeholders out of both communities (technology suppliers and food industry representatives).

1.2.1 Objectives of the roadmapping efforts

To develop roadmaps linking demands and technologies

Based on the findings in the previous steps, roadmaps towards successful implementation of the emerging technologies in the food sector have been set up. The roadmaps propose ideas for national and European research programmes as well as proposals of research projects. They also propose recommendations on how to avoid the technical, economical, industrial, ethical and regulatory constraints identified previously. For three specific food chains, one roadmap each has been prepared (three roadmaps in total). These three food chains have been selected among the different food chains covered based on initial work in WP1, WP2 and WP3, plus advice from the user group, EC and reviewers.

These roadmaps do not duplicate roadmaps developed in other initiatives (e.g. MinacNed, Mancef, NEXUS, MINAM, Patent-DfMM, ENIAC, Food4life, EPoSS) as they are specific to food sectors. The main added value is that the roadmaps are built on a detailed analysis of users needs, hence allow being very specific to the users needs. These roadmaps will be utilised at EU level as an input for preparing Horizon 2020 and at national level with the view to stimulate cooperation between food and microelectronic research actors.

1.2.2 Methodology for the FoodMicroSystems roadmaps

Before starting the real roadmapping activity, first the generic needs and priorities for the specific subject must be determinated. Hereafter the needed capabilities can be defined. From combining the knowledge about the state of the art in R&D and on the market a list of initial technologies to be roadmapped can be derived. The most difficult activity is to determine the technology readiness levels, key performance indicators and estimated timelines. Together they form the bases for the roadmap. The basic process is shown in figure 1.2.2.

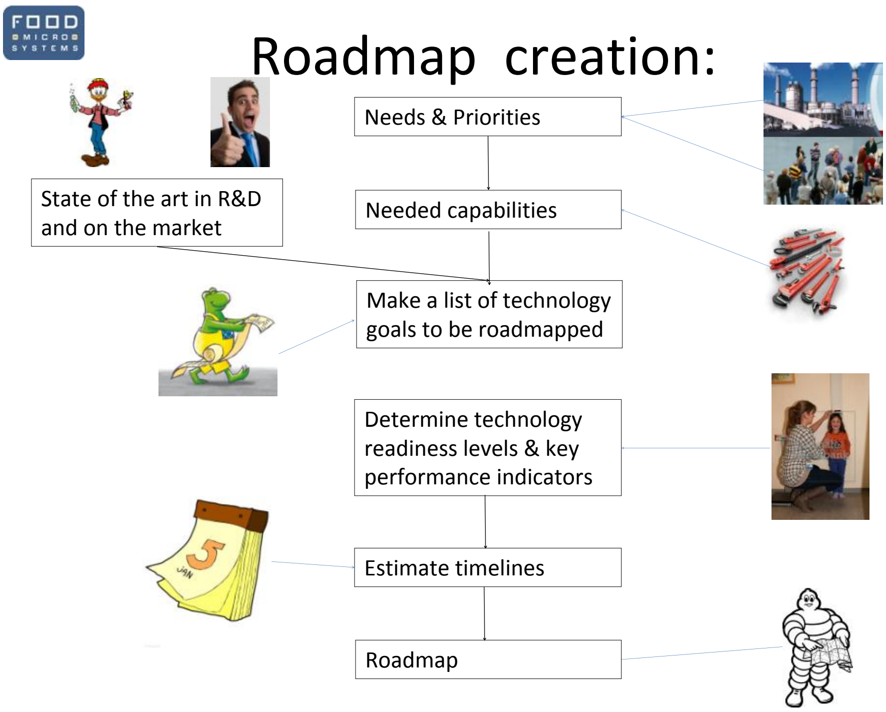


Fig. 1.2.2 Roadmap creation methodology (Source: enablingMNT, 2013)

Note: Not all products and technologies can be roadmapped. It often doesn't make sense to do it for niche applications. The FoodMicroSystems roadmap(s) focus on food areas where micro- and smart systems are expected to have a significant market potential within the next 3 to 10 years.

The Term “roadmap” is used with a lot of different definitions and implementation methodologies in European projects; a roadmap can be in text description and (as much as possible) visualised thought different formats of diagrams, tables, SWOT graphs, added by a description of what and why. For more information about the roadmapping methodology used in this project and background, see deliverable D4.1 Roadmapping Methodology.

It was agreed to use a roadmapping methodology based on the NEXUS approach (developed more than 10 years ago). However NEXUS developed the roadmaps through their User-supplier Clubs (USCs), which were specifically set up for each of the relevant application fields. During the roadmap development, they met regularly (approx. 5-8 times for each group) and built their roadmap through these iterative steps (see also deliverable D4.1). As for the FoodMicroSystems project, we neither had the time, nor the budgets for this complex iterative process; thus, it was necessary to find a way of implementing a much faster approach with fewer meetings.

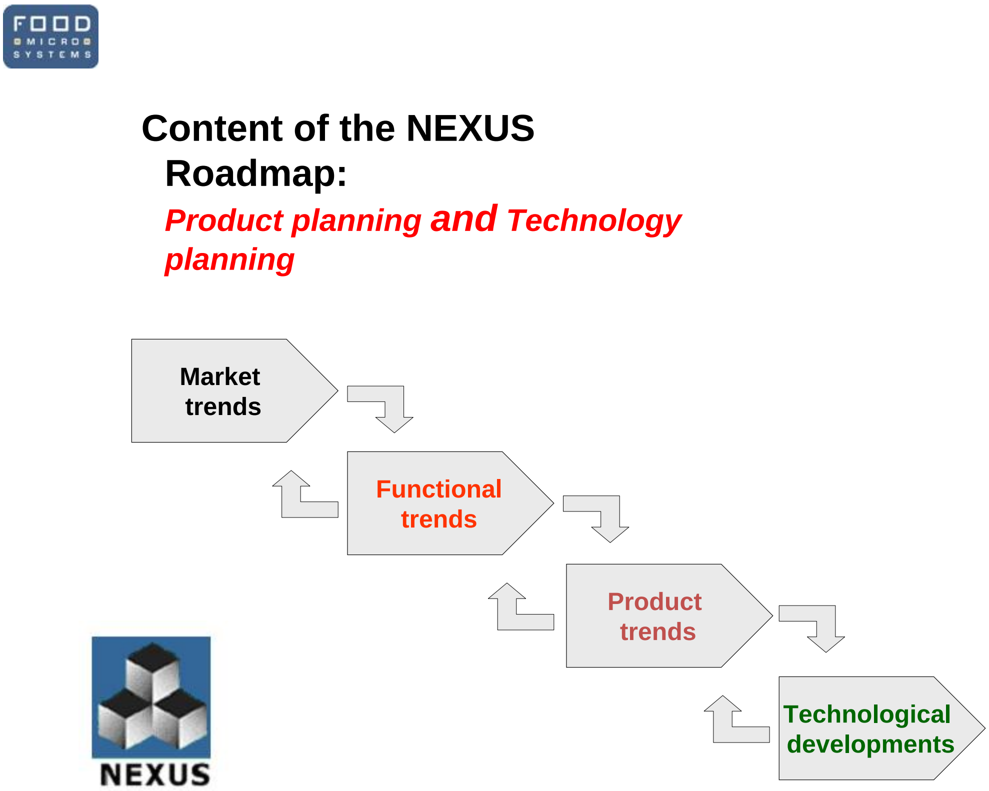


Fig. 1.2.3 NEXUS roadmapping methodology for product and technology planning (Source: NEXUS, 2000)

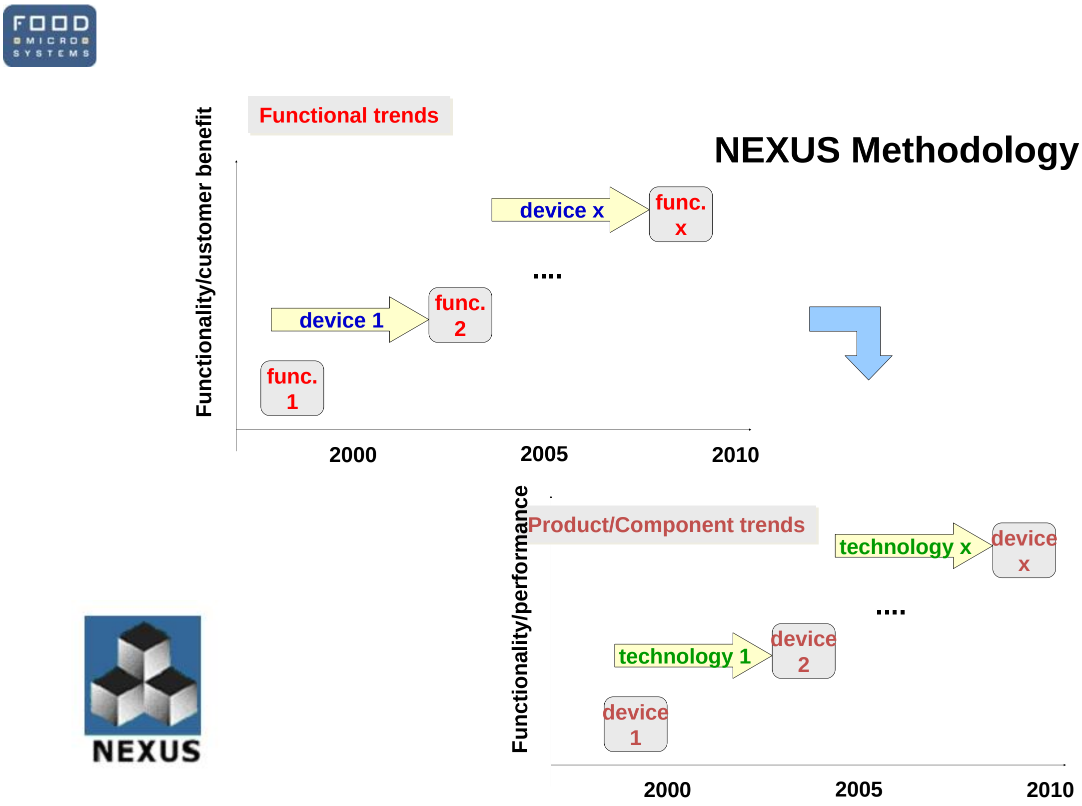


Fig. 1.2.4 NEXUS roadmapping methodology (Source: NEXUS, 2000)

In the project a large data collection had been organised within work packages 1 and 2, leading to a good overview on existing Microsystems technologies that were relevant for the food industry, an overview on relevant research projects. Assessments of the needs of the food industry and consumer perceptions have been added within work package 3. Based on these inputs, 2 roadmapping workshops had been organised for each application roadmap (dairy, meat, wine&beer) and, depending on the quality and completeness of the information generated, this has been supplemented by interviews with stakeholders and a further assessment of publications, books, and articles.

The first roadmapping workshop “Innovative Processes and Analysis Methods for the Dairy Industry, how can Micro technologies and Smart Sensors help the Dairy Industry to improve food quality, reduce cost, and strengthen consumer confidence?” took place on 25th September 2012 at ACTIA, Paris, France (for details, see annex 2). The workshop format consisted in some general overview presentation, a round table introduction / discussion and breakout sessions, which were moderated according to a template of questions / guidelines. We had dairy industry and other representatives with a “user perspective” present but generating clear information about the needs of the dairy industry proved to be more difficult as expected. Thus we carried out additional interviews with stakeholders and did an additional review of relevant literature before organising the second workshop in Wageningen, The Netherlands, on 18th January 2013. Despite a lot of valuable discussions and input from participants, a significant amount of additional desk research was needed to get to the roadmap deliverable as it has been published now. Also the knowledge within the consortium has been used extensively during our project meetings to define the basics of the roadmap structures.

For the workshops relating to meat and wine&beer, a different approach was used with the objective of generating clearer data that could be directly used for the roadmaps. Instead of parallel breakout sessions, only plenary meetings took place and these directly worked on prioritising food industry needs and allocating these into roadmap diagrams on flipcharts. As expected, the results were on the one hand much more appropriate to be directly used for the roadmaps, but on the other hand they didn't have the depth as generated through the breakout sessions. Details on roadmapping workshops (agenda, participants, notes) and other sources (interviews, literature, references) are covered in the specific roadmap documents (see deliverables D4.3 and D4.4).

As a summary of the roadmapping approach, the three roadmaps (microsystems for dairy, microsystems for meat, and microsystems for wine&beer) are based on initial findings from WP 1-3, enhanced by the discussions at two roadmapping workshops for each area. Additionally interviews and visits to key stakeholders were used to add to and verify the roadmaps. Especially in the meat sector, where it was most difficult to get the user community into a workshop, interviews via phone or direct visit were the main methodology to gather the information needed.

2 The dairy supply chain and main drivers for innovation

2.1 The dairy supply chain

The dairy supply chain (as we look at it from the FoodMicroSystems project) starts with the milking process / raw milk and continues through processing, producing the dairy product (with a number of steps depending on which product to look at), packaging, transport / tracking, and through sale and consumption by the consumer.

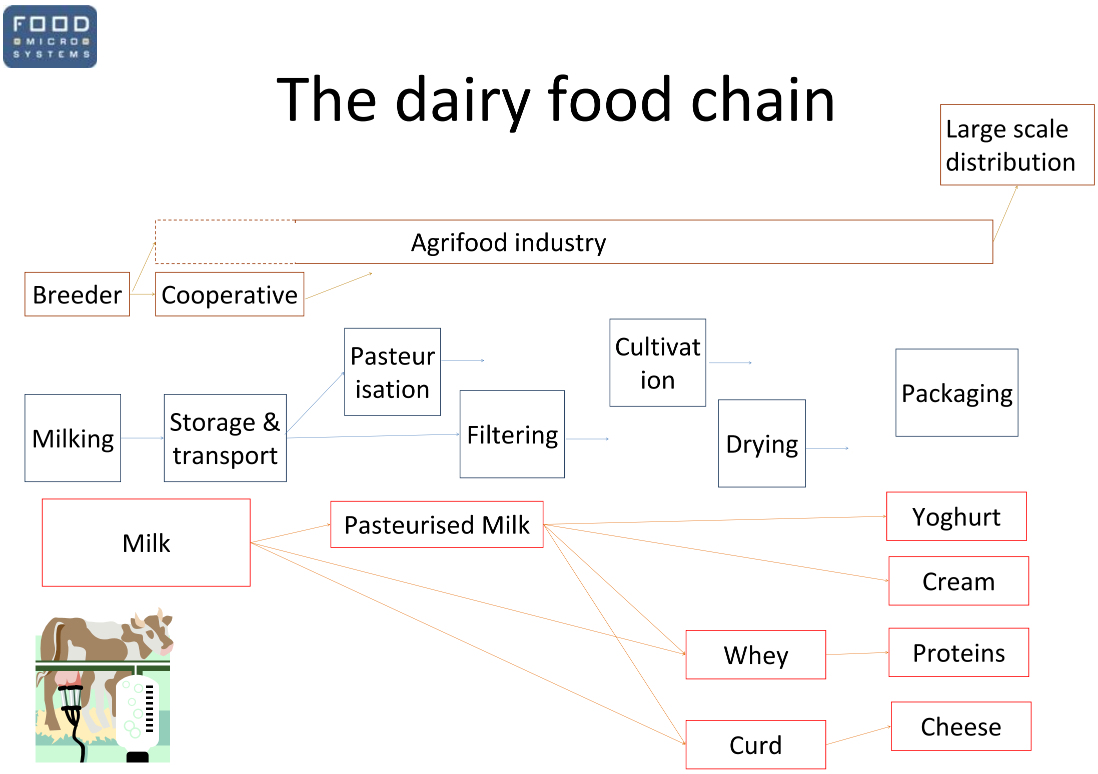


Fig. 2.1.1: Dairy supply chain (source: FoodMicroSystems, ACTIA & enablingMNT)

Another, more complex, diagram of dairy products and their production chains is given in annex A1.1, figure A1.1.4.

Starting from the basic supply chain, the question is "in which areas of the supply chain are":

- Microsystems used already? …what needs to be improved?
- Problems to be solved? …maybe through Microsystems?
- New opportunities for Microsystems?

Results from this assessment have been added throughout the following chapters. More specifically the assessment of opportunities along the supply chain has led to the considerations "where to measure" and "what to measure" (see following chapters).

2.2 Motivation for using new technologies in the dairy sector

Because milk and other dairy products are a crucial part of the daily diet for most people in the EU, consumers are concerned about the quality and safety of the products, with safety aspects being far more important. Although dairy products are considered as rather safe, the dairy sector has been affected by food scandals in recent years; a few examples:

- In 2010, the German discounter Lidl and the producer Prolactal had to face legal actions for not sufficiently warning the public about cheese contaminated with Listeria, from which seven people died.
- In the beginning of 2013, the cheese company Finger Lakes Farmstead (New York) recalled 12 wheels of Gouda cheese also contaminated with Listeria.
- In May 2013, Hong Kong recalled Australian low-fat milk over an excessive bacteria count, which was above legal limit, but probably not high enough to cause food poisoning.

A public food crisis, even when no loss of lives occurs, has an enormous impact. In addition to economic losses it creates a lot of unrest and undermines the trust in the food industry in general. While food safety is very much in the public’s eye, spoilage of food is also a serious matter, and has an even higher economic impact, besides the environmental burden of it. In general, consumer and government awareness of critical flaws in the dairy supply chain is growing, resulting in a demand for more sensitive, faster tests and more food and environmentally friendly processes.

During the first FoodMicroSystems roadmapping workshop, the following items were ranked high as a motivation to introduce new technologies in the food sector:

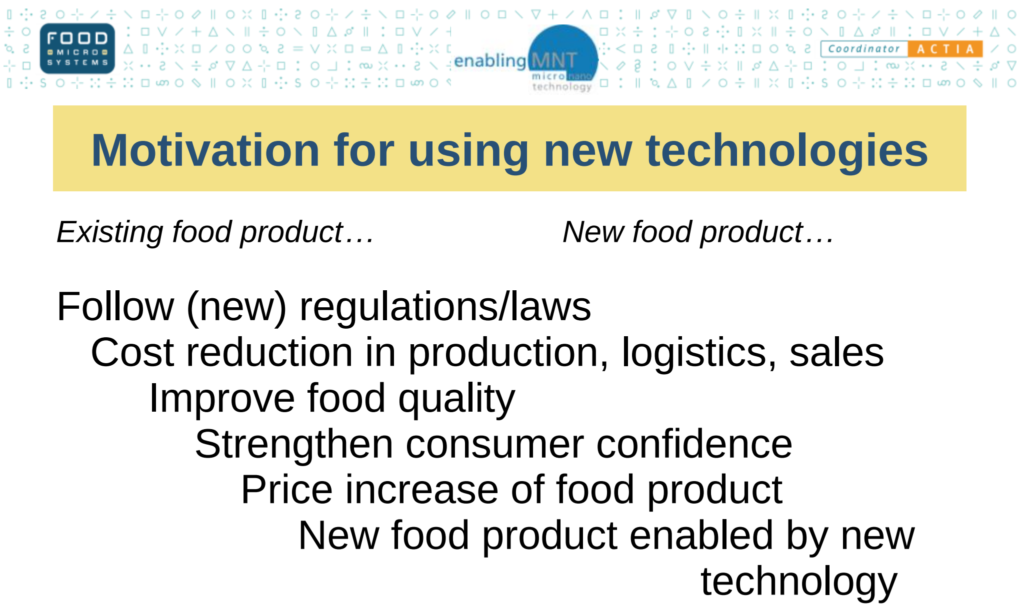


Fig. 2.2.1: Motivations for introducing new technologies in the food sector (Source: FoodMicroSystems workshop, Paris, 25 Sept 2012)

If we have to rank the drivers from a **consumer perspective**, the main ones are cost and safety, followed by quality, authenticity and health.

The priorities from an **industry perspective** are mainly driven by financial considerations: In the first place it is efficient usage of resources and secondly reduction of waste. Hereafter it is safety: detection of unwanted content, which is also cost driven. Further down the line profiling is on the wish list – this might enable a better usage of raw materials.

Considering both, drivers from the user perspective and industry priorities, leads to a number of technological capabilities needed. For most capabilities several methods and technologies are needed, e.g. to detect all kinds of "unwanted content" in milk. A high priority is on detecting this unwanted content, such as pathogens, pesticides, herbicides, heavy metals, etc.

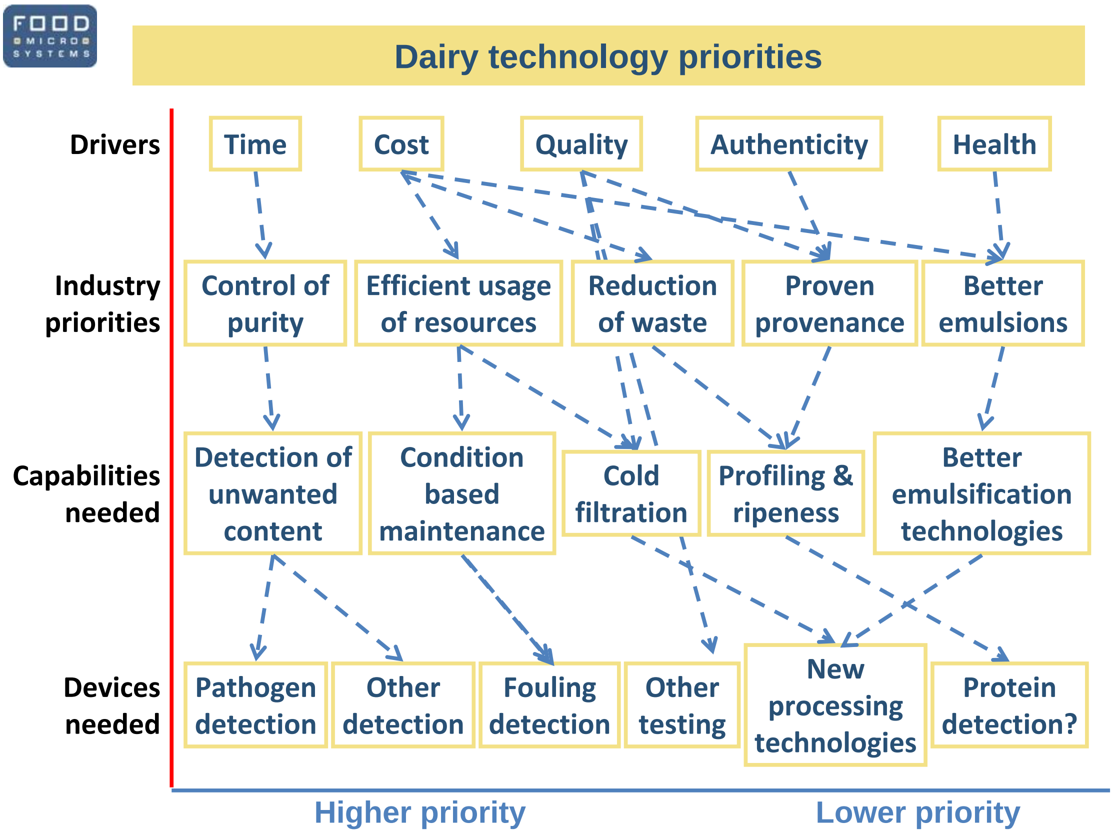


Fig. 2.2.2: Dairy industry: from drivers to technologies needed (Source: enablingMNT)

A second big item is the time between cleaning of dairy installations. Increasing the uptime of the installations and the interval between cleaning will lead to less energy consumption, decrease of chemical usage and decrease of total processing costs. To enable this, efficient ways of detection of fouling are needed.

Another way of decreasing cost (and increasing the quality of the products) is to replace heating as sterilisation method by filtration. Better emulsification technologies, leading to better defined emulsions, is also an example where new technologies can have an impact.

Other drivers behind the need for innovation in the food supply chain are (1) the demand for more resource efficient processing and logistic – driven by the industry perspective, and (2) the demand for higher quality food with proven origin – driven by the consumers' perspective.

Lastly many kinds of profiling technologies are needed. This will enable better defined selection of incoming materials but also of outgoing products.

Across the dairy supply chain, sensing (measuring, testing) is the most wanted technology in the dairy industry, where microsystems can play a key role to address the above mentioned drivers for safety and quality, but also for cost, authenticity and health.

2.3 The need for testing & measuring

In general it makes sense to do testing as early as possible in the supply chain, for instance, a sensor in the milking robot. Yet further tests might be required later in the logistic chain, where new contaminants can occur. The specific places to test the quality of the milk are:

- During milking
- After milking at the farm
- Before collection / at delivery to the factory
- During dairy processing (on-line, in-line, off-line)
- In the package
- At home

Final product control in milk is not that important as a lot of effort is already made during the process control. On the other hand, cheese needs some final product quality analysis to check how bacteria acted on the cheese and for the general "look and feel" quality that the consumer uses for the selection of cheeses at the retail store.

2.3.1 Where to measure?

To assure total quality and safety of the products and at the same time deliver as quickly as possible, the whole process must be managed and optimised. This can be achieved by fast measurements along the chain and rapid feedback systems for process control. Sampling and analysis can be done in-line, on-line, at-line, near-line or off-line. There exist several definitions of these terms and their distinction is not always clear. In the following, we define these terms according to[16]:

- **In-line:** the measuring point is situated in the main process line enabling direct feedback for process control (direct sensor measurement)
- **On-line:** data on a process stream segment is available in real time or with a short delay after the segment has passed the measuring point (measurement on a sample)
- **At-line:** samples are taken from the process line and analysed with instruments located in the production area (small benchtop laboratory system)
- **Near-line:** samples are taken from the process line and analysed with instruments located near the production area (benchtop laboratory system, possible shared by a number of production lines)
- **Off-line:** none of the aforementioned are applicable, usually samples are taken from the process line and analysed in the laboratory (classical laboratory analysis)

The following table summarises key parameters of the aforementioned categories:

Parameter	Off-line	At/near-line	In-line
Measurement time	> 1h	0.2h	Immediate
Sampling interval	1h	0.5h	Immediate
Measurement uncertainty	1%	30%	50%
Process controllability	0.46	0.73	0.87
Remaining disturbance	90%	70%	50%

Fig. 2.3.1: Table: Summary of key parameters of different analysis types (adapted from [2])

From the table it can be seen that not only time is a crucial parameter, but also the measurement uncertainty is highly variable. This is mainly due to the fact that for off-line analysis, skilled personnel, sophisticated instruments, validated and standardised procedures including calibration and quality control are available. At-line instruments are considered as a compromise between time/costs and accuracy. In-line and on-line methods provide the fastest results, yet the accuracy decreases to approximately 50%. Considering the controllability of the complete process (with values between 0 and 1), in-line and at-line methods are clearly advantageous over off-line methods, which make the process hardly controllable due to the delay in time. The remaining disturbance directly correlates with the process controllability and is therefore favourable for in-line and on-line methods more than for at-line or off-line.

To achieve the highest possible level of safety and quality, i.e. total process control, fast and cost-effective analysis methods should be included in several segments along the chain. In the next chapter, the parameters to be measured along the chain are discussed with respect to existing solutions and technologies.

[16] G. Smit, Dairy processing – improving quality. Woodhead publishing, 2003

2.3.2 What to measure

The main need is to control the production process in the dairy supply chain: from cow to raw milk (measuring quality and contamination). Secondly it is about quality control (analysis of final dairy product):

- Specific sensors / analysis for liquid dairy products (e.g. yoghurt, milk)
- Specific sensors / analysis for creamy to solid dairy products (e.g. cheese, butter, cream)

The third aspect is cleanliness: thickness and characterisation of bio-film, residue of cleaning materials, milk-stone. Further down the list, we find items related to the product quality and properties; knowledge about dry matter content and profiling leads to better process control & less low quality / low price products.

Overall, the following categories of parameters need to be measured:

- Cell count of micro-organisms
- Detection of specific micro-organisms
- Chemical residues
- Composition of the product (fat, protein and dry matter content)
- Physical parameters like temperature, etc.

The list of specific items to be tested for in the dairy industry is large and diverse. Examples are given below:

1) Pathogens and other organic ingredients and contaminants: herbicides, pesticides, antibiotics, dioxins/PCBs, allergens, mycotoxins, native protein vs. denatured protein, lactose
2) Inorganic ingredients and contaminants: pH, detergents/residual chemicals from cleaning, heavy metals, water activity: linked water vs. free water
3) Physical parameters: pressure and temperature during pasteurization, viscosity measurement before separation, humidity (in cheese), density
4) Information about cells, somatic cell content, fat content, dry matter (quantity)

Not in all cases above the use of microsystems makes sense and not always testing on a large scale is economically attractive.

The two decisive factors for proposed test methods are **cost of test** and **time to result**, considering that sensitivity, selectivity, accuracy and quality of results can be achieved at some point. But also this differs for the different application areas (depending on where in the chain the test will be and what will be tested).

Generally spoken, tests should be low cost, easy to operate, and fast. However, as will be discussed later, testing cost have to be related to the amount of material tested and to the value it provides; also, not all tests in the dairy chain need to provide fast results:

For instance to test milk for cheese production, a 24 hr time frame is no problem for the total test procedure. But in general the main driver for microsystems in the dairy chain is the need for shorter time to result:

- Faster tests will minimise product loss by early removal of suspected batches.
- It will enable early response to production problems.
- Tests can optimise the use of the equipment by optimising maintenance procedures and time.

A critical point is the sensitivity, i.e. which concentration needs to be detected according to the regulations/needs and which concentration is realistically detectable with microsystems now and in the near future.

3 Roadmaps for safety and process & quality control in the dairy sector

The prevention of safety hazards is one of the key challenges that the food industry is facing, and a high priority here is on detecting / preventing a possible hazard as early as possible in the production chain as opposed to a sole finished product inspection. This needs an industry wide effort, to align available competence and to create solutions that fit optimally in so important segment of the European industry. A systematic preventive approach to food safety and allergenic, chemical, and biological hazards in production processes that can cause the finished product to be unsafe, and designs measurements to reduce these risks to a safe level developed is known as "Hazard analysis and critical control points (HACCP)[17]". The HACCP system builds on seven principles and can be used at all stages of a food chain, from food production and preparation processes including packaging, distribution, etc. The International HACCP Alliance was launched in 1994 to provide a uniform program to assure safer meat and poultry products. It is housed within the Department of Animal Science at Texas A&M University. Later the focus had been extended to all other food areas, including dairy. More information is available at www.haccpalliance.org.

3.1 Safety aspects - detection of unwanted biological and chemical contents

Food safety is high on the agenda in many countries. The most common contaminants to be tested for are pathogens (Salmonella, Listeria, E-coli, etc.), pesticides, allergens, and, at least in Europe, GMOs (genetically modified organisms).

It makes sense to do contamination detection as early as possible in the supply chain, for instance at the farm or at the entrance of the dairy factory. If done at the farm, it is still possible to isolate suspected batches from the good ones. Besides pathogen detection, also the quality of the milk (fat, protein, cell etc.) is to be measured. (Having consequences for payment to the farmer and determining the optimal processing route.)

In this chapter, the most critical "unwanted" substances to be tested for in the dairy chain are briefly described and their detection methods analysed. The contaminations can be grouped in the following categories:

1. Microbiological contamination
2. Chemical contamination, residues and other unwanted ingredients

3.1.1 Microbiological contamination

From the discussions during the FoodMicroSystems workshops and from interviews with stakeholder communities it was concluded that one on the most urgently needed capabilities was better (faster, cheaper) detection methods for micro-biological contamination in food, especially to be used during food processing. In addition to pathogens (bacteria that make sick), there are micro-organisms that cause spoilage or interfere with processes (e.g. cheese making) and the ones that are beneficial. Pathogens and process interfering organisms need to be detected; spoilage and beneficial organisms usually need to be quantified.

Consumers are becoming increasingly aware of food contamination and its consequences on consumption. In the USA alone about 5000 deaths each year are caused by contaminated food[18]. There are already many regulations for food handling and testing, and it is expected that there will be more in the future. Not surprisingly the market for food safety tests is large and, according to Research and Markets, has been steadily growing in parallel to the increasing availability of new rapid microbial detection methods. Time to react is important and directly related to cost of processing. Particularly of interest from an economic point of view are bacteria that spoil the cheese-making process and bacteria and spores, that can develop into new organisms that limit the shelf life of milk. Pathogen detection needs to be as fast as possible, since any batch will only be released after the results are known. If the dairy company can guarantee that there are no pathogens in the milk, sale of unpasteurised milk might become possible[19].

Method	CFU*	Entero-bacteria	Listeria	Salmonella	Yeasts & mould
Cultivation methods	72 h	48 h	96 h	96 h	96 h
PCR**			30 h	26 h	

**Colony forming units as a measure for the total viable organisms, **Regular PCR cannot distinguish between live and dead microorganisms and also detects DNA in the absence of microorganisms.*

Table 3.1.1: Overview on analysis times and methods for some food and dairy relevant pathogenic microorganisms (Source: Fraunhofer-IME)

Pathogens account for the largest share in the global food safety testing market, owing to their large prevalence in food types such as meat and vegetables and their severe potential risks. For detection, the most used methods are based on time consuming culture enrichment processes, but more rapid methods based on immunoassay and PCR-based technologies are increasingly used. Those new detection methods offer more sensitive testing, but are still off-line laboratory

18 Numbers from World Health Organization

19 See the chapter about fractionation, were microfiltration is discussed as an option to remove bacteria from skimmed milk.

centred approaches and time consuming: currently it requires two days to determine if there are spores in the milk. An example of a new kind of detection, potentially in-line, is a sensor that detects gases developed by the spores when developing into new organisms.

If pathogenic bacteria or their spores are not destroyed during treatment of milk (heat treatment, filtration, or others) the initial (often low) contamination of milk may develop during processing or curing, e.g. in the cheese, and reach dangerous levels for human health. Furthermore, the presence of pathogenic bacteria in the dairy plant increases the risk of colonization of the plant environment with these bacteria having the ability to form bio-films which are subsequently very difficult to eradicate. The microbial composition of milk and dairy products is key information and therefore required by the dairy industry. Regardless if fermentation is desired (e.g. yoghurt, cheese) or strictly avoided (e.g. for infant formula), the microbiotic state is of major importance. In most cases, there is a **zero tolerance** for pathogenic organisms rather than a tolerance threshold. In particular during the process steps, the absence of even individual pathogenic microbes should be aspired, since they might proliferate during storage or further processing steps. The range of pathogens that might pose a risk in food is large (see annex A1.2), however, some represent a higher risk for the consumer then others as shown in the following table:

Organism	Shed directly in milk[#]	Contaminant of raw milk[##]	Survives pasteurisation	**Severity of illness[§]**	Dairy/dairy products implicated in food-borne illness
Aeromonas spp.	×	✓	×	Serious	+
Bacillus cereus	×	✓	✓	Moderate	++
Brucella spp.	✓	✓	×	Severe	+
Campylobacter jejuni/coli	×	✓	×	Serious	++
Clostridium botulinum	×	✓	✓*	Severe	+
Clostridium perfringens	×	✓	✓	Moderate	+
Corynebacterium spp.	✓	✓	×	Serious	+
Coxiella burnetii	✓	✓	×	Serious	+
Cryptosporidium	×	✓	×	Severe	+
Enterobacter sakazakii	×	✓	×	Severe^	++
Pathogenic *E. coli*	×	✓	×	Severe	++
Listeria monocytogenes	✓	✓	×	Severe^	++
Mycobacterium avium subs. *paratuberculosis*	×	✓	×	–	–
Mycobacterium bovis	✓	✓	×	Severe	+
Salmonella spp	×	✓	×	Serious	++
Shigella spp.	×	✓	×	Serious	+
Staphylococcus aureus	✓	✓	×**	Moderate	++
Streptococcus spp.	✓	✓	×	Serious	+
Yersinia enterocolitica	×	✓	×	Serious	+

transmission through udder; mastitis etc
via faeces, the environment etc
* neurotoxin is heat labile
** enterotoxin is heat stable
^ for vulnerable populations
§ based on ICMSF (2002) severity ranking[9]
– No data/unknown
\+ Reported, but rare
++ More commonly associated with food-borne illness

Table 3.1.2: Summary of bacteria in the dairy food chain (Source: A Risk Profile of Dairy Products in Australia, Food Standards Australia New Zealand, 2006)

Furthermore, some products are more prone to pathogen contamination then others. See below.

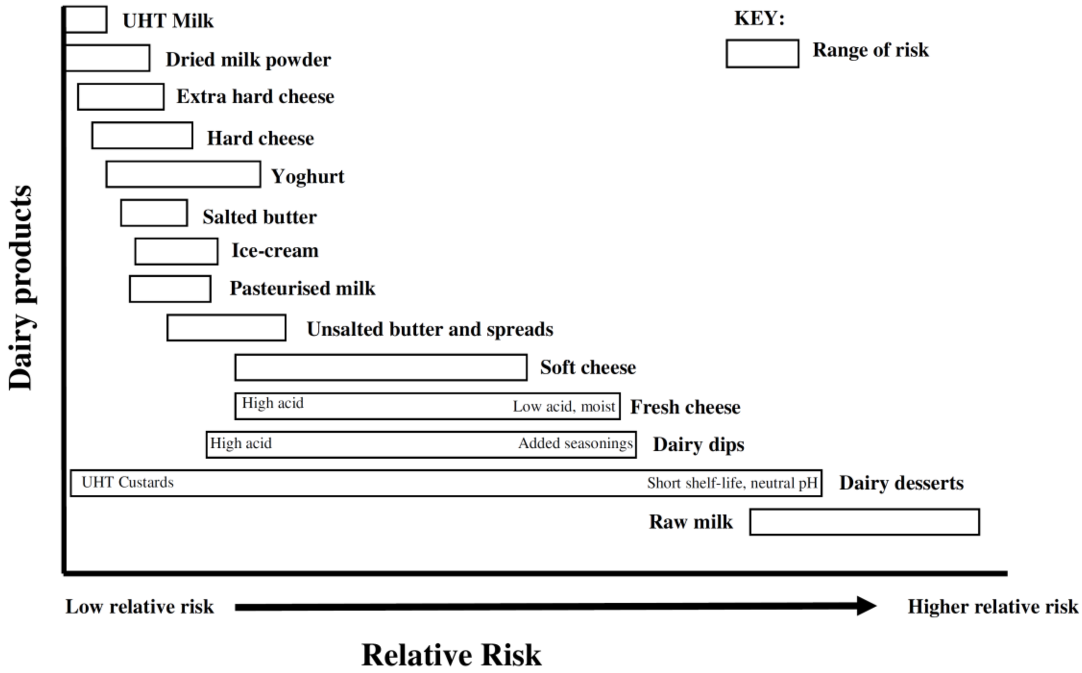


Fig. 3.1.3: Table: Summary of micro-organisms considered in the risk profile (Source: A Risk Profile of Dairy Products in Australia, Food Standards Australia New Zealand, 2006)

It can therefore be concluded that the number and type of specific sensors can differ substantially from one process line to another.

State of the art of microbiological analysis and pathogen detection

Although many sensors are developed specifically for this industry, it is important to mention the observation that this segment can often use technologies that have been developed for medical diagnostics, where many demands are similar.

Any pathogen can be detected as long as one takes the time and the effort to do the test. Up to date these tests require fully equipped laboratories and are elaborate, expensive, and time consuming. The state of the art in this field consists of a complex set of activities to prepare the sample, label the target and detect the microbiological contaminants/pathogens to be identified (PCR, concentrating, labelling and fluorescence detection)[20]. This is a standard lab procedure which can be done for an affordable price, but which takes a long time (one to several days).

An overview of common laboratory detection methods is given in the following figures:

[20] There are other methods, but this method is seen as a starting point for further innovations.

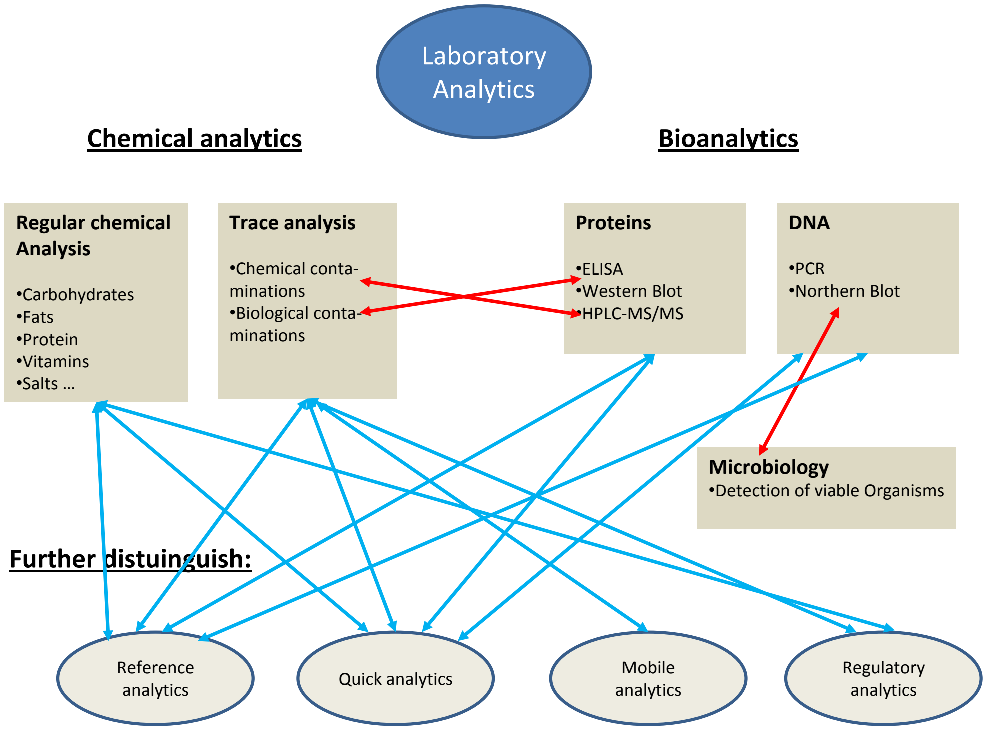


Fig. 3.1.4: Laboratory analysis methods (Source: Fraunhofer-IME)

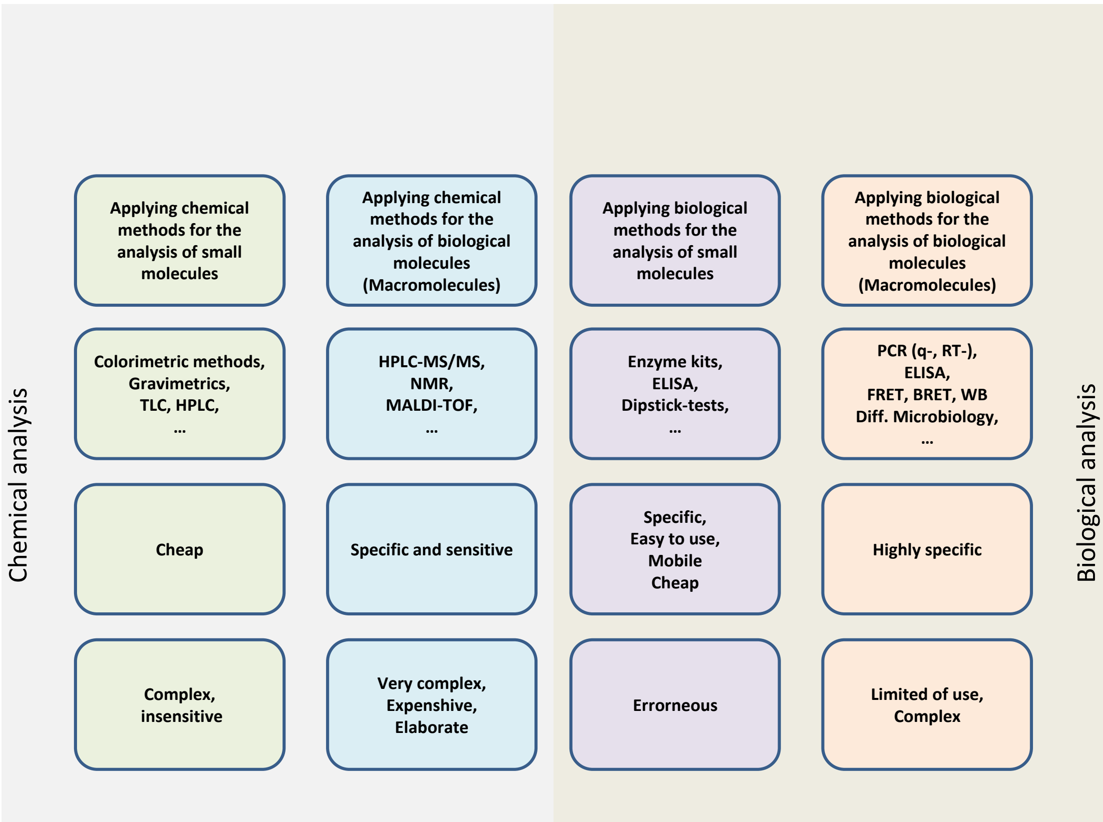


Fig. 3.1.5: Chemical and biological laboratory analysis methods (Source: Fraunhofer-IME)

For most detection targets, several analytical possibilities exist. The decision for the method of choice is usually made upon:

- Detection level
- Accuracy
- Urgency
- Cost
- Availability of required equipment and personnel

PCR is a time consuming activity accounting all steps from start to final results, but the throughput can be substantially increased by using integral microfluidics approaches: e.g. <2 h compared to 24h in conventional systems is possible. The particularity of RNA-based Reverse-Transcription-PCR (RT-PCR) is that it leads to the detection of living molecules/pathogens. With direct biosensor-type sensing, usually dead and living organisms are detected. Detecting RNA could overcome this problem as RNA is short lived and therefore an indication of living organisms.

However, while the detection with laboratory instruments may take about 45 minutes and could be reduced to 10 sec through direct sensing, the bigger challenge is to reduce times for sample preparation, intermediate steps and the transport from one workbench to another to much less than the current state of the art, which is at least one working day.

Sample preparation - Increasing the sensitivity of the system can be done by pre-concentration. The following three methods are generally used:

- Adhesion to fixed structures like pillars or herringbone structures covered by antibodies and washing. (Note: three dimensional structures can also be used to increase sensor sensitivity),
- Adhesion to particles, which can be concentrated. For instance magnetic beads, as is proposed for instance by Philips,
- Filtering & washing.

Newly proposed techniques based on fast sample preparation / pre-concentrating:

- Innosieve uses a filtering technique with a fully automated read out, and the whole set up makes it a lab technique; it is not suitable for use in-line or on-line. But the time to result is significantly shorter compared to conventional systems.
- Fraunhofer-IME proposes a Mobile High-Speed Detection of Microbial contaminations via microfluidics-based PCR: A microfluidics-based PCR system enables a mobile at-line performance of tests for microbial contaminations. An aliquot of a test solution would be mixed with a master mix containing all ingredients required for the amplification of genetic material. This mix is pumped along serpentine cavities within a waver, and passes thermo stages of 60°C, 72°C and 95°C for 30 times. In this process the desired gene is amplified, only in case it was present in the test liquid. For the detection, microsystems technologies provide a variety of possibilities ranging from fluorimetric to spectroscopic or other microelectronics based

sensors. This procedure would reduce or eliminate a long sample preparation and could also be applied to surface extracts from process-lines of the dairy industry.

The easiest way to breakup cells, single cells or as part of whole tissues, is lysis with alkaline buffers and/or detergents or the destruction via heat treatment. Both methods are state of the art. Alternatives proposed are ultrasonic or mechanical methods. A rather difficult issue, however, is the creation of liquid sample solutions out of solid samples. Another challenge is the avoidance of contaminations with foreign DNA which readily causes false results due to the high sensitivity of DNA/RNA based methods. A few bench-top devices are available for automated DNA-clean-up that focuses on the avoidance of such contaminations. However, even when using sophisticated machines at all individual steps, microorganism detection remains a multi-step full lab procedure. Only the integration of all steps in a single device can reduce the risk of false results to an acceptable level.

The following table provides an overview of the process steps involved in micro-organism detection via genetic material and their impact on time and cost:

Method	Price	Time	Contamination risk, risk of losing material
Sampling	+	+	+
Cell lysis	O	-	+
DNA/RNA cleanup	+	+	+
Reverse transcription	+	+	+
Amplification	+	+	-
Separation of Amplicons	O	+	-
Detection	+	+	-

+ demand for optimisation, o neutral in this regard, - no need for optimisation

Table 3.1.6: Process steps involved of micro organism detection via genetic material and their impact on time and cost (Source: Fraunhofer-IME)

One way of optimising both, speeding up testing time and omitting the need of specially trained technical staff, could be to reduce or even avoid extensive sample treatment (i.e. clean-up, amplification). Reducing/skipping sample preparation time is not enough to achieve acceptable testing times; also more sensitive sensors are needed. This can be aided by miniaturisation.

Miniaturisation decreases the processing / transportation times within the detection system by using shorter microfluidic pathways. This leads to further integration of the sensor and for example microfluidic components. This may take place in two steps. The first could integrate microfluidic components and the sensor in one package. The next step could then integrate all the functionalities on one chip. Such an approach is expected to lead to test systems that operate in minutes and maybe even seconds instead of hours to days. Even more importantly, it will bring back the cost of tests below one Euro.

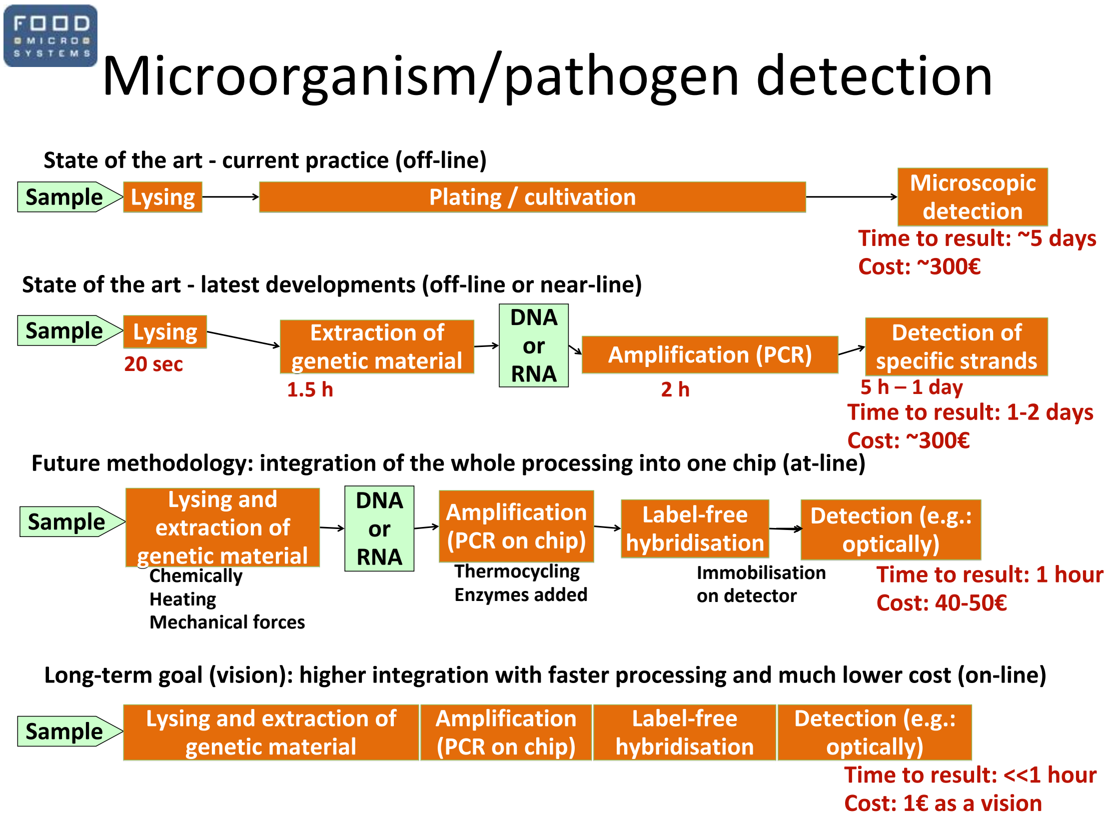


Fig. 3.1.7: "Flow chart" of microorganism detection, with possible improvements towards fast and low-cost µPCR as one example for future direction (Source: Wageningen UR, enablingMNT, Fraunhofer-IME)

To miniaturise and speed up the traditional PCR, different concepts are under development. Based on the initial methodologies and exemplary visions as displayed in figure 3.1.4, the following steps are expected to significantly develop traditional PCR into a fast and cost efficient µPCR of the future (see figure 3.1.5). To extract the fluidic components that contain the organisms of interest, a sample preparation with sieving and filtering methods "on chip" and for solid products an integrated liquid extractor will need to be developed. For the extraction of genetic material, integrated non-chemical methods for lysing as well as methods for the immobilisation of DNA and the reverse transcription RNA -> DNA have to be implemented (provided that work with RNA is preferred for safety assurance instead of simple screening tests where detecting DNA might also be useful). On-chip PCR concepts need to be industrialised and made faster, smaller, more robust and cheaper. For the detection, two options exist: if specificity is to be achieved in the detection, then hybridisation needs to be significantly improved, or detection methods need to become more specific, faster and cheaper. For the second option the different complementary DNA strands will be immobilised on chip and the hybridisation events detected individually. A more sophisticated concept would even allow the simultaneous detection of multi-specific strains / organisms.

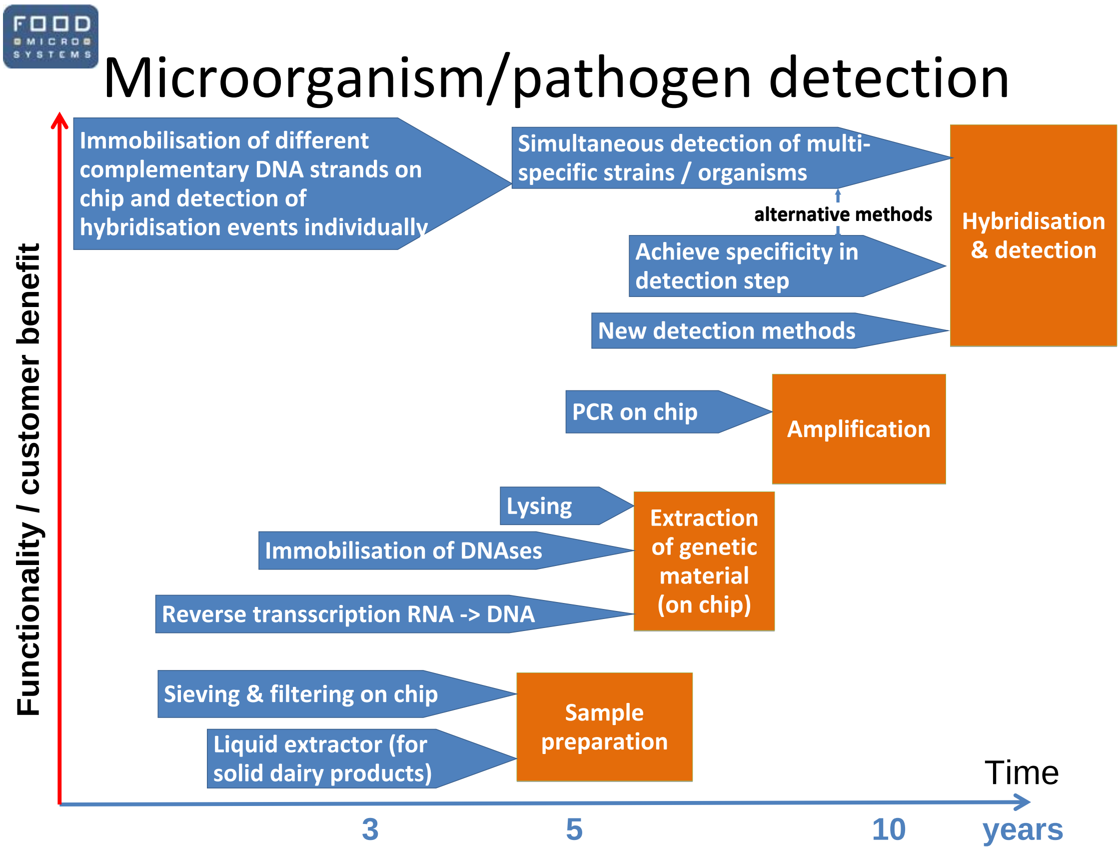


Fig. 3.1.8: Microdevices/components needed for a new concept of a µPCR with the whole process completely integrated in one µfluidic chip

As side effects, those new approaches lead to smaller sample sizes, more automation, possibilities of multi-parameter testing and the avoidance of contamination with foreign genetic material. One of the approaches that can lead to very efficient multi-parameter testing is an electronic nose. Electronic noses combine the information form different sensors into one "picture". From that the presence of certain contaminants is concluded.

There are already several new tests for food bacteria under development as shown in annex A1.2, table A1.2.1. This overview provides us with a good view of what the industry is capable of at this moment and what the major developments are. Furthermore, this allows an estimation of time lines to develop a high level roadmap (see figure 3.1.6).

So far, even for methods that are state of the art from a technical point of view, the implementation in the industry may take decades in the legal/regulatory approval. A key constraint is the current regulation of using 25g samples for official methods. Thus, the developed miniaturised devices may at a first stage only be used for screening. On the long term, legal adaptations are required to pave the way for miniaturised devices and the associated measuring methods to become officially certified methods.

High-level concept roadmap

Testing time is of essence in the processing industry in general and especially the food industry. Bringing the test to the processing line and out of the (external) laboratory is a recurrent theme in any food testing roadmap. The first step is to replace the complicated large equipment used in external labs by equipment that can be used in a factory lab by non-specialists (bench top instruments/ at-line). The next step will bring the test into the processing line in the form of handheld instruments (on-line). Lastly automatic sensors will be placed in the processing line (in-line). Considering the complexity of these research items, the overall approach will be a rather long-term visionary activity. Based on the discussions and a thorough investigation of tests available and in development, 3 major achievements are to be expected following the currently widely used lab instruments:

1. At-line: Benchtop instruments with a response time less than an hour, to be used by trained engineers.
2. On-line: Handheld devices with a response time of less than 10 minutes, used by process operators[21].
3. In-line: Fully automatic sensor devices.

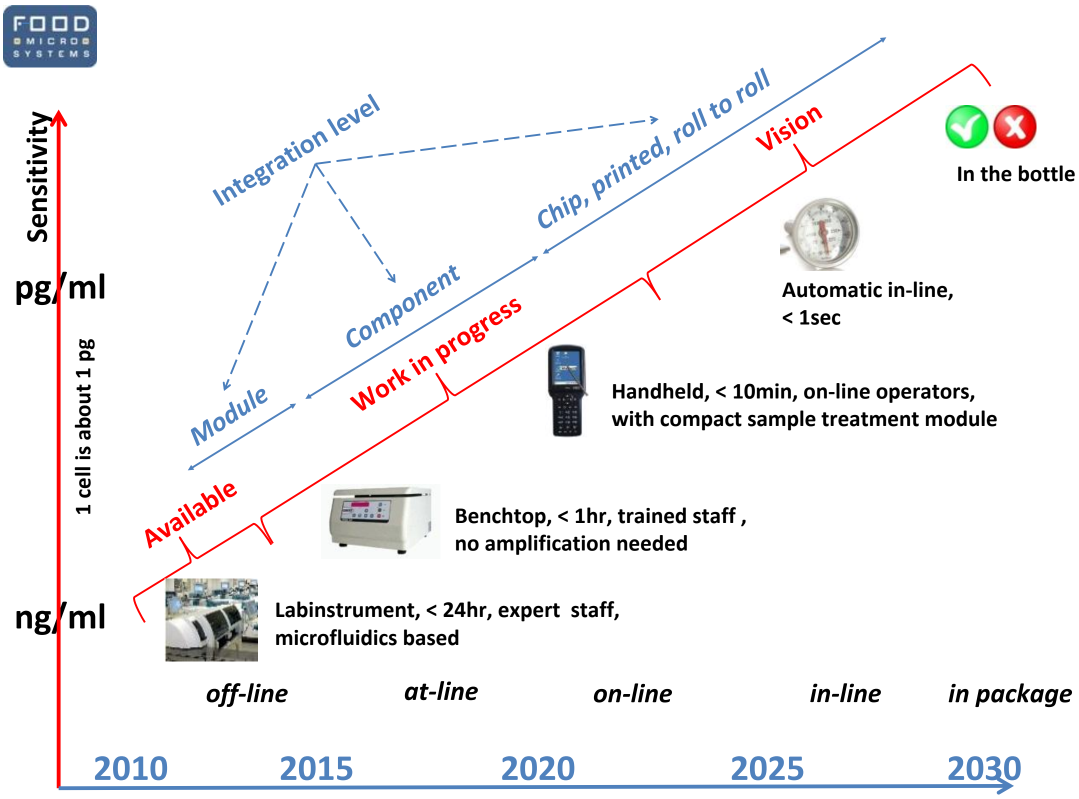


Fig. 3.1.9: High-level roadmap for the detection of microbiological contamination (Source: FoodMicroSystems workshops and enablingMNT)

[21] The same concept might be useful for farmers during outbursts of diseases (think of bird-flu, Q fever etc.)

Figure 3.1.9 outlines a possible technology roadmap for the long-term:

- Step 1: PCR, concentrating, labelling and fluorescence detection.
- Step 2: PCR, concentrating, direct detection with biosensor.
- Step 3: Concentrating, detection with biosensor.
- Step 4: direct detection with biosensor.

It is assumed that amplification via PCR is only suited for offline control due to the inherent complexity and the slowness of this method (high equipment costs only affordable for massive parallel testing), however, there are also concepts that do not require a PCR step. The key performance indicators/ specifications (from a user's point of view) that can be used to check the progress of the roadmap execution are five main characteristics that determine the performance of any proposed pathogen detection system:

- time to result,
- portability,
- ease of use,
- sensitivity,
- reliability.

(All assuming that the cost of testing is acceptable.)

Only the first steps in the process of bringing the lab to the processing line are clearly distinguishable and can be regarded as Work in Progress. Further in time the roadmap becomes visionary. All the technologies needed for the roadmap are already envisioned by researchers and developers. Several concepts have recently been presented, however most of them are still in a state of development or even basic research (see table 3.1.4). It can be assumed that, even if a prototype is already available, it will still take about 3 years before it may enter the market.

An important goal in the development of pathogen detection methods is towards having a generic platform technology that can be used in principle for each pathogen, at least after adaptation. Much work is being done in pathogen detection for medical diagnostics and environmental testing. Several small, fast systems are in development. Practically all these systems deal with liquid samples. It is therefore expected that the detection of pathogens in liquid food will come to the market first.

Vision on applications

It might even be of interest to integrate a sensor in the milking robot. That way even milk from suspected cows or even infected quarters of the udder can be separated from the others. For mastitis, conductivity measurement or cell count might be an option. In-line detection of pathogens should do the trick too, but this idea faces a number of practical problems in terms of robustness, cleanability, etc. In-line detection of pathogens has been investigated by one company at least, but this technology is far away from being market ready. Introduction in the water supply chain will be earlier then in the food supply chain.

A detection system that can be used by the driver of the van that transports the milk must be preferable handheld or at least desktop. It should be able to do the test during the loading or during transport. If it is a fast system, it could also be done at the entrance of the dairy company. Essential is that the device is fully automatic and robust. We are therefore looking for a disposable cartridge based system. The cartridge should cost less than 5€[22].The lower the price of the cartridge, the higher number of potential users.

3.1.2 Chemical contamination, residues, and other unwanted ingredients

These types of contamination can either be environmental or processing contaminants/residues: The first are, for instance, chemicals that are present in the environment in which the food is grown, harvested, transported, stored, packaged, processed, and consumed. Examples are radio nuclides from air or cadmium / nitrates / perchlorates from the soil. Other examples are given in annex A1.2. A summary of the expected sequence of development and industrial take up is given in the following picture:

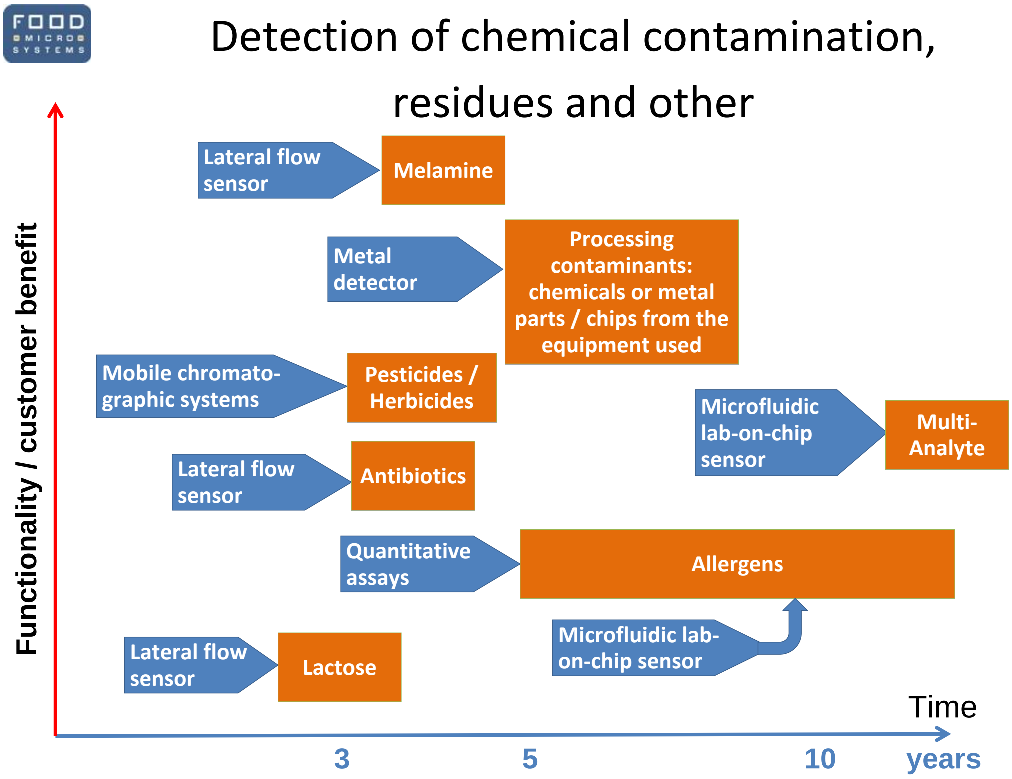


Fig. 3.1.7: Roadmap for the detection of chemical contamination, residues and other (Source: FoodMicroSystems workshops and enablingMNT)

[22] Based on the following rough calculation: There is a wide range of farm sizes in Europe. Suppose a "high end" farm with 200 cows @ 100 l /cow/day @ 20 ct per liter. The value of a batch is 4000 €.

The trends, also in the detection of chemical contamination, residues and other substances is, towards cheap, quick, and specific measurements - perhaps even down to the specific substance or at least down to the chemical class. Preferably mobile devices are envisaged. To keep cost down, multiple parameter sensing is needed.

3.1.3 Conclusions

The area of contamination detection in food is highly diverse in terms of applications and technologies, but very much in development. The market demands differ not only because of the wide range of potential contaminates and quality aspects of dairy products, also the diversity of products (like for instance cheese) and the many country specific regulations needed to be taken into consideration. Thus, there will be several technology developments in parallel and the food sensor roadmap will show several detours, parallel lanes and splitting roads. This makes it difficult, if not impossible, to sketch a complete picture of a long-term roadmap.

Based on the existing detection methods that are usually laboratory based, there are two major paths for development, (1) to improve and speed-up the lab method and (2) to replace the lab method by direct detection. However, in many applications fast and cheap screening (with very few false negatives) based on microsystems would be very helpful in combination with accurate but expensive and slow (golden standard) techniques to check the suspects that were detected in the screening. Thus, a co-existence and co-development of both paths will be of high probability.

An interesting concept could be a standard measurement/detection platform, where only small components (e.g. sensor elements) need to be exchanged for different types of measurements.

One clear trend is that in coming years many more sensors will become available at a commercial level that can increase the quality and safety of dairy products and reduce cost. With more and more individual sensor types being commercialised, the trend to sensor fusion concepts will become visible on a longer term.

As in other food areas, reducing cost is a major driver. Safety and quality tests are not only beneficial for the consumer’s health; when properly used (for instance for early detection of contamination) they can also contribute significantly to cost reduction programs in the food processing industry.

3.2 Process & quality control in cheese-making

Cheese is an important part of the diet in most European countries, as illustrated by the following diagram:

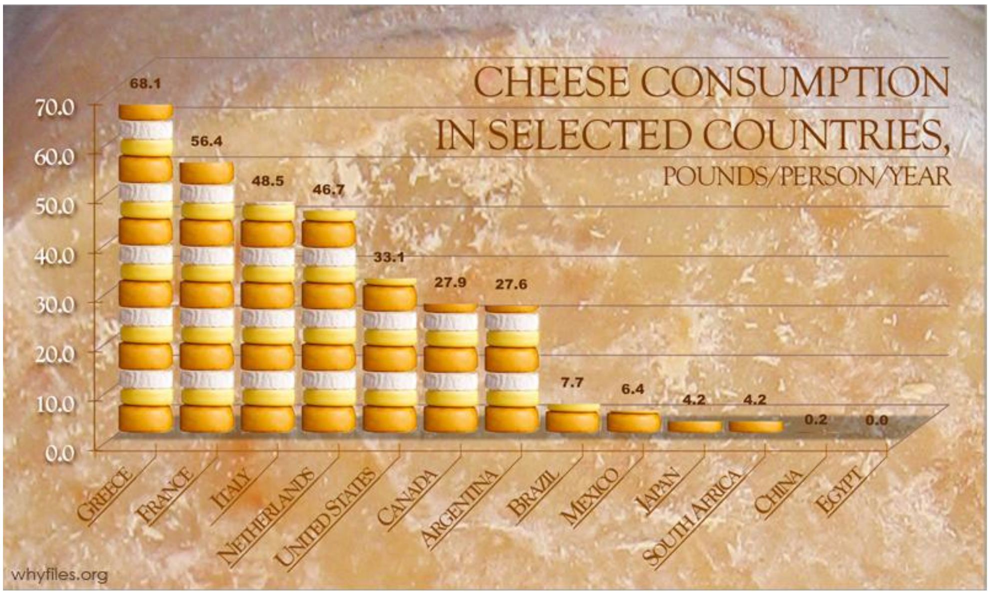


Fig. 3.2.1: Cheese consumption in selected countries (source: Canadian Dairy Information Centre, Agri-Expo, Hoard's Dairyman, US Department of Agriculture)

Most types of cheese worldwide are made from cow's milk, but also from goat or sheep. For cheese-making, the milk is in most cases pasteurised or heat-treated. Some types of cheese are made from non-pasteurised milk: Emmental, Grana, etc. Starting with the quality of the milk, in Europe the cheese must be controlled during its processing according to strict regulations. Yet specific pasteurization requirements differ from country to country due to specific cheese varieties.

Opportunities / demands from the cheese sector

In-line measurement is becoming increasingly important in the quest for more efficient production with less product loss: With an analyser in the lab, measurements can usually be taken once an hour only, thus, the production can be out of specification for a whole hour. And there is also always a certain margin of error due to measurement error and sampling error. Of course, this margin of error also exists with in-line analysis, but with an averaged result every 15 - 30 seconds, the overall margin of error is significantly reduced. For instance, for butter production, with the classical laboratory setup one result per hour is produced and a variation in moisture down to 0.20% can be achieved. With in-line process analysis, up to 120 results per hour can reduce the variation to get below 0.10%. This will enable him to reduce the safety margins in the process and achieve substantial cost savings.

The food supply chain for cheese

The processing of milk towards a variety of cheeses involves a number of steps, of which the main stages are illustrated in the following graph (there are special cheese products that use different processing):

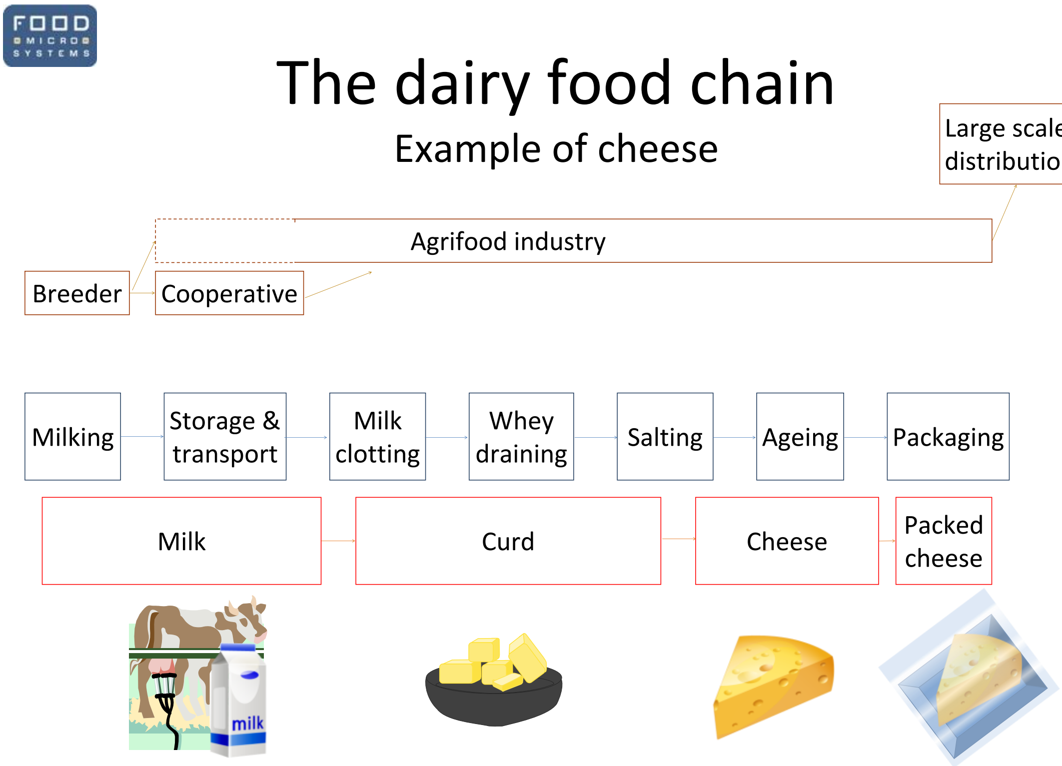


Fig. 3.2.2: The dairy food supply chain for cheese (source: FoodMicroSystems)

The variety of habits and tastes of cheese consumers worldwide on the one hand, paired with the variety of cheeses and their production processes on the other, lead to a large number of process & quality parameters to be controlled.

Below, an example of the different measurements performed during cheese-making is given for Gouda cheese by the University of Waikato[23]:

[23] www.biotechlearn.org.nz

Step	Controls
Testing of milk quality	• Milk solids • Water and fat content • cleanliness (filter)
Milk pH test	• pH is measured three times (throughout a day) to show the decline after addition of starter bacteria
Coagulum test before clotting	• „blade test“: needs to be a clear cut, no residues on the blade
Curd testing before moulding	• manual test: required dryness depends on kind of cheese
Milk tempera-ture check	• throughout maturation of curds the temperature is steadily increased • frequent monitoring and documentation
Testing of cheese before brining	• pH check after pressing • color change (almost invisible) • documentation required
Brine testing	• again check of pH (must be neutral) • salinity test
Firmness test before brining	• manual test of firmness to optimize procedures for next batch

Fig. 3.2.3: Process and quality control procedures during cheese-making of Gouda (adapted from www.biotechlearn.org.nz)[24]

[24] An example of a relative light control. No microbiological control, antibiotics, dry matter, fat content of the cheese.

A discussion of the most common tests in cheese making is given in annex A1.3. From this it can be concluded that the detection diversity is huge, but that not all tests need to be inline. There will be room for established lab based tests. Newer test methods can therefore be seen as screening tools, complemented by certified laboratory based tests.

Prioritisation

During the FoodMicroSystems roadmapping workshops, participants expressed the following parameters as being of biggest interest to be measured, considering areas only where microsystems are expected to deliver solutions in a near-to-medium timeframe.

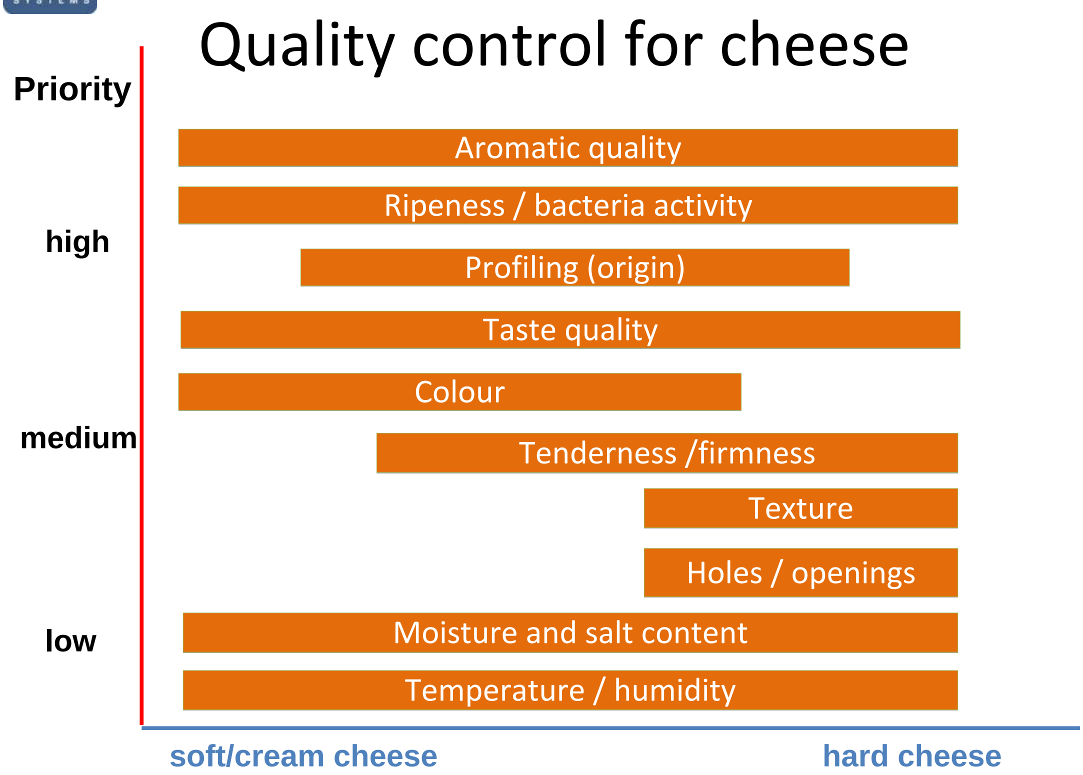


Fig. 3.2.4: Priorities/needs of cheese makers as discussed in the FoodMicroSystems workshops (source: enablingMNT/FoodMicroSystems)

Preferably an in-line or on-line, cost-effective, solution should be provided.

State of the art: technologies and their potential to be implemented/aided through microsystems

Some devices to solve these issues are already available on the market (but might need improvement or cost reduction), while some devices still need to be developed or need major improvements done to be suitable for the quality control in the cheese making industry.

Attribute	Method	Place of action & remarks	Microsystems envisioned?
Profiling, soluble protein content	Fluorescence analyser	off-line, 5 minutes	Long term potential
Profiling, origin	GC/MS	Cost intensive and lab based	Short time: off-line NIRS, long term: Electronic nose, or in-line
Fat content	Hyperspectral imaging		Potentially in-line, high throughput, but no microsystems
Milk clotting	Rotating bottle method	Off-line and time consuming, rotational viscometer proposed	Nothing envisaged
Dry matter	No test available		Nothing envisaged, but needed
Whey protein and denaturation rate	Physical, spectrometric, image sensing	On-line	Long term potential
Aromatic quality	Gas sensor for specific chemicals	On-line or at-line; sensitive to selected compounds in a wide concentration range	Electronic nose, shorter timeframe potential
Taste Quality	Different sensors for ions and organic molecules such as sugars	On-line or at-line during ripening storage	Shorter timeframe potential
Ripeness / bacteria activity	Biological or chemical	On-line	Being introduced in other food packages
Colour	Physical, spectrometric, image sensing	On-line or at-line, depending on storage	Shorter timeframe potential
Tenderness / firmness	Tactile sensors	Manual subjective test	Shorter timeframe potential
Texture	Mid infrared spectroscopy	Off-line	Mid term potential for in-line sensors
Opening/holes characteristics in cheese	Imaging techniques, including ultrasound		Potentially in-line, high throughput, microsystem sensor and actuators, midterm opportunities
Temperature and humidity	Physical	In-line or on-line; already state of the art	Available already - optimisation useful; or integrate in package label
Moisture and salt content	Dielectric sensors	Rapid and non-invasive	Short term opportunities

Table 3.2.5: Parameters for the quality control of cheese products (Source: Fraunhofer-IPM)

In a discussion with technology providers the following technologies were taken into account, being regarded as potentially able to solve some of the more urgent problems:

Near Infrared Spectroscopy (NIRS)
Rational behind the measurement: Determination of composition as well as the quality and authenticity of milk, butter and cheese. The spectra measured are the result of intra-molecular vibrations due primarily to the covalent bonds within molecules. The discriminative power of NIRS lies in the very high signal-to-noise ratio, which enables subtle differences between signals, invisible to the naked eye, to be reliably used to discriminate between samples. NIRS requires relatively small sample quantities and is very fast. The test may take only seconds per sample. NIRS equipment can be placed close to the process line (near-line, at-line). However, the majority of the instruments are not particularly suited to in-line or on-line implementation yet, owing to issues such as sample size, scan time, sample preparation, etc.

Mid-Infrared Spectroscopy
It is necessary to control the composition as well as processing conditions of the cheese in the process line itself. Miniature mid-infrared spectroscopy equipment is used in cheese production plants for determining composition and textural properties, mainly used for the rapid characterisation of cheese and milk. So far, this type of equipment is not suited to be placed directly in the processing line. With the introduction of guided wave optics and linear detector technology, the need of using a broad spectrum of the radiation can be replaced by the narrow spectrum. This will open a path towards miniature equipment suitable for the on-line and in-line measurement of the dairy products.

Imaging Techniques
In dairy processing, information about the surface and internal properties of the products are often judged by humans. Several efforts have been made to mimic human sight to judge the quality and composition of dairy foods in the process line with high speed. This has improved considerably with the introduction of high resolution cameras, and with using monochrome or visible infrared light. Thus, the efficiency of this technology has been enhanced to detect and discriminate between acceptable and unacceptable (including contaminants) products at high throughput rates.

Hyperspectral Imaging
Hyperspectral imaging, like other spectral imaging, collects and processes information from across the electromagnetic spectrum. There are numerous researchers working on HSI technology to determine the quality and composition of dairy products. The optical properties of turbid liquids including milk can be well determined by HSI. The scattering effects or optical properties of milk are correlated with the fat content in milk. By analysing the spatial images, the distribution of food constituents are detected. The amount of protein, fat and carbohydrate can be

determined by using various image data and analysing these data in the perspective of partial least square regression errors. Products with inhomogeneous distribution of the constituents can be assessed by changed colouration of spatial images. Especially for cheese quality control, this method produces spatial images to determinate the fat distribution pattern in the cheese.

Ultrasound Imaging

Ultrasound imaging is also called ultrasound scanning or sonography. It produces real images by exposing the objects to ultrasound waves. Based on the acoustic properties of the objects, some of the waves are reflected while others are transmitted with different speed depending on the impedance throughout the object. These properties are useful to assess the different objects as well as difference within the same objects. Thus the sonography or ultrasound scanning is useful in detecting extraneous materials in the objects as well as quality of the dairy products in a very short time. An important advantage is that it does need direct contact with the product. The sonography can also be utilised for mapping the internal structure of cheese. The formation of cracks, eyes, cheese matrix and ripening age of hard cheese is better assessed by the three dimensional (3D) ultrasound images.

Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) is also known as “nuclear magnetic resonance imaging” (NMRI) or “magnetic resonance tomography” (MRT). This can be used for visualising the internal structure, phase separation, component distribution, rheology and basic structure and composition of dairy food.

Dielectric sensor

Dielectric spectroscopy is a low cost sensing quality system for monitoring dairy products. Dielectric methods use the complex impedance (which is made up of the capacitance and the conductance) as a function of frequency to determine the dielectric spectrum. Dielectric spectroscopy is a real time, very rapid and non-invasive technology for measuring the moisture and salt content of food products, especially cheese and butter. The continuous on-line control of moisture and salt in butter and cheese is very important for controlling the quality of the product. Dielectric sensors are safe, economical as well as efficient and are capable of replacing the labour intensive and costly laboratory equipment.

Process Viscometer

Viscosity is the resistance felt by a liquid during flowing and considered as important quality parameter of several dairy products. The Process Viscometer measures the viscosity of dairy products on-line or in-line and thus helps in the production of good quality milk products as well as initiation of corrective measures to fix a problem during the processing. The viscosity is correlated with the consistency of food and thus directly addresses the preferences of a consumer.

Direct sensing with electronic nose technology

In dairy processing, electronic nose technology[25] can be used to assess aromatic quality or different classifications. However, the term “electronic nose” is somehow misleading, as one might think of sensor technology mimicking or replacing the human sense of smell. Yet electronic noses, comprising sampling technology, sensor technology and data evaluation, are rather a complementary technology to human sensor panels or sophisticated laboratory analyses. They offer a comparably easy and quick way to assess the volatile compound profile of a substance or product, and therefore can be used in a large variety of applications.

Electronic noses are found in many applications in food and beverage, yet only a limited number of studies report the use in dairy processing, probably due to the complexity of their matrices. If chosen, electronic noses are mainly used for milk and cheese. Table 3.2.2 gives examples of electronic noses potentially used in the dairy chain.

Milk	Cheese	Dairy
Ageing and shelf-life prediction	Classification by cheese variety and aroma	Classification and quantification of off-flavors
Classification of bacteria cultures	Detection of “rind-taste” in Swiss Emmental cheese	Classification by the geographical origin of a dairy product
Classification of milk by trademark, fat level, preservation process	Classification of cheese by ripening stage	Evaluation of Maillard reactions during heating process
	Detection of mold in cheese	Identification of single strains of disinfectant-resistant bacteria in mixed cultures

Table 3.2.2: Application examples of electronic noses in the dairy chain (Source: Fraunhofer-IPM)

Roadmap

For the aspects of highest priority to cheese makers, an assessment of possible microsystems-based devices or functions (in case devices do not exist yet) has been made:

[25] Ampuero, S., Bosset, J.O., The electronic nose applied to dairy products: a review. Sensor and Actuators B 94 (2003), 1-12

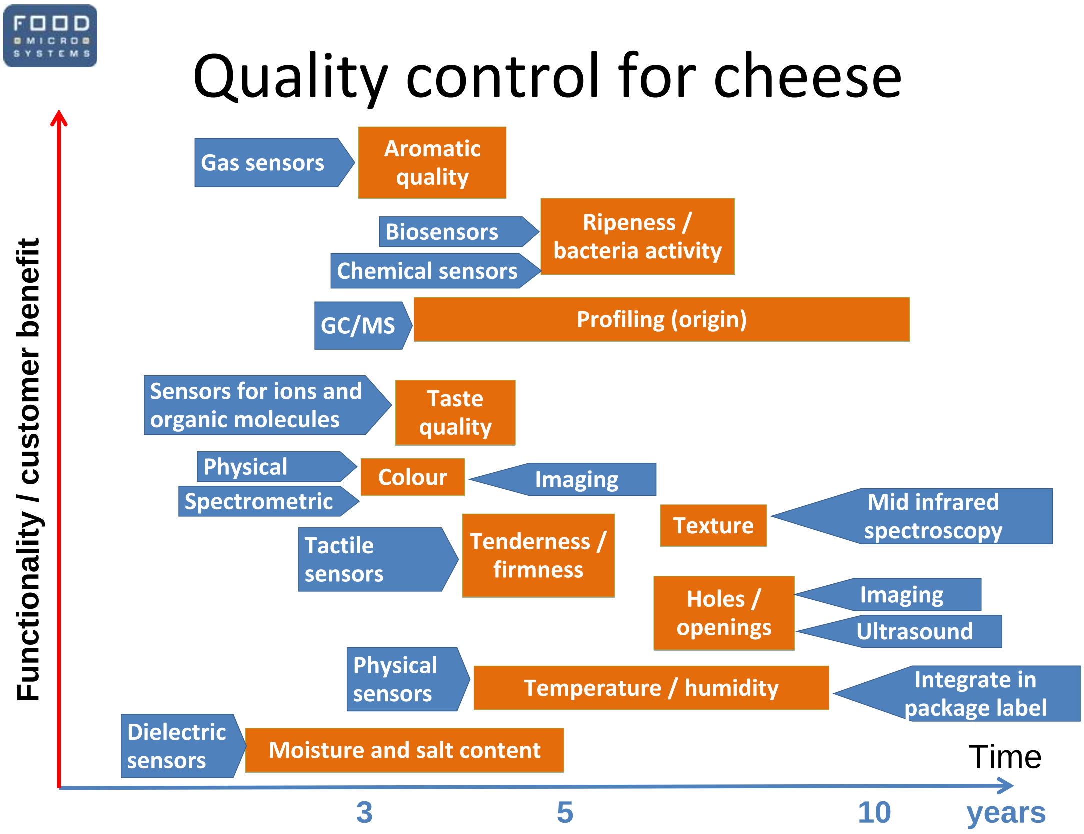


Fig. 3.2.5: Devices/functions needed for cheese quality control (source: enablingMNT /FoodMicroSystems)

Conclusions

For the process and quality control of cheese products, a number of parameters are of interest - many of them are measured with “human senses” (smelling, tasting, touching, comparing colour, etc.) so far. The cheese processing industry requires increased automation for faster and more comparable results (i.e. physical-chemical parameters) and **at lower cost**.

Lower cost of the cheese production can be achieved through:

- faster measurements (and detection of problems),
- improved quality (less waste of products),
- improved yield,
- longer “run-time” of processing equipment.

Additionally, better “look and feel” quality of cheese products may lead to higher sales prices; thus, improving quality of cheese can also have an impact on this aspect. However, this seems to be only a minor aspect of making money in the food industry these days.

3.3 Cleaning and maintenance in dairy processing

As in many other food processing industries, the key environmental issues associated with dairy processing are the high consumption of water and energy. Cleaning is a major cause for the high consumption of water and energy, and thereby substantially contributing to the processing cost and environment. Another important cost factor is maintenance due to its impact on the utilisation of equipment with two aspects, “off-time” and wear-out of equipment. According to the European Roadmap for Process Intensification[26] a 20% capacity increase and 60% energy reduction in food processing is possible by a combination of increase of cleaning efficiency and reduction of fouling. This chapter set out a more detailed roadmap towards achievement these goals.

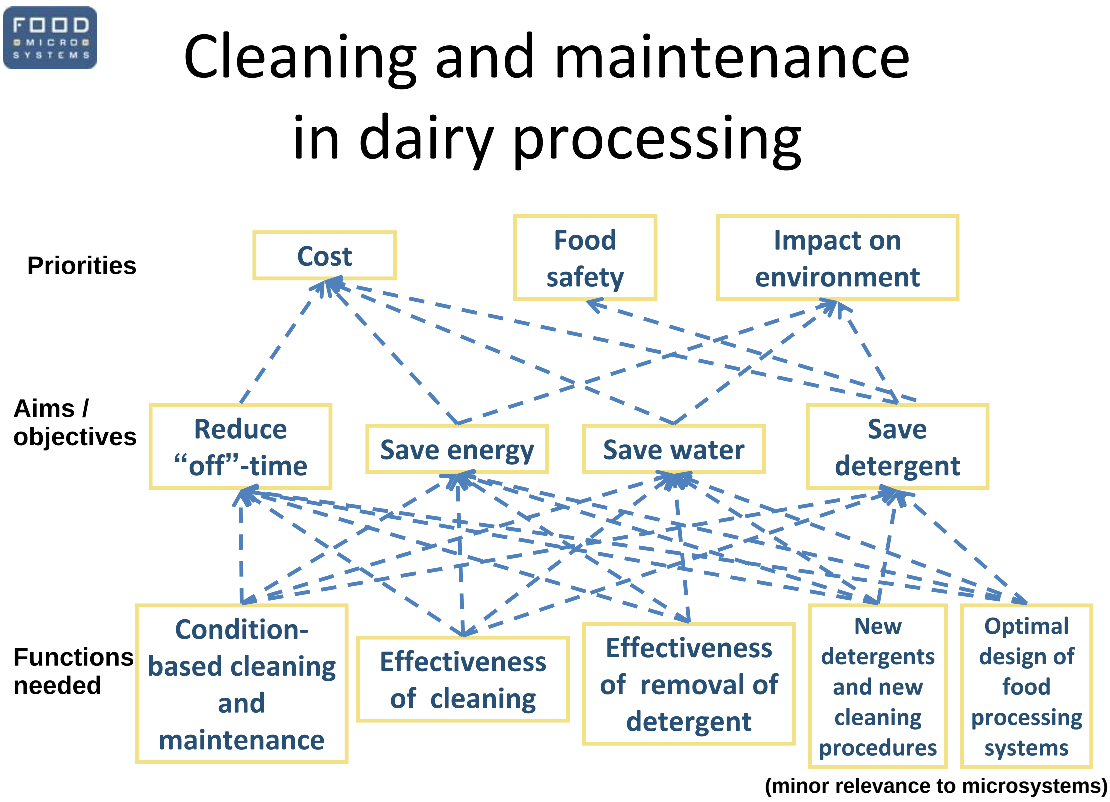


Fig. 3.3.1: Cleaning and maintenance – from priorities to functions needed (source: enablingMNT)

Currently cleaning and maintenance are in most dairy (and food in general) processing factories planned at a regular base, irrespective of the real need. To be on the safe side, there are more cleaning and maintenance sessions planned then might be necessary.

---

[26] Creative Energy (2008). European Roadmap for Process Intensification (2008). The Netherlands, (www.creative-energy.org)

Opportunities for and demands from the dairy processing industry

Condition-based maintenance, also known as "predictive maintenance" is maintenance based on real-time assessment of the system's condition obtained from embedded sensors and/or external tests and measurements using built-in diagnostic equipment. This promises enhanced effectiveness of maintenance programs, preventing unplanned downtime, making better use of maintenance resources, and maximizing the operational life of the asset.

For all cheese factories that had been interviewed by FoodMicroSystems, cleaning operations had been identified as a key area for improvements, where microsystems can find applications, even on a short term. Performance monitoring and optimisation of units of Cleaning in Place (CIP) would allow a significant gain in productivity by:

- a decrease in cleaning time that allows a lower cost of cleaning labour and a greater availability of production equipment;
- a decrease of water consumption;
- a decrease of energy consumption;
- a decrease of detergents consumption.

When to clean

Cleaning is done to remove residues of previous batches of the product and to remove and/or prevent fouling. Fouling, the build-up of a layer of bacteria, is a complex phenomenon in food processing and happens in varying rates and thicknesses. Control of fouling is essential in relation to process performance, energy consumption and water management. Monitoring fouling during heating and cleaning can provide useful information for operation of the plant. Various devices to do this have been reported in literature[27]. As the fouling can't be seen from the outside, most existing methods are based on its effect on heat transfer or pressure drop. Alternative methods based on checking the properties of the fluid are usually not suited for an industrial environment.

Currently the best method to monitor fouling and its subsequent cleaning is a sensor using differential thermal analysis. However, this method is also an indirect measurement: instead of measuring the actual fouling in the system, it measures the fouling on a sensor system, which is supposed to give a good indication for the fouling in the system itself. This method is intrusive, i.e. the element for monitoring must be put inside the pipeline.

Methods based on ultrasound are potentially advantageous while they are not intrusive and register fouling at the equipment itself instead of only on a sensor. Variations of amplitude and frequency signatures, resulting from the presence of

[27] J. Crattelet et.al, Journal of Food Engineering 119 (2013) pages 72-83.

inner tube fouling layers are analysed and used to come to an estimate of the fouling thicknesses[28].

Indirect measurement based on pressure drops in the systems, or sensors that check the fouling on them with differential thermal analysis		
Configurable monitoring ranges:	0-1 mm or 0-5 mm	Accuracy of ± 50 mu
Response time:	< 5 minutes	
Running conditions:	0-150 C (<1 C/min)	up to 20 bar max.

Table 3.3.1: Detecting fouling - state of the art (Source: enablingMNT, based on J. Crattelet et.al, Journal of Food Engineering 119 (2013) pages 72-83.)

When to finish cleaning

For further improvement of productivity, determining precisely when cleaning is needed is not sufficient. Presently, the length of cleaning cycles is based on empirical means. Dairy companies need to have a reliable means of monitoring the effectiveness of their cleaning so they can precisely control and thus minimise cost and environmental impact of cleaning operations, particularly while in 99% of the cases so far, cleaning is overkilling.

When to re-start production

In addition, there is a need to determine when the detergents have been eliminated and production can start again.

State of the art methodologies and their potential to be implemented/aided through microsystems

Currently the following checks are used to monitor the effectiveness of cleaning:

- upstream controls to check the good application of instructions for use of detergents to bring a good efficiency to cleaning products (detergent concentration, exposure time and temperature);
- monitoring of water consumption and products used by the cleaning station is also carried out (weekly or monthly) to identify any drift;
- regular visual inspections of surfaces (wall tanks, valves inside…), detergent solutions and rinsing solutions can allow to identify dysfunction in the cleaning step;
- disinfection monitoring is performed by direct or indirect bacteria count;
- quantitative tests which measure the whole population of microorganisms present on the surface. Depending on the desired response time, these tests are performed either by conventional counting or by indirect method like ATP-metry;

[28] J. Silva, Sensors & Transducers, January, 2010

- qualitative tests for determining species of microorganisms. In some cases, whole microbial count is not good enough to evaluate the effectiveness of cleaning. The absence of pathogenic species is often necessary to demonstrate the effectiveness of the cleaning plan.
- testing with coloured pH indicators are also used to visually evaluate the quality of rinsing;

All these tests give an idea of the fouling and of the level of bio-contamination at a given time but they are not sufficient to control the process of cleaning and disinfection. This evaluation is only possible through the use of online sensors related to the automation which drives the cleaning station. Therefore, there is not only a need for sensors to see if a cleaning process is needed, but also a need for in-line sensors to decide if it is clean or not: e.g. measuring pH, presence of bacteria, and presence of fouling layers.

Possible methods are electrical, to determine the layer thickness inside the pipe, instead of systems based on checking the fouling layer on a sensor. If this layer grows thicker than a certain value then the cleaning is needed. There are some companies which measure this thickness but the methods or techniques involved have not been disclosed. Resonant sensors or electrical impedance measurements might be used. Magnetic measurements could also be feasible but it's not clear at this stage.

Microsystems are needed in this area, not so much because of their performance gains, but more because they offer a route towards small handheld on-line or even in-line monitoring systems. Microsystems enable bringing the tests towards the production line and to shorten reaction times.

Alongside the cleaning efficiency, the interviews also identified a need for controls on the persistence of cleaning products. Indeed, cleaning products may pollute the raw material and cause problems in the lactic fermentation necessary for the fabrication of many dairy products. However this problem does not seem to have any options of using microsystems.

Essential for the design of food processing systems is the understanding of role of the used materials (especially its surface) in the fouling process. In this area, three major topics were identified:

- Qualification and quantification of interactions between materials and cleaning products;
- Sensitivity of surfaces to the development of biofilms;
- Monitoring of the mechanical properties of a material (for example the porosity of mould and the capacity to evacuate the whey).

These are important research topics, hopefully leading to increase of process utilisation. Research on these topics is enabled by the increased understanding of phenomena at the nanoscale, but also by the increased availability of microsystems-enabled tools to study such phenomena.

Roadmap

The first step the industry has to take is to introduce sensors that mimic the process of fouling and thereby give an indication of its progress (e.g. thermal analysis sensors). The next step will take a more holistic picture of the system's condition by combining information from a range of sensors (sensor fusion). For this there is a need for robust and small in-line sensors (e.g. pressure, temperature, turbidity, fouling[29]). This, combined with thorough process scans and modelling[30], will lead to better interpretation of and response to measurement results.

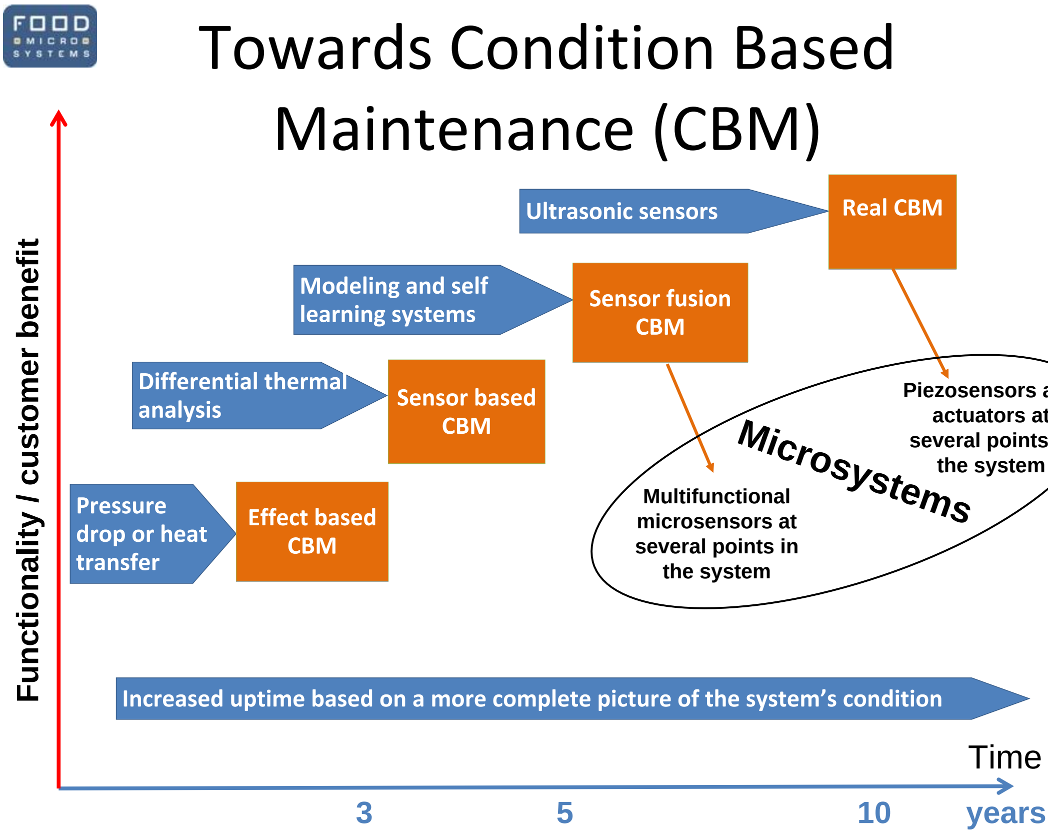


Fig. 3.3.2: Roadmap for Condition based Maintenance (CBM) in dairy processing (source: enablingMNT)

In 3-5 years' time, the industry will see the coming of integrated sensor systems and decision methodologies based on such systems, i.e. condition-based maintenance, based on embedded sensors and/or external tests and measurements using built-in diagnostic equipment. This promises enhanced effectiveness of maintenance programs, preventing unplanned downtime, making better use of maintenance resources, and maximizing the operational life of the asset. This information will also have its impact on the design of dairy processing systems.

[29] Some of these sensor are also to be used to check cleaning processes.
[30] See for instance NIZO Quick Scan

The last envisioned microsystem-based step is the introduction of ultrasonic sensors. The introduction will follow current developments in microphone, accelerometer and gyro production, where the sensors are becoming smaller and more affordable each year.

In a longer time frame, 10 year or maybe even longer, current research on surface modification and coating might start to pay off. For this it is essential that there is an understanding of the role of the used materials (especially its surface) in the fouling process.

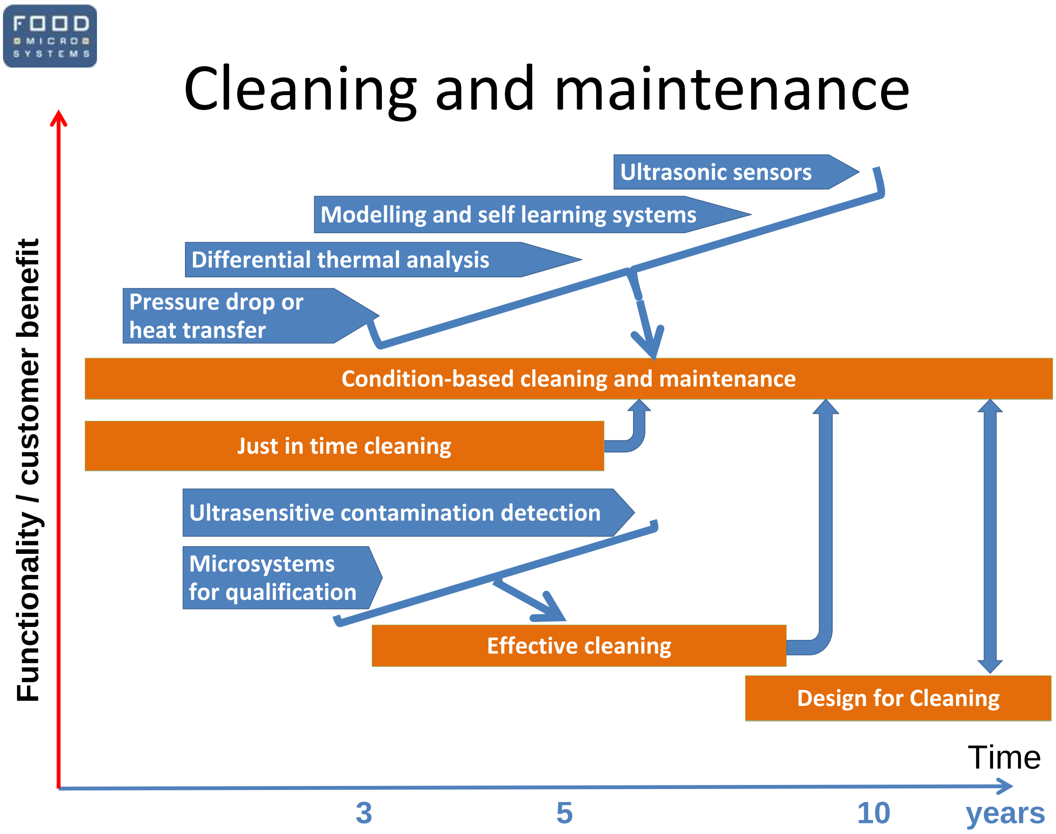


Fig. 3.3.3: High-level roadmap for cleaning and maintenance in dairy processing (source: enablingMNT)

Conclusions

Improving the cleaning and maintenance in dairy processing is clearly cost driven. Specific microsensors and sensor systems will help increase "up-time" of processing equipment, save resources (water, energy, detergent) and decrease cost in the dairy production.

These new microsystems have to be "embedded" into new cleaning and "design for cleaning" methodologies, together with new materials and surface technologies that will lead to new and optimised dairy production systems - it is evident that this will be a long term activity rather than being achievable on a short term.

3.4 Micro fractionation

Basically, fractionation is the separation of milk into its component parts. This is not a new concept. Dairy farmers traditionally struggle with the problem that their capacity of producing milk is often too large for the market at that particular season - this is even made more severe by the limited shelf life of milk. Historically, farmers dealt with this issue by fractionating milk into cream and skim milk. The cream was then churned into butter. The skim milk was fermented into cheese. The remaining ingredients were mainly fed to the farm animals.

But nowadays, with the increasing industrial production of dairy products, fractionation means more and a long-term goal is isolating milk components into separate proteins. The major components of milk include water (88%), lactose (4.8%), fat (3.5%), protein (3.2%) and minerals (0.7%). Of these components, protein is considered to be the most valuable. To get dairy protein by itself, manufacturers start with milk or the whey left over from the cheese-making process. They run the liquid through a filter so that they end up with a densely concentrated protein solution. After the protein is concentrated, they can evaporate and dry it to form a powder.

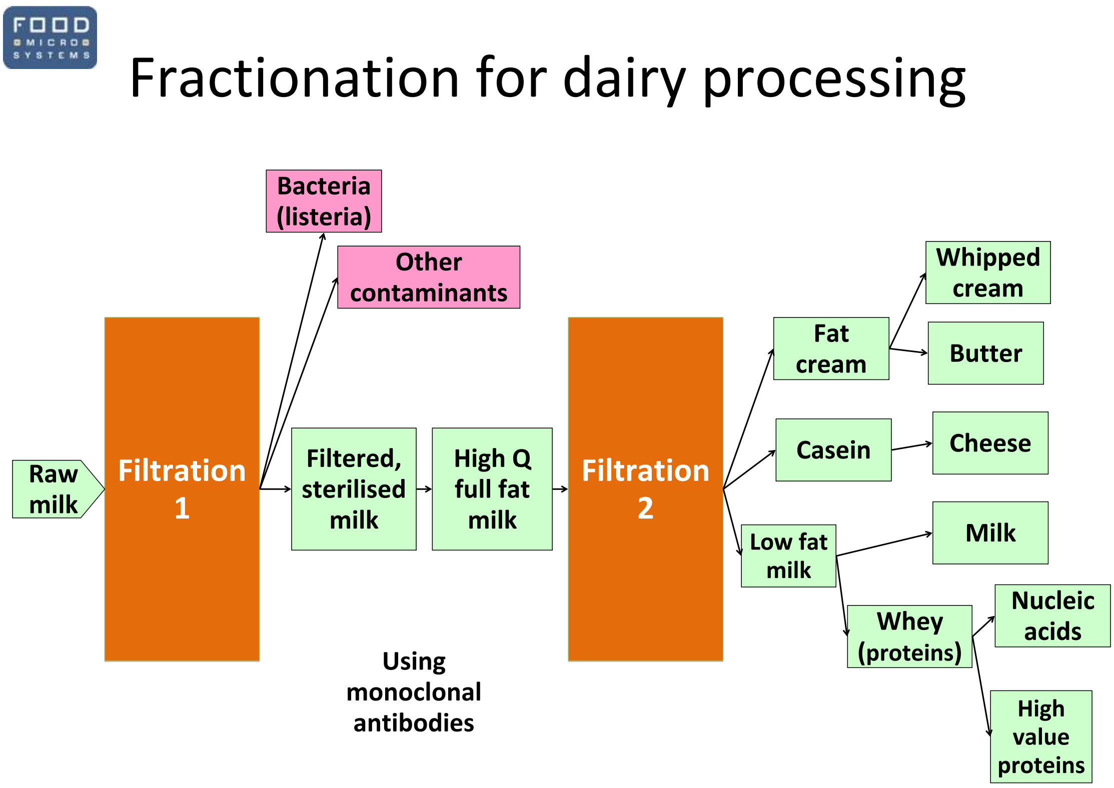


Fig. 3.4.1: Generic fractionation methodologies to enable new/better dairy products (source: enablingMNT/Wageningen UR)

Protein powders appear in many products, for instance baked goods, nutrition bars, beverages, yogurt, infant formula etc. The protein present in milk consists of two major fractions called casein and whey protein. Simple filtration is performed by passing milk through a semi-permeable membrane that fractionates milk into two components: the permeate passing through the membrane and the retentate - the material retained by the membrane.

Opportunities for and demands from the dairy processing industry

The dairy industry is a sector of small margins. So far the costs of microsystems are usually high, which will increase the price of the end product. To limit this increase the numbers of devices (e.g. sieves) must be high. The total costs of the new technology must be compared with the costs of the technologies currently used (capex/opex). Energy (=cost) saving could trigger the use of new technologies. Calculations for these cases show that a technology has a financial margin to fit in of 0.03 ct/l.

	Extended shelf life milk	Pasteurised milk
Shelf life (@ 4-6 C)	3 weeks	5 weeks
Taste	+	-

Table 3.4.1: Disadvantages of traditional pasteurisation (source: Microfiltration - Applications and potentialities in the dairy industry, 27 February 2013, Geneviève Gésan-Guiziou)

Being able to store micro-filtered milk products un-cooled for several months would be a relevant advantage for the consumer but according to the discussion at FoodMicroSystems workshops there is hardly a need for better but more expensive products, rather there is a demand for same function at a lower price. Developments of new technologies are often restricted for economic reasons. Maybe in a specific niche market the advantages could be capitalised on. Added value for the consumers must be transparent, because if they see a benefit, the industry will invest. Replacing sterilisation avoid a heat treatment that influences certain constituents of the product which could change the flavour for example.

Existing and emerging milk ingredients and fractions have many food and beverage applications. The functionality of the various components in milk (e.g. whey protein, casein and fat) could be utilised more effectively, if they were available as separate components. Therefore, the fractionation of milk is of interest, not only for improvement of product quality but also for economic reasons. Fractionation of dairy proteins can be considered as value-added processing which improves the functionality and broadens the use of dairy proteins as ingredients.

Customers desiring only the milk solids often have costs that are attributed to the waste disposal and yield of their raw materials. Besides that, fractionation can help to decrease transportation costs. Besides clear economic benefits, there are others: proteins derived directly from milk can provide some highly desirable functional properties, like clarity (having smaller particle size), foaming (being lower in fat, producing more, stronger and longer-lasting foams), gelation (forming stronger gel networks).

The differences in attributes between whey proteins isolated from milk and those isolated from cheese whey are becoming an important factor for dairy protein processors considering new technologies for fractionation. Over time, fractionation technology will become more sophisticated. On lab scale it is already possible to isolate certain parts of proteins that have the specific nutritional or functional profile they're looking for. But the developments will not stop at isolating the major proteins, there is also an interest interested in “bioactive peptides,” (parts of proteins which are produced in the human body and in some fermented dairy products), vitamins etc.

Roadmap

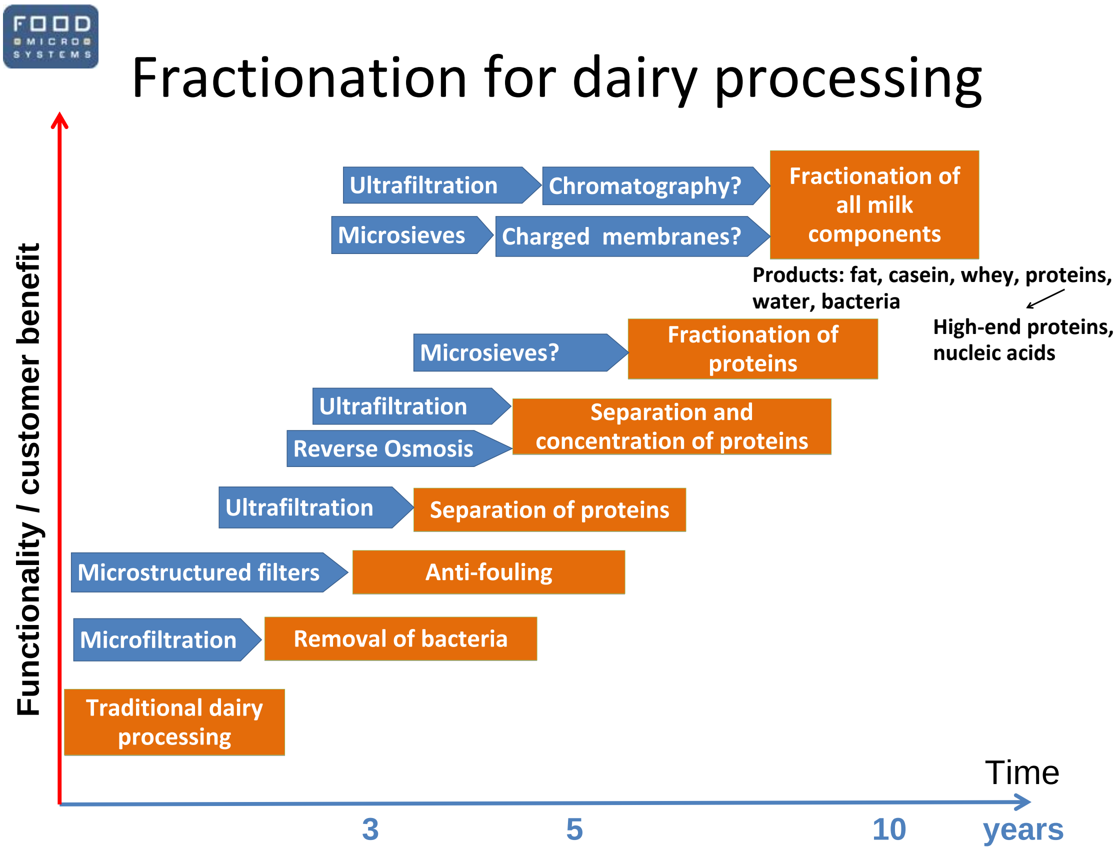


Fig. 3.4.2: Roadmap for fractionation methods from short to long term (source: FoodMicroSystems / enablingMNT)

Different microfiltration techniques in the Dairy industry are described in annex A1.3, while an overview of the most important processes is also given here:

	Heat treatment	Micro-filtration (MF)	Micro structured MF	Ultra-filtration (UF)	Reverse Osmosis (RO)	UF+RO	Microsieves	Charged membranes
Effect on taste	--	++		++	++	+	++	++
Removal of bacteria	++	+		--	--	--	+	--?
Proteins	--	--		+	++	++	yes	yes
Fractioned proteins	--	no		no	no	no	yes	yes
Status	In use	In use		In use	In use	R&D	R&D	Research
Anti-fouling	--	--	++	--	--	--	+	?

Table 3.4.2: Overview on fractionation methods for dairy processing (source: FoodMicroSystems / enablingMNT)

Short to mid term perspective

Microfiltration (MF) is a membrane unit operation that has recently been widely investigated for the fractionation of milk proteins. Casein and whey proteins from skim milk may be separated using 0.1µm MF membranes. This technique provides a non-thermal processing alternative to the more traditional coagulation operations for casein separation. The selectivity and efficiency of current membranes are not sufficient to make the fractionation process an economically feasible reality. Recently, micro sieves have become available: a new type of membrane with low flow resistance, and defined uniform pore size. The properties are such that the fractionation of milk seems possible on a commercial scale.

MF separated casein retains functionality and thus is an excellent source of raw material for cheese and fermented product manufacture. The permeate may be termed an 'ideal whey' as it has superior functional and nutritional characteristics compared to traditionally produced sweet whey and contains no added chemicals. Thus MF may be used to manufacture high-quality protein and protein concentrates without chemical usage and with significantly reduced environmental impact.

SiN membranes with very well defined pores (100 nm and up) are used to sieve components from milk or beer or in a reversed process to make emulsions of e.g. oil droplets in water or foams of e.g. aerated desserts. Because of the very high uniformity of the pores, the thinness of the membranes and the unlimited control over the shape of the holes, the characteristics of the end product can be controlled to a very high extend[31]. Remarkable are the relatively high throughputs (40-100 x higher flux, when compared to conventional filtration). Filtration units on industrial scale are already commercial available for the beer industry.

[31] Presentation by Cees van Rijn (Aquamarijn) at FoodMicroSystems workshop June 2012

Very small pores (less than 1nm) are created in a ceramic membrane. Ceramic membranes with pores <1nm are typically used for dehydration and removal of small molecules from larger mw Dalton solvents. Contrary to dehydration, Pervatech[32] offers also organophilic membranes to remove organics from watery streams. These membranes can be used to extract specific molecules from the product stream (e.g. aromas, off-flavours). The intermediate products in the manufacture of the ceramic membranes for dehydration can be used also for emulsification, where the desired pore size can be set from 1nm up to 100nm. Indicative experiments show potential of the ceramic membranes for the reversed process to produce emulsions.

Long term perspective

Ultrafiltration is widely used to concentrate proteins, but fractionation of one protein from another is much less common. However, research indicates that when a charge is added to a UF membrane, existing UF equipment can be used to fractionate milk proteins. This could be especially beneficial for fractioning ingredients with overlapping particle sizes. This means dairy ingredient manufacturers can increase the return on investment of their membrane systems by producing higher-value milk protein fractions.

Opportunities for fractionation

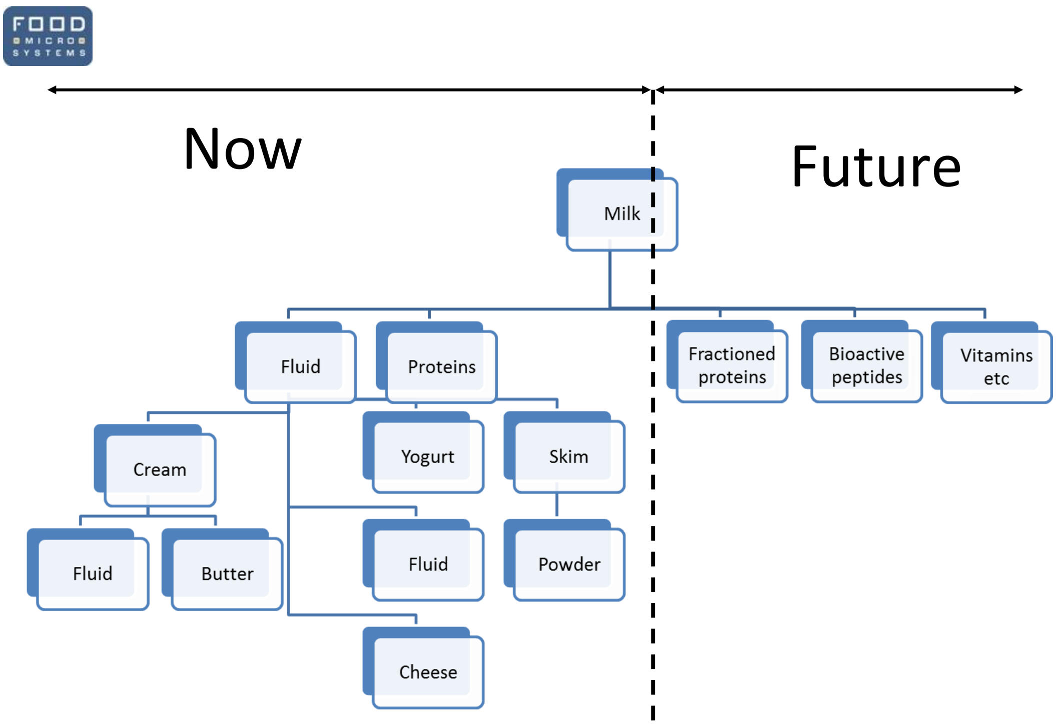


Fig. 3.4.5: Vision on future fractionation methods for dairy processing (source: FoodMicroSystems / enablingMNT)

[32] Presentation by Frans Velterop (Pervatech) at FoodMicroSystems workshop June 2012

Milk is a complex colloidal suspension containing many classes of different size components (salts, soluble proteins, casein micelles, fat globules, microorganisms, etc. which can be separated from others according to their size or charge thanks to advanced membrane techniques which are expected to gain foothold in the future. Isolating proteins is not only about creating a new type of yogurt or granola. There is also an interest in "bioactive peptides," parts of proteins which are produced in the human body and in some fermented dairy products. It might also be possible to remove the lactose or the vitamins and minerals that are in milk.

In summary:

- Microfiltration could revolutionise the processing of milk the way ultrafiltration revolutionised the processing of whey.
- Microfiltration in combination with ultrafiltration will be used to separate casein from whey protein without making cheese.
- Microfiltration and ultrafiltration will be used to separate individual casein and whey protein fractions.

It should be noted, that the dairy industry is not quick with the uptake of new technologies and some of that might not be accepted by the general public, except for a few isolated case.

3.5 Vision beyond 2020

In the future, the quality check in the dairy industry will be held as early as possible in the supply chain. This will enable containment of bad quality products, but also, and even more importantly, better tuning of material flow and processing. I.e. deciding which batches will be best suited for cheese, cream, etc. To implement this, a range of advanced multifunctional sensors is needed; each of these sensors must be easy to handle and maintenance friendly. The milk collecting van of the future or even the farm of the future will contain pathogen and profiling test equipment to sort the milk according to quality. There will also be equipment to remove a substantial amount of water. The van will have several tanks to separate the loads of different quality. This will optimise the logistics in three ways:

- minimising transport cost,
- maximising usage of milk ingredients,
- minimising material loss by avoiding (cross-)contamination from "bad" batches.

For the consumer, the package of the future will provide more and more meaningful information. It will feature several visual signs to indicate its fitness for use and its suitability for certain diets. Electronics in the package should also be able to send the price – so at the counter the total cost is directly available.

Functional foods will have even more information in the package; it will provide the potential buyer with information about the suitability to his/her individual needs and condition. Another step further will be the "food on demand concept". Separation of milk into individual components can offer personalised re-blending in the shop or at home, i.e. making the product exactly as the customer wants it.

The afore-mentioned quality sensors at the farm will be integrated in a sensor system that will also include sensors that check the cow's health & condition, and quality of the feed intake. The will also help creating a better quality of life for the animal (animal welfare). The food factory of the future will be ensured of the quality of the incoming material, and will be able to concentrate its measurement strategy on (a) controlling the influence of the processing on the product quality, (b) check for introduction of unwanted material (contamination) and (c) checking the status of the equipment. (Semi-) continuous control of equipment status will lead to a change from the current time-based Preventive Maintenance to Condition Based Maintenance (i.e. when the need arises). This will optimise the utilisation of equipment and decrease product variation.

It should be taken into account that there are some essential differences between screening (is something present?) and accurate determination (i.e. how much is present?). Screening is likely to be introduced quicker then accurate determination as the latter needs more complex sensor technologies.

The vision above is still far away. To achieve this, technology developments are needed in the directions:

- Sensors that can detect a range of pesticides, herbicides, pathogens, metals and milk ingredients like proteins. As cost is an important issue in the dairy industry, these sensors should be multifunctional and affordable. This calls for integrated sensors based on low costs disposables or, preferably, sensors that do not need disposables. The resulting devices will provide accurate and timely information about safety (no unwanted (bio)chemicals or organisms) and quality of the products (profiling).

- When it comes to sensors in packages, these sensors need to be very low cost and will likely be printed.

- Thirdly there is a need for sensor systems that can assess the status of the inner surfaces of process equipment in a dairy plant. However, changes in processing will take substantially longer than in quality control, due to the long lifespan of process equipment that needs to be replaced and the understandable conservatism in this industry. As a consequence, introduction of this technology will be slow, following introduction of other food applications, were the advantages are more pronounced (for instance drying of fish oil). On the long term, 10-20 years, the impact will be considerable.

- Even more difficult to introduce will be advanced processes that modify the product itself, e.g. lactose-free milk or double emulsions that will minimise the fat content.

4 Synthesis

This chapter summarises the findings from the above, dairy application-driven, roadmap sections and in particular gives hints towards the potential of further technology developments in these areas. More detailed roadmaps for the underlying microsystem devices and technologies across all food application sectors will be discussed in FoodMicroSystems deliverable D4.5.

Significant potential from microsystems research is expected in the area of contamination detection in food. This area is highly diverse in terms of applications and technologies, but very much in progress in both research and industrialisation. The market demands differ not only because of the wide range of potential contaminates and quality aspect of dairy products, but also the diversity of products. Furthermore, many country specific regulations need to be taken into consideration. Thus, there will be several technology developments in parallel and the food sensor roadmap will show several detours, parallel lanes and splitting roads. This makes it difficult if not impossible to sketch a complete picture of a long-term roadmap. Based on the existing detection methods that are usually laboratory based, there are two major paths for development:

- to improve and speed-up the lab method and
- to replace the lab method by on-site detection.

In many applications fast and cheap screening (with very few false negatives) based on microsystems would be very helpful in combination with accurate but expensive and slow (golden standard) techniques to check the results that were detected in the screening. Thus, a co-existence and co-development of both paths will be of high probability.

For the process and quality control of cheese products, a number of parameters are of interest - many of them are measured with “human senses” (smelling, tasting, touching, comparing colour, etc.) so far. The cheese processing industry requires increased automation for faster and more comparable results (i.e. physical-chemical parameters) and at lower cost. Lower cost of the cheese production can be achieved through:

- faster measurements (and detection of problems),
- improved quality (less waste of products),
- improved yield,
- minimising down time of processing equipment.

Additionally, better “look and feel” quality of cheese products may lead to higher sales prices; thus, improving quality of cheese can also have an impact.

Cost will be a major driving force for improving the cleaning and maintenance in dairy processing. Specific microsensors and sensor systems will help increase “up-time” of processing equipment, save resources (water, energy, detergent) and decrease cost in the dairy production. These new microsystems have to be "embedded" into new cleaning and "design for cleaning" methodologies. Together with new materials and surface technologies this will lead to new and optimised dairy production systems - it is evident that this will be a long term activity rather than being achievable on a short term.

Milk is a complex colloidal suspension containing many classes of different size components (salts, soluble proteins, casein micelles, fat globules, microorganisms, etc.) which can be separated from others according to their size or charge. Advanced membrane techniques for separating these are expected to gain foothold in the future. This might lead to an optimised use of milk ingredients and even new types of dairy-based products.

In terms of ethical issues and consumer perception, it was already noted in FoodMicroSystems deliverables D3.2.1 and D3.2.2 that it is unlikely that consumers will be willing to pay any price premium for products produced with or incorporating microsystems in the product or package. An opportunity of having product level allergen detection for dairy products was considered a potential benefit for allergic people, as well as product level ingredient declaration accessible through modern ICT means (e.g. smart phones). Also, opportunities are seen in the use of microsystems to improve specific processes in the dairy industry, allowing the preparation of new or improved food products (mainly passive microsystem devices for pasteurisation and for emulsion) with superior characteristics. However, for the time being this corresponds to a niche market application.

Most other views given by consumers in relation to microsystems and food are not very specific to dairy, thus they will not be further addressed here – just to re-call that the main drivers "safety, price, and quality are valid for dairy as for all other food areas".

When comparing the "FoodMicroSystems for dairy roadmap" results with the Food-for-Life roadmap/SRA, it becomes obvious that challenges and priorities in both documents align rather well, such as safe food, improving health and well-being, sustainable and ethical production, food quality, and real innovation. E.g. the chapter "The Food Safety Challenge" of the Food-for-Life SRA[33] describes "microbiological hazards and challenges, chemical hazards including toxins of biological origin, robust and cost-effective risk analysis concepts based on sound, cutting-edge scientific understanding and real-time & rapid detection tools to ensure safety and security of the food chain, including food defence" as key the challenges and areas to be addressed – the same areas have been addressed in this microsystems for dairy roadmap, based on stakeholder needs identified through interviews and workshops.

[33] European Technology Platform "Food for Life" Strategic Research and Innovation Agenda (2013-2020 and Beyond)

5 Conclusions

This roadmap report addresses the following high level challenges of the dairy supply chain:

- Guaranteeing product safety (preventing contaminated food reaching the market.
- Improving product quality (more homogenous and optimised production)
- Increasing equipment utilisation (Condition based Maintenance).
- Process efficiency (using less energy and decreasing product loss).

The prevention of safety hazards is one of the key challenges that the food industry is facing, and a high priority here is on detecting / preventing a possible hazard in the whole supply chain. Preferable as early as possible in the production chain as opposed to a sole finished product inspection. Besides detection of unwanted content like pathogens, also the quality of the milk (fat, protein, cell etc.) is to be measured. One on the most urgently needed capabilities are better (faster, cheaper) detection methods for pathogen micro-biological contamination in food, especially to be used during food processing. If only because of the fact that industry and consumers are becoming increasingly aware of food contamination and its consequences on consumption. Time to react is important and directly related to cost of processing.

Any pathogen can be detected as long as one takes the time and the effort to do the test. Up to now these tests require fully equipped laboratories and are elaborate, expensive, and time consuming. One way of optimising both, speeding up testing time and omitting the need of specially trained technical staff, could be to reduce or even avoid extensive sample pre-treatment (i.e. clean-up, amplification). Reducing/skipping sample preparation time is not enough to achieve acceptable testing times; also more sensitive sensors are needed. This can be aided by miniaturisation. Miniaturisation decreases the processing / transportation times within the detection system by using shorter microfluidic pathways. This leads to further integration of the sensor and microfluidic components. This may take place in two steps. The first could integrate microfluidic components and the sensor in one package. The next step could then integrate all the functionalities on one chip. Such an approach is expected to lead to test systems that operate in minutes and maybe even seconds instead of hours to days. Even more importantly, it will bring back the cost of tests below one euro.

Legal adaptations are required to pave the way for miniaturised devices and the associated measuring methods to become officially certified methods. So far, even for methods that are state of the art from a technical point of view, it may take decades to get legal approval. Until this is achieved, newer test methods can often only be considered as screening tools, to be complemented by official lab based tests.

Regarding chemical contamination, residues, and other unwanted ingredients, these types of contamination can either be environmental or processing contaminants/residues. The trends, also in the detection of chemical contamination, residues and other substances is, towards cheap, quick, and specific measurements - perhaps even down to the specific substance or at least down to the chemical class. Preferably mobile devices are envisaged. To keep cost down, multiple parameter sensing is needed.

One clear trend is that in coming years many more sensors will become commercially available that can increase the quality and safety of dairy products and reduce cost. With more and more individual sensor types being commercialised, the trend to sensor fusion (combining the information of individual sensors) concepts will become visible on a longer term.

The quality control during the processing of cheese products still depends very much on human senses. To achieve more consistent result, better sensor systems are needed. These systems should be able to detect fast and at low cost a wide range of physical and chemical parameters and combine the results.

As in many other food processing industries, the key environmental issues associated with dairy processing are the high consumption of water and energy. Cleaning is a major cause for the high consumption of water and energy, and thereby substantially contributing to the processing cost and environmental burden. Another important cost factor is maintenance due to its impact on the utilisation of equipment with two aspects, “down-time” and wear-out of equipment. Optimising down-time is possible by replacing the current maintenance practice that is based on regular intervals by “just in time” maintenance. This promises enhanced effectiveness of maintenance programs, preventing unplanned downtime, making better use of maintenance resources, and maximizing the operational life of the asset. This condition-based maintenance will be enabled by the integration of sensor systems with completely new decision methodologies. The first step the industry has to take is to introduce sensors that mimic the process of fouling and thereby give an indication of its progress (e.g. thermal analysis sensors). The next step will take a more holistic picture of the system’s condition by combining information from a range of sensors (sensor fusion). For this there is a need for robust and small in-line sensors (e.g. pressure, temperature, turbidity, fouling). These new microsystems have to be “embedded” into new cleaning and “design for cleaning” methodologies, together with new materials and surface technologies that will lead to new and optimised dairy production systems - it is evident that this will be a long term activity rather than being achievable on a short term.

Microfiltration has the potential to revolutionise the processing of milk the way ultrafiltration revolutionised the processing of whey by separating individual casein and whey protein fractions. Specifically this area calls for very interdisciplinary approaches between technologists and the dairy processing industry to evaluate and address future opportunities.

As in other food areas, reducing cost is a major driver. Safety and quality tests are not only beneficial for the consumer's health; when properly used (for instance for early detection of contamination) they can also contribute significantly to cost reduction programs. An interesting concept could be a standardised measurement/ or detection platform, where only small components (e.g. sensor elements) need to be adapted for different types of measurements.

To move towards the visions described above, the following challenges need to be addressed with new research programmes with high priority:

- Sensors that can detect a range of pesticides, herbicides, pathogens, metals and milk ingredients like proteins. As cost is an important issue in the dairy industry, these sensors should be multifunctional and affordable. This calls for integrated sensors based on low cost disposables or, preferably, sensors that do not need disposables. The resulting devices will provide accurate and timely information about safety (no unwanted (bio)chemicals or organisms) and quality of the products (profiling).

- When it comes to sensors in packages, these sensors need to be very low cost and will likely be in a "printed technology".

- Thirdly there is a need for sensor systems that can assess the status of the inner surfaces of process equipment in a dairy plant. However, changes in processing will take substantially longer than in quality control, due to the long lifespan of process equipment that needs to be replaced and the understandable conservatism in this industry. As a consequence, introduction of this technology will be slow, following introduction of other food applications, were the advantages are more pronounced (for instance drying of fish oil). On the long term, 10-20 years, the impact will be considerable.

- Even more difficult to introduce will be advanced processes that modify the product itself, e.g. lactose-free milk or double emulsions that will minimise the fat content.

Annex 1: Literature / references

A1.1: Additional material on dairy markets, consumption and supply chain

WESTERN EUROPE
ALL DAIRY PRODUCTS*

The Top-100 Companies by West European Market Share in 2011

Company Ranking	Ultimate Holding Company	Market Shares West Europe	Market Shares Cumulative	Company Ranking	Ultimate Holding Company	Market Shares West Europe	Market Shares Cumulative
1.	Danone	7.10%	7.10%	51.	C. Latte Torino	0.28%	77.44%
2.	Unilever	6.99%	14.09%	52.	Skånemejerier	0.27%	77.71%
3.	FrieslandCampina	6.81%	20.90%	53.	DFB	0.27%	77.98%
4.	Nestlé	5.59%	26.49%	54.	G7	0.26%	78.25%
5.	Arla Foods	5.37%	31.87%	55.	Laiteries Réunies	0.26%	78.51%
6.	Lactalis	3.92%	35.78%	56.	Milchunion Hocheifel	0.26%	78.77%
7.	Sodiaal	3.11%	38.89%	57.	Milko	0.26%	79.03%
8.	Nord Contor	2.59%	41.49%	58.	Rosen Eiskrem	0.26%	79.29%
9.	Parmalat	2.34%	43.83%	59.	Intermilch	0.24%	79.53%
10.	Muller	2.27%	46.10%	60.	Milchw. Regensb.	0.21%	79.75%
11.	Consorzio Granlatte	2.08%	48.18%	61.	Schwälbchen	0.20%	79.95%
12.	Oetker	1.96%	50.14%	62.	Tirol Milch	0.20%	80.15%
13.	Hochwald Gruppe	1.83%	51.97%	63.	Triballat	0.20%	80.34%
14.	Dairy Crest	1.54%	53.51%	64.	Yeo Organic	0.20%	80.54%
15.	Tine	1.45%	54.96%	65.	Hugli	0.19%	80.73%
16.	Robert Wiseman	1.42%	56.38%	66.	Glasskiosken	0.19%	80.92%
17.	Oaktree Capital	1.32%	57.70%	67.	Llet Nostra	0.19%	81.11%
18.	Lactogal	1.17%	58.87%	68.	Medina Dairy	0.18%	81.30%
19.	Ehrmann	1.16%	60.02%	69.	Leite Rio	0.18%	81.48%
20.	Clas	1.05%	61.07%	70.	Milchwerke Mainfranken	0.18%	81.65%
21.	Andros	1.04%	62.11%	71.	Iparlat	0.17%	81.82%
22.	Valio	1.02%	63.13%	72.	Alsace Lait	0.17%	81.99%
23.	Milcobel	0.87%	64.00%	73.	Lactiber	0.17%	82.16%
24.	Mars	0.85%	64.86%	74.	Latte S. Matese	0.16%	82.32%
25.	Bergland. Rottaler	0.82%	65.68%	75.	LCP Lactis	0.16%	82.48%
26.	Ebro Puleva	0.75%	66.43%	76.	Mila	0.16%	82.64%
27.	Migros	0.74%	67.16%	77.	Farm Frites	0.15%	82.79%
28.	Senoble	0.66%	67.83%	78.	Hennig Olsen	0.15%	82.94%
29.	Leche Pascual	0.65%	68.48%	79.	Sterilgarda	0.14%	83.08%
30.	Zott	0.61%	69.09%	80.	Uniq	0.14%	83.21%
31.	ZMV	0.60%	69.69%	81.	Moraco	0.14%	83.35%
32.	Frischli	0.56%	70.24%	82.	Gu	0.13%	83.48%
33.	Bongrain	0.52%	70.76%	83.	Alstermilch	0.13%	83.62%
34.	Bayer. Milchind.	0.49%	71.25%	84.	ILAS	0.13%	83.75%
35.	DMK	0.45%	71.70%	85.	CNP	0.13%	83.88%
36.	Glanbia	0.44%	72.14%	86.	Zapfquell	0.13%	84.01%
37.	Bauer	0.44%	72.58%	87.	Mont Blanc	0.12%	84.13%
38.	Sammontana	0.43%	73.01%	88.	Rolland	0.12%	84.26%
39.	Coopagri Bretagne	0.42%	73.43%	89.	Cremo	0.12%	84.38%
40.	Kerry Group	0.41%	73.84%	90.	Kuhne	0.12%	84.50%
41.	Fage	0.40%	74.24%	91.	Ennstal	0.12%	84.62%
42.	NÖM	0.39%	74.63%	92.	Alpenmilch Salzburg	0.12%	84.74%
43.	Vivartia	0.37%	75.00%	93.	Feiraco	0.11%	84.86%
44.	Anders Müntzing	0.34%	75.34%	94.	Cooperlat	0.11%	84.97%
45.	Nueva Rumasa	0.33%	75.68%	95.	Bergamin	0.11%	85.08%
46.	Swiss Dairy Food	0.33%	76.00%	96.	Sill	0.11%	85.19%
47.	TMT Finance	0.32%	76.33%	97.	Gis Gelati	0.11%	85.30%
48.	General Mills	0.28%	76.61%	98.	UDF	0.11%	85.41%
49.	PNIC	0.28%	76.89%	99.	Bofrost	0.11%	85.52%
50.	Coopér. 3A	0.28%	77.16%	100.	Longslow	0.10%	85.62%

* Notes: Products Covered: Liquid milk, Cream, Yoghurt, Condensed milk, Powdered milk, Ice cream, Chilled dairy desserts
Countries Covered: Austria, Belgium/Luxembourg, Denmark, Finland, France, Germany, Greece, Ireland/Eire, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

Source: Food for Thought (FFT)

Fig. A1.1.1: TOP 100 Dairy companies Western Europe 2011 (Source: Food&Drink Business Europe / Food for Thought FFT)

European Union Dairy Supply and Utilization

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023	2025
(Thousand Head)													
Milk Cow Numbers	23,662	23,536	23,419	23,303	23,168	22,980	22,795	22,599	22,406	22,215	22,117	21,903	21,790
(Kilograms)													
Milk Production per Cow	5,672	5,718	5,812	5,892	5,944	6,000	6,054	6,108	6,166	6,225	6,282	6,456	6,572
(Thousand Metric Tons)													
Cow Milk Production	134,200	134,570	136,112	137,295	137,712	137,880	138,000	138,047	138,150	138,285	138,937	141,402	143,193
Fluid Milk Consumption	33,850	33,917	33,732	33,829	33,950	34,013	34,087	34,138	34,144	34,121	34,120	34,044	33,971
Manufacturing Use	104,180	104,483	106,234	107,343	107,662	107,792	107,860	107,880	108,002	108,184	108,862	111,476	113,389
Butter													
Production	1,980	1,951	1,954	1,947	1,934	1,921	1,915	1,909	1,898	1,887	1,879	1,853	1,836
Beginning Stocks	103	53	0	0	0	0	0	0	0	0	0	0	0
Domestic Supply	2,083	2,004	1,954	1,947	1,934	1,921	1,915	1,909	1,898	1,887	1,879	1,853	1,836
Consumption	1,895	1,885	1,849	1,846	1,836	1,827	1,823	1,818	1,812	1,805	1,801	1,784	1,774
Ending Stocks	53	0	0	0	0	0	0	0	0	0	0	0	0
Domestic Use	1,948	1,885	1,849	1,846	1,836	1,827	1,823	1,818	1,812	1,805	1,801	1,784	1,774
Net Trade	135	120	105	101	98	94	92	91	86	82	78	69	62
Cheese													
Production	6,970	7,049	7,095	7,202	7,307	7,441	7,575	7,708	7,833	7,957	8,087	8,473	8,726
Beginning Stocks	0	0	0	0	0	0	0	0	0	0	0	0	0
Domestic Supply	6,970	7,049	7,095	7,202	7,307	7,441	7,575	7,708	7,833	7,957	8,087	8,473	8,726
Consumption	6,451	6,489	6,540	6,642	6,753	6,887	7,027	7,163	7,288	7,413	7,540	7,908	8,151
Ending Stocks	0	0	0	0	0	0	0	0	0	0	0	0	0
Domestic Use	6,451	6,489	6,540	6,642	6,753	6,887	7,027	7,163	7,288	7,413	7,540	7,908	8,151
Net Trade	519	560	555	560	554	553	548	545	544	544	547	566	574
Nonfat Dry Milk													
Production	980	967	968	956	942	928	919	910	897	884	873	840	819
Beginning Stocks	259	170	75	42	20	7	0	0	0	0	0	0	0
Domestic Supply	1,239	1,137	1,042	998	962	935	919	910	897	884	873	840	819
Consumption	724	730	687	682	674	669	666	668	667	666	665	659	654
Ending Stocks	170	75	42	20	7	0	0	0	0	0	0	0	0
Domestic Use	894	805	729	701	681	669	666	668	667	666	665	659	654
Net Trade	345	332	314	297	281	266	253	241	230	218	208	181	165
Whole Milk Powder													
Production	750	717	667	614	562	506	491	485	482	470	464	455	442
Beginning Stocks	0	0	0	0	0	0	0	0	0	0	0	0	0
Domestic Supply	750	717	667	614	562	506	491	485	482	470	464	455	442
Consumption	330	331	327	326	326	326	324	322	320	317	315	307	302
Ending Stocks	0	0	0	0	0	0	0	0	0	0	0	0	0
Domestic Use	330	331	327	326	326	326	324	322	320	317	315	307	302
Net Trade	420	386	340	287	236	181	167	163	162	153	150	147	140
Prices (Euros per 100 Kilograms)													
Milk Target	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Milk Producer	29.23	30.00	30.55	30.31	29.91	29.60	29.27	28.98	28.79	28.67	28.45	27.79	27.24
Butter Domestic	337	311	328	319	313	311	307	304	302	301	298	287	277
Cheese Domestic	335	345	353	353	350	348	344	340	338	336	333	325	319
NFD Domestic	209	238	233	233	225	217	212	207	204	200	197	188	182
WMP Domestic	252	247	251	246	239	232	229	226	223	224	222	216	212
Butter Intervention	246	246	246	246	246	246	246	246	246	246	246	246	246
NFD Intervention	175	175	175	175	175	175	175	175	175	175	175	175	0

Fig. A1.1.2: EU Dairy Supply and Utilisation from 2010 to 2025 (Source: FAPRI-ISU 2011 World Agricultural Outlook, www.fapri.iastate.edu/outlook/2011/)

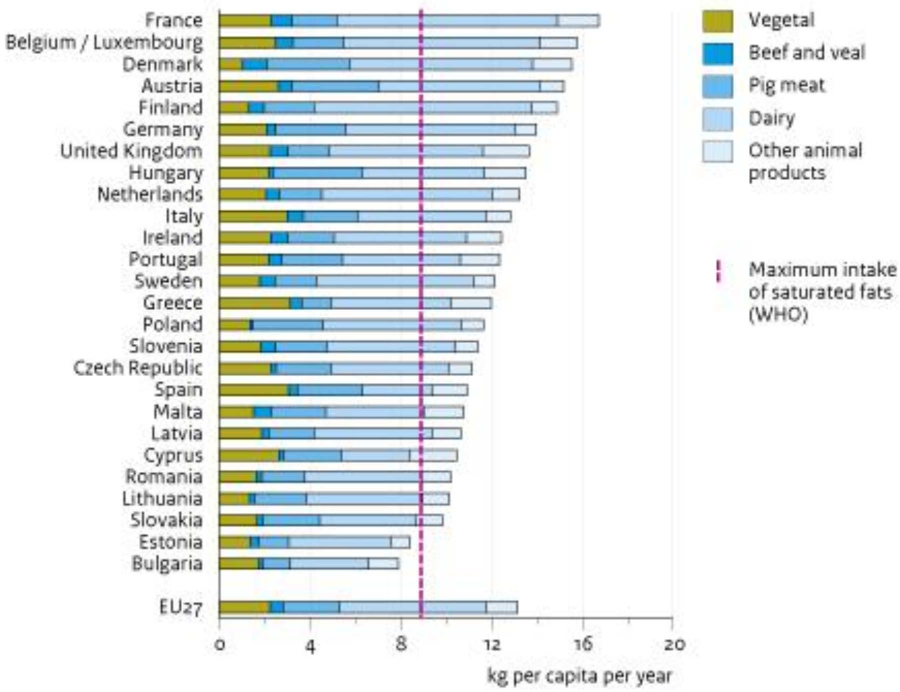


Fig. A1.1.3: Intake of saturated fats in EU27, 2007 (Source: PBL analysis based on FAO (2010), NEVO (2010), www.pbl.nl)

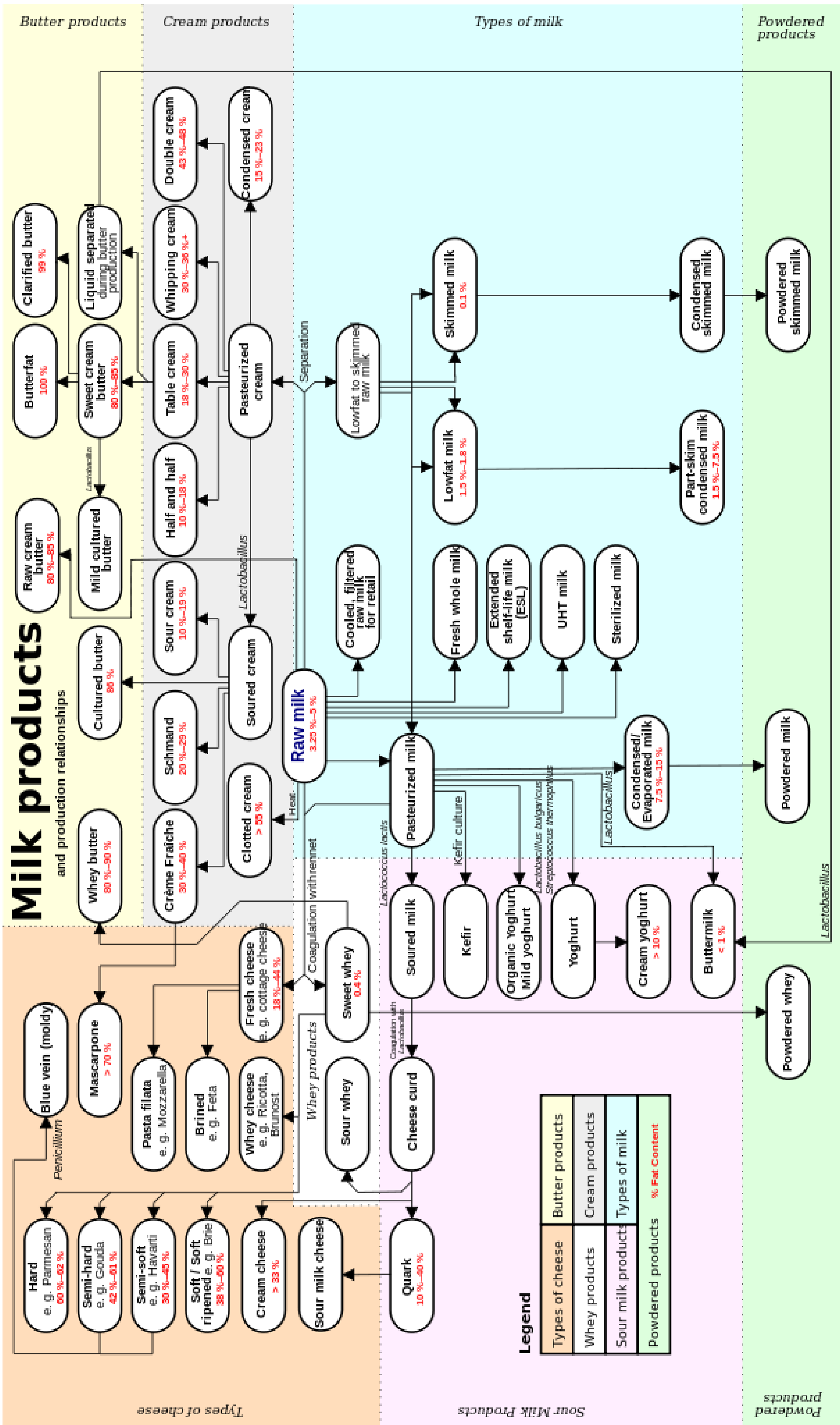


Fig. A1.1.4: Complex diagram of dairy products and their production chains (source: http://en.wikipedia.org/wiki/File:Milkproducts_v2.svg)

A1.2: Additional material related to pathogens and other unwanted materials

The following Pathogens have been identified as most critical ones in the food chain:

E. coli (Enterobacteriaceae) is a large family of Gram-negative bacteria that includes, along with many harmless symbionts, many of the more familiar pathogens, such as Salmonella, *Escherichia coli* (incl. EHEC), *Yersinia pestis*, Klebsiella and Shigella. E. coli is found in cattle and may enter milk through faecal contamination; however E. coli is heat-sensitive and does not survive pasteurisation. It can however be present in the environment and can gain access to product after heat treatment. Initial sources are often birds and rodents. It is occasionally present in raw milk. Non-dairy ingredients can be an important source of contamination.

Listeria is a group of gram-positive organism that does not form spores. The main pathogenic species is *Listeria monocytogenes*. L. monocytogenes is destroyed by pasteurisation. Its presence in heat-treated products is due to post-pasteurisation contamination. L. monocytogenes is a concern to the dairy industry as it can even grow at 0 ºC (refrigeration temperatures). It causes a risk mainly in raw milk products that are of special interest rather for local markets and as delicious food for a subgroup of customers. However, there is a latent risk along the dairy food chain for a recontamination, especially while Listeria may grow in biofilms that protect them against environmental stress.

Cronobacter has been linked to the use of baby formula. Cronobacter is a recently proposed genus consisting of six genomospecies that encompass the organisms previously identified as Enterobacter sakazakii[34]. Cronobacter are opportunistic pathogens and are known to cause serious infections in infants, particularly neonates. Due to its resistance[35] to drying, acid pH and heat; its biofilm formation properties and its persistence on food preparation surfaces, Cronobacter may end up in powdered formula. Chronobacter cannot grow in a dry substrate, but it can survive a long period of time and is a potential hazard when the powder is reconstituted and held for long periods of time at favourable temperatures. Contamination and subsequent growth may occur during reconstitution and preparation. Current tests are PCR or culture based.

Other pathogens in dairy products[36]

Salmonella is commonly found in raw food products that come from animals, such as eggs, egg products, meat, meat products, unpasteurised milk, or other

[34] Characterization of Cronobacter recovered from dried milk and related products, Walid M El-Sharoudet al, www.biomedcentral.com/1471-2180/9/24

[35] Presence of Enterobacter sakazakii in Milk Powder, Whey Powder and White Cheese Produced in Konya, Kemal Kaan TEKİNŞEN et al, http://vetdergi.kafkas.edu.tr/

[36] Adapted from "A Risk Profile of Dairy Products in Australia, Food Standards Australia New Zealand, 2006"

unpasteurised dairy products. Thorough cooking and processing effectively kills salmonella bacteria.

Staphylococcus.aureus is destroyed by heat-treatment; however its toxins are heat stable, thus control of growth of this organism prior to heat treatment is essential. S. aureus does not grow well at low temperatures (i.e. refrigeration).

Bacillus cereus - vegetative cells of B. cereus do not survive pasteurisation; however spores will survive heat treatments. B. cereus is rapidly outgrown by gram-negative psychrotrophs at refrigeration temperatures, but in their absence, B. cereus, if present, may then be able to grow to high levels. This is a concern with extended shelf-life chilled products, such as desserts.

Campylobacter spp. is destroyed by pasteurisation and its presence in milk products is due to environmental contamination after heat treatment. Campylobacter spp. are fragile organisms unable to grow in foods.

Yersinia enterocolitica is destroyed by pasteurisation and its presence in heat-treated milk products is due to environmental contamination after heat treatment. Y. enterocolitica is able to grow in dairy products held at refrigeration temperatures and therefore may be considered as a hazard in prolonged shelf-life products.

Pathogen detection systems available or under development

	Technology	Application	Porta-bility	Time to result	Sensi-tivity	Status
Seattle Sensor Systems	SPR	*Y. pestis*, Ovalbumin, Staph Enterotoxin B (SEB), *F. tularensis*, *B. anthracis*, Norwalk VLP, Ricin A, and BG Spores, Ara h 1 (peanut allergen)	Porta ble	<10 min	100-1000 cfu[37]/ml, PPM-PPB concentration	R&D use only
NanoRETE	Antibody functionalised nanoparticles & electrochemical detection	anthrax, *E. coli*, salmonella, tuberculosis	Hand-held	<1 hr	5-10 cells/ml or fg/ml DNA	In concept
BioDetection	microfluidic bio-separator/reactor captures target pathogens from a	*E. coli* 0157:H7, Salmonella Typhimurium and *L. monocytogenes*	Bench top	1-2 hr	*E. coli* down to 10-100 cells/ml[38]	Proto-type

[37] Cfu: colony forming units
[38] To be able to compare test methods, we assumed that 1 cell is about 10^{-12} g

	sample and hosts the immunological and enzymatic reaction, which is followed by an optical or electrochemical measurement.					
Veredus	multiplex PCR and microarray hybridization	*E. coli*, salmonella, listeria, campylobacter and several others	Bench top	< 2hr	Limit of detection 100-500 copies of extracted genomic DNA or virus RNA	R&D use only
Capwave	Antibody / fluorescence	*E. coli*, salmonella, listeria and campylobacter	Bench top	8-12 hr sample prep and 22 min. test	0,1 pg/ml / 133 *E. coli* in 1 mL	In develop ment
Bisen technologie s	Sensor array, no amplification needed					In concept
instantlabS	Real-time PCR	*E. coli*, salmonella, listeria,	Bench top	8-24 hr		
Foodsniffer	Optical detection					In researc h phase
Lovefood	acoustic detection biochip, magnetic beads technology, PCR					In researc h phase
Pathogeneti x	automated sample preparation system, fluorescent tag	*E. coli*, salmonella, listeria	Bench top	4 hr	Pg	Expecte d in 2013
Ostendum		*Listeria monocytogenes*	Bench top		10 cfu/ml?	In develop ment
	Traditional	Many pathogens	Lab instru ment	18 hr	0.25 ng	On the market

Table A1.2.1: Pathogen detection systems available or under development (Source: market research by enablingMNT)

Other major unwanted materials in dairy products

Melamine is sometimes illegally added to food products to increase their apparent protein content. Melamine is known to cause renal and urinary problems in humans and animals so its use in food production is universally banned. A lateral flow test is state-of-the-art and applied as an on-line melamine analysis.

Other chemicals: Due to the high versatility of chemical (trace-)contaminations in terms of chemical diversity and possible applications, all analytes or analyte groups require specialised laboratory methods often including elaborate sample preparation procedures. State-of-the art methods usually require HPLC-MS/MS or GC-MS/MS with high resolution instruments. Therefore very specific solutions will be required taking account to the high versatility of chemical cues that may occur.

Residues and unwanted ingredients

Drugs - Nowadays, the presence of drug residues, especially antibiotics in raw milk is analysed in the dairy industries when receiving the raw milk. A positive analysis involves a cost of destruction of the complete batch of milk. Therefore, a fast method which allows the analyses before the collection of the milk in the farm, and enabling separation of contaminated batches, would be desirable.

Pesticides are chemical or biological agents often used to protect plants from damaging influences such as weeds, diseases or insects. Pesticides can be further subdivided into according to their target groups: e.g. herbicides, biocides, fungicides, etc. Pesticides may cause acute and delayed health effects to workers who are exposed. Furthermore, they can cause environmental damage, and are generally a problem if occurring in upstream commodities, e.g. dairy products. There are a large number of different pesticides. For instance over 200 bio-pesticides (pesticides derived from natural materials as animals, plants, bacteria, and certain minerals) are registered. This diversity causes specific problems in detection.

Mycotoxins are rapidly becoming more important due to the increased concern for food safety and resulting in advanced control. Mycotoxins are secondary fungal metabolites with structural and toxicological properties that induce a variety of toxic and carcinogenic effects when food contaminated with these compounds is ingested. The occurrence of mycotoxins in agricultural commodities depends on the conditions under which a particular crop is grown, harvested and, or stored. Mycotoxins are stable under most food processing conditions and therefore, persist to the final product. It is, therefore, impossible to eliminate them once any food ingredients are contaminated – this makes it imperative to eliminate contaminated materials as early as possible in the processing chain in order to allow the timely and economical processing of non-contaminated batches. State-of-the-art testing in a lab is based on ELISA followed by HPLC.
As an example, the reported sensitivity (for Aflatoxin M1 in raw milk) is 100 to 2000 ppt; time to result < 5 minutes. In terms of the dairy industry it is also important to monitor feed, since this is the major intake route for mycotoxins into the dairy food chain. The following table provides an overview of FDA action levels for Aflatoxins, relevant for dairy chain:

Directly Affected Species	Commodity	Critical level (ppb)
Human	Milk	0,5 (Aflatoxin M_1)

Human	Other food (except milk)	20
Dairy animals	Grains	20

Table A1.2.2: FDA action levels for Aflatoxins, (Source: usda.gov)

Metal parts / chips from the equipment are a risk in food processing. Of the officially published food warning system in Germany[39] a majority of the warnings is due to physical risks, such as wooden parts, metal parts or broken pieces of glass. It is not known if microsystems are used for the detection of these parts. Optical systems can detect plastics, wood or glass fragments. Idem electronic (Hall-effect based) detectors for metal parts. On the other hand, the fear of food processing companies from introducing such parts puts severe restrictions on the design and construction of in-line sensors and other tools which are in contact with the food.

Lactose - Although Lactose is a natural ingredient of milk, lactose free products are on the market for those who have lactose intolerance. In this case lactose is an unwanted residue. The present methods of analyses of lactose need time, are expensive or are based on indirect measurements (as the glucose produced after the decomposition of lactose). Therefore, a fast and inexpensive direct method is desirable. The error of the analyses has to be low enough to assure that a supposed lactose-free-milk has less than 0.01% of lactose.

Products may be declared **gluten-free,** if they contain less the 20 ppm of gluten. The routine analysis method is a full-lab requiring enzyme linked immunosorbent assay (ELISA). New on the market is the EZ Gluten Test[40], an easy to use kit that will quickly detect the presence of gluten in foods and beverages. It is sensitive enough to detect levels of gluten as low as 10 ppm. This simple test is small and portable enough for use at restaurants or when travelling, and is sensitive and robust enough for use in industry and food manufacturing. It can be used to test individual ingredients in foods and beverages.

A1.3: Additional material related to cheese type specific tests

Examples of cheese type specific tests are:

- Excess acidity in cheeses like cheddar and Colby turn it brittle, grainy and bitter.
- Bad flavours in the milk, which can result when the cows eat a strong flavour like wild onion, can cause off-flavours, especially in raw milk cheese.
- A “barny” odour - uncomfortably close to cat urine - can result from protein degradation or wild strains of lactobacillus. (Unlike most bacteria, lactobacillus, the group of bacteria used to make cheese and yogurt, can survive in acidic milk.)

[39] http://www.lebensmittelwarnung.de/bvl-lmw-de/app/process/warnung/start/bvllmwde.p_oeffentlicher_bereich.ss_aktuelle_warnungen
[40] www.ezgluten.com

Most general tests used in cheese making:

Although is practically impossible to list all used and proposed tests, some of the more common ones are discussed below:

Milk composition analysis
Before the cheese-making process starts, the milk composition is analysed. This includes fat content, protein content (especially casein), and whey protein content. These parameters can be determined using infrared analysers. Additional quality measurements include total bacteria counts, tests for inhibitors and somatic cell counts. These measurements are sometimes already done by the milk producers.

Cheese analysis
Almost throughout the complete cheese-making process, fat, moisture and salt need to be monitored. Fat is determined by either Babcock, Mojonnier, or NIR procedures. Cheese pH, which depends on the type of cheese, is monitored together with the aforementioned parameters during manufacture, 3-4 days after manufacture, and during curing. The cheese pH profile is a crucial parameter in the cheese making process with respect to process and quality control. Other process control parameters derived from these measurements are the ratio of salt to moisture (S/M), moisture in non-fat substance (MNFS), and fat in dry matter (FDM). Microbial analysis (in greater detail described in chapter 3.1) is done on yeasts and moulds, total coli forms and staphylococci. If raw milk is used, the cheese has additionally to be tested for Salmonella, Staphylococci, Listeria and enteropathogenic E. coli.

Specific tests

Profiling
Profiling of products can enable tracing the place of origin but also optimise the processing by selection of incoming products according to contents. The origin of volatile compounds in cheese is heterogeneous and can be classified into two groups: native volatile compounds in the milk which are not altered during cheese-making, and compounds produced in the cheese during manufacturing or maturation. For example, the type of cow and feeding gives distinctive volatile compound profiles, but also the process of cheese-making, which can be different depending on the producer and the regional traditions.
State of the art regarding measuring soluble protein content in milk: the Amaltheys fluorescence analyser developed by Spectralys Innovation, enables to measure milk-soluble proteins and gives also an indicator of its thermal history within 5 minutes.
Usually the origin of the cheese can be determined by GC/MS methods[41] or electronic noses based on mass spectrometry, both methods measure the

[41] Pillonel, L., Ampuero, S., Tabacchi, R., Bosset, J.O., Analytical methods for the determination of the geographic origin of Emmental cheese: volatile compounds by GC/MS-FID and electronic nose. Eur Food Res Technol 216 (2003), 179–183

characteristic volatile compound profile. Yet these methods are cost-intensive and laboratory based.

Milk clotting

To achieve a maximum yield of cheese and the best quality of cheese, the cheese maker is looking for a precise determination of the firmness of the coagulum for optimal cutting. Moreover, changes in equipment (closed tanks), labour legislation (safety), the increase of the size of cheese plant and the increasing importance of automation explain the need of an objective instrumental method on-line and in real-time for the monitoring of clotting characteristics.

Dry matter

There is no method to measure the draining of whey in fat. However this parameter is critical to determine the time of moulding the curd. As for clotting characteristics, changes in equipment and the increasing importance of automation make it even more relevant the need for a measure of dry matter online and in real time.

Whey protein and denaturation rate

To increase yields, dairy industries apply to milk important heat treatments to denature the whey proteins which can thus be recovered in the curd and will be better valued. Monitoring the denaturation rate would improve regularity of yields and decrease the standard deviations of weight. This would allow for a lower average weight of the cheese with an increase in profitability.

Aromatic quality

The aroma is the most crucial parameter for the consumer to decide for one or the other cheese. A straightforward way is using the sensory perception of trained staff. But for products with less intense smell, accurate analytical data are required. Many approaches have targeted the construction of electronic noses so far, never fulfilling the desired performance. Microelectronic approaches in detecting a variety of specific volatile organic compounds (i.e. odorants) could finally provide the required performance. Parameters to be measured are the quantity of all odorants (that can be several hundred per cheese) or at least some key impact/signature odorants.

Ripeness / bacteria activity

The ripeness cannot be directly measured, however it is the sum of several parameters listed above (temperature, colour, pH, salinity) and those highly depend on the type of cheese. The bacterial activity cannot be directly measured.

Colour

The colour of the cheese is checked before brining. Up to now this is done by the producer by simple visual inspection (which needs a lot of training and experience to distinguish fine nuances in colour). Here microsystems could aid in the future by combining colour sensors with intelligent software for colour discrimination, although this might be a minor issue.

Tenderness
Today the tenderness is checked manually by touching/pressing the cheese and is therefore also subjective. Tactile sensors are currently under development in several research teams and can be optimised in the future for application in cheese-making.

Texture
Assessing texture can probably be best solved with CCD cameras; this is however not a topic for microsystems.

Opening/holes characteristics in cheese
An objective method to determine the characteristics of cheeses openings/holes would allow better management of ripening cycles (out of hot room, temperature, humidity...). Parameters to be measured: distribution, uniformity, size, etc.

Temperature and humidity
These parameters are important but they can already be measured will with state-of-the-art products, thus, they will not be addressed further in this chapter.

A1.3: Additional material related to microfiltration techniques for dairy

Since the 80’s, Microfiltration has been widely used in dairy industries in order to concentrate the protein fraction of milk without any denaturation. This operation is generally carried out on spiral wound polymer membranes or to a lesser extent on tubular ceramic membranes with molecular weight cut off (MWCO) 10-50 kDa and at a transmembrane pressure of 200-400 kPa. The differences and benefits between these membranes depend on the applications.

Ceramic
A ceramic membrane has a nominal pore size of 0.1 micron and is more tubular in shape. It provides numerous benefits, including high-heat tolerance and quicker clean-up and flushing after processing. The cost to operate, however, is higher than using a polymeric membrane.

Polymeric
The spiral-wound polymeric membrane pore size is wider at 0.3 micron. While more energy efficient and less costly to operate, its recovery of soluble proteins is very low. Also, spiral-wound membranes are more challenging to clean following processing, and the life of the membrane is shorter than that of a ceramic membrane. There are ideas to microstructure the filters to improve its anti-fouling properties.

Ceramic microfiltration membrane filtration systems are especially suitable for certain specialised applications in the dairy industry, while polymeric membrane systems are simpler and much less costly to operate. A disadvantage of microfilters is the complex operation conditions to prevent fouling and to keep the system in its preferable window of operation. Microfilters are mainly used for the removal of bacteria form milk and selective separation of casein micelles from soluble proteins. Extended shelf life milk is created form microfiltered skimmed milk and heated cream.

Microfiltration can also be used to improve the cheese making process, without any influence on flavour or texture. Chromatographic processes are widely used in industry to extract milk components with a high added value. They are not (yet) practical for use in volume processing.

As to the techniques, milk can be concentrated well by membrane techniques like reverse osmosis (RO) and ultrafiltration (UF). Milk is pressed through a porous membrane under high pressure. The type of membrane technique (size of the pores) defines what the composition is of the retentate. The permeate can be used as cleaning or drinking water, but depending on the purity. It can be assumed that an increase of percentage of dry matter form 12.5% to approximately 25% is possible.

A1.4: References

http://ec.europa.eu/agriculture/eval/reports/dairy/

Competiveness and innovativeness of the EU Dairy Industry, J.H.M. Wijnands et. Al.

Human nutrition in the developing world, 1997, FAO Food and Nutrition Division

Milk and Diary Product Technology, Spreer & Dekker, 1998

A Risk Profile of Dairy: Products in Australia, Food Standards Australia New Zealand, 2006

Lactose Tolerance, KurdishDNA.blogspot.com

Global Geography of Milk Consumption and Lactose (In)Tolerance, http://geocurrents.info/cultural-geography/culinary-geography/global-geography-of-milk-consumption-and-lactose-intolerance#ixzz2Yw6y2VSF

http://en.wikipedia.org/wiki/Pasteurization

http://en.wikipedia.org/wiki/Homogenization_(chemistry)

http://en.wikipedia.org/wiki/Raw_milk

http://www.milkmaps.com/

http://www.realmilk.com/

http://www.foodstandards.gov.au/code/proposals/pages/proposalp1007primary3953.aspx

THE ENVIRONMENTAL IMPACT OF DAIRY PRODUCTION IN THE EU 2000, European Commission (DGX I), submitted by CEAS Consultants Ltd, Centre for European

Agricultural Studies and The European Forum on Nature Conservation and Pastoralism

http://ec.europa.eu/environment/agriculture/pdf/dairy.pdf

R. Bertsch, Efficient production of energy in Bulletin of the international dairy federation 2000

G. Smit, Dairy processing – improving quality. Woodhead publishing, 2003

Ampuero, S., Bosset, J.O., The electronic nose applied to dairy products: a review. Sensor and Actuators B 94 (2003), 1-12

Pillonel, L., Ampuero, S., Tabacchi, R., Bosset, J.O., Analytical methods for the determination of the geographic origin of Emmental cheese: volatile compounds by GC/MS-FID and electronic nose. Eur Food Res Technol 216 (2003), 179–183

http://www.uoguelph.ca/foodscience/cheese-making-technology/section-b-analytical/process-and-quality-control-procedures, 12.07.2013

http://www.food-info.net/uk/dairy/cheese-production.htm, 12.07.1213

http://www.biotechlearn.org.nz/focus_stories/cheesemaking/quality_control_in_cheesemaking, 12.07.2013

A Risk Profile of Dairy Products in Australia, Food Standards Australia New Zealand, 2006)

Canadian Dairy Information Centre, Agri-Expo, Hoard's Dairyman, US Department of Agriculture)

www.biotechlearn.org.nz

J. Silva, Sensors & Transducers, January, 2010

Microfiltration - Applications and potentialities in the dairy industry, 27 February 2013, Geneviève Gésan-Guiziou)

Presentation by Cees van Rijn (Aquamarijn) at FoodMicroSystems workshop June 2012

Presentation by Frans Velterop (Pervatech) at FoodMicroSystems workshop June 2012

European Technology Platform "Food for Life" Strategic Research and Innovation Agenda (2013-2020 and Beyond)

Food&Drink Business Europe / Food for Thought FFT)

FAPRI-ISU 2011 World Agricultural Outlook, www.fapri.iastate.edu/outlook/2011/

PBL analysis based on FAO (2010), NEVO (2010), www.pbl.nl

Complex diagram of dairy products and their production chains (: http://en.wikipedia.org/wiki/File:Milkproducts_v2.svg)

Characterization of Cronobacter recovered from dried milk and related products, Walid M El-Sharoudet al, www.biomedcentral.com/1471-2180/9/24

Presence of Enterobacter sakazakii in Milk Powder, Whey Powder and White Cheese Kemal Kaan TEKİNŞEN et al, http://vetdergi.kafkas.edu.tr/

A Risk Profile of Dairy Products in Australia, Food Standards Australia New Zealand, 2006”

usda.gov

http://www.lebensmittelwarnung.de/

Annex 2: workshops organised for preparing the roadmap

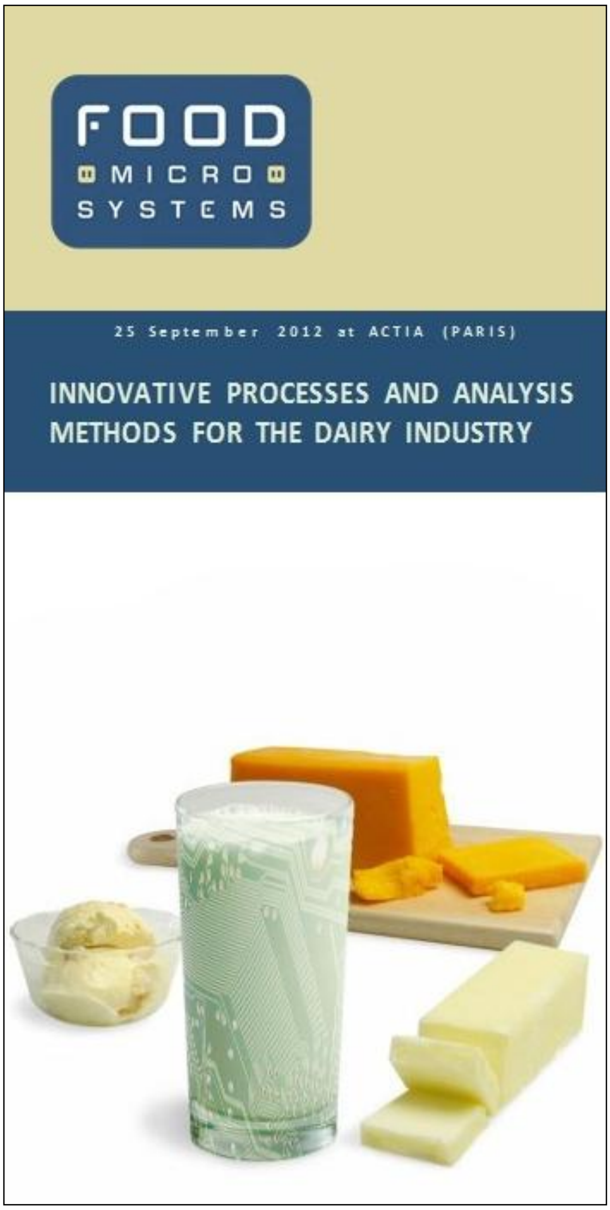
A2.1: Expert Workshop "Innovative Processes and Analysis Methods for the Dairy Industry" 25th Sept 2012 in Paris

International Expert Workshop

Innovative Processes and Analysis Methods for the Dairy Industry

How can Micro technologies and Smart Sensors help the Dairy Industry to improve food quality, reduce cost, and strengthen consumer confidence?

25th September 2012 at ACTIA, Paris, France



Objectives and Programme (invitation text)

This workshop will bring together specialists from the microsystems community with equipment providers and key players from the food industry. The objective is to assess opportunities & challenges and drivers & barriers for the use of micro technologies and smart systems in the food industry. The workshop will set the grounds to an application driven technology roadmap that can draw the foundations for future collaboration between the dairy industry and the microsystems community, support strategy decisions, and supply investors and funding bodies with guidelines to support their investment decisions.

Fig. A2.1.1 Workshop announcement on website (25th Sept 2012)

Programme

09:30 Registration, Coffee and Networking

10:00 Welcome & Overview of the FoodMicroSystems Project and Funding Opportunities, Christophe Cotillon, ACTIA (The French Food Association), France

10:15 Opportunities for Microsystems in the Dairy Sector, Frans Kampers, Wageningen University, The Netherlands

10:45 Round the table introduction of all participants

11:00 FoodMicroSystems Roadmapping Methodology and the Dairy Supply Chain, Patric Salomon, 4M2C/enablingMNT, Germany

11:30 Coffee Break and Networking

11:50 Break-out session 1: New Microtechnologies for innovative processes in Dairy Production … and the needs of the Dairy Industry

12:30 Lunch Break and Networking

13:40 Break-out session 2: Microsystems for analysis and quality control for the Dairy Industry … and the needs of the Dairy Industry

14:20 Summary from Break-out sessions; discussion and questions; what are the major challenges?

14:50 Coffee Break and Networking

15:10 Break-out session 3: Drivers and barriers of using new (micro) technologies in the dairy production and supply chain

15:50 Summary and Conclusions: "R&D Project Needs", "Recommendations to the EU", "Challenging topics to be discussed further".

16:30 End of Workshop

Contacts

(local organiser)
Stéphane Gavoye, Actilait
Paris/France
Tel.: +33 (3) 81559285
E-Mail: s.gavoye@actilait.com

(international contact)
Patric Salomon, 4M2C/enablingMNT
Berlin/Germany
Tel.: +49 30 24357870
E-Mail: Patric.salomon@4m2c.com

All presentations, the flyer, and notes have been made available at www.foodmicrosystems.eu.

Fig. A2.1.2 Workshop Invitation/Flyer (25th Sept 2012)

All participants had the opportunity to give a short introduction about their organisation's activity, their relation to dairy processing and to raise comments and questions for discussion, more specifically "to describe one or two (major) problems in Dairy Processing that you think might (possibly) be solved with new Microtechnologies or Smart Sensors". These presentations are also available from www.foodmicrosystems.eu .

Notes from presentations and general discussion

For many microsystems proposed or demanded for the food sector, there have products already been developed and brought onto the market in medical diagnostics. Billions of Euros have been spent in developing technologies there. Using and adapting these to food applications is advisable.

Food will be a technology follower, unless there is an acute unmet need (e.g. after the milk scandal in China).

Comment on importance of microsystems in food: consumer is much more interested in food safety than in food quality.

Huge steps have been made in the development and understanding of the emulsification and encapsulation processes, but the problem of affordable manufacturing in large volumes is still not solved. TNO Netherlands investigates alternative ways of encapsulating using lasers.

The weakness of filtration and fractionation with microsieves is that there are plenty of good alternatives.

A replacement system is absolutely not allowed to cost more than the old system.

Pathogen detection: especially an area where using concepts from medical diagnostics is a realistic option.

If a farmer uses a test and detects a problem, it is not in his interest to destroy the batch! Therefore it might be advisable to have direct internet connection/RFID?

State of the art: soluble protein content in milk can be measured within 5 minutes offline by Amaltheys (but this will also cost 5-10 minutes of the operator time. Assume the operator cost at 60 Euro per hour, this will mean that even without disposables the test would cost 5-10 Euros.)

There is an interest in bioreactors for testing during cheese processing; issues:
1) control variables: accurate and quick. 2) process state versus control variables,

Potentials for Microsystems in dairy processing: cleaning the processing line (detergents, biofilms, allergy); inline detection of pathogens; authenticity (also GM food); pesticides, herbicides, etc.

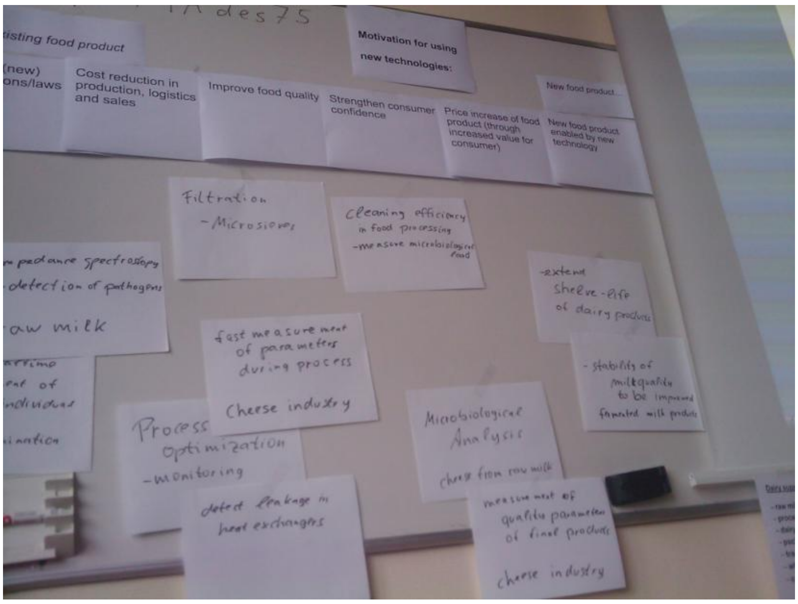


Fig. A2.1.3 Discussion notes from presentations

Measurements along the food chain:

- Farmer: outgoing check
- Dairy company: incoming check, inline control, final test
- Retailer: check at time of sale
- Consumer: check at point and time of use

Some long term goals:

Cheese: during ripening: daily check on: Protein, fat, water, minerals, proteolysis[42] (different peptides), lipolysis[43] (Free Fatty Acids), water activity[44], F. V. Acids.

Milk may need hourly screening

Break-out sessions

2 Break-out sessions were organised with 3 parallel groups each to allow for a more in-depth discussion. From the 6 topics proposed, 5 were covered in the groups:

1. From cow to raw milk (Quality, contamination)
2. Measurement in process (on-line, in-line)
3. Quality control (analysis of final product)
4. Filtration (process innovation, micro sieves) – not covered in break-out session
5. Cleaning efficiency
6. Packaging / transport / tracking

Each break-out group had a moderator, who took notes and reported back to the overall workshop later. The following headlines/questions were prepared to guide the discussion in each group:

Problems in the Dairy supply chain that might (possibly) be solved with new Micro technologies or Smart Systems

Problem to be solved or Parameter to be improved

Opportunities / benefits / drivers for user (food industry / consumer)

Challenges / problems / barriers in the realisation
- from user (dairy industry point of view):
- from Microsystems supplier / research point of view:

Urgency / expectations on availability (3, 5, 10 years)

Key parameters / specification range

Other issue / discussion items

Fig. A2.1.4 Headlines/questions to guide the discussion in break-out sessions

[42] Breakdown of proteins into smaller polypeptides or amino acids.
[43] breakdown of lipids and involves the hydrolysis of triglycerides into free fatty acids followed by further degradation into acetyl units by beta oxidation.
[44] was developed to account for the intensity with which water associates with various non-aqueous constituents and solids.

Notes from Break-out sessions

Problems in the Dairy supply chain that might (possibly) be solved with new Micro technologies or Smart Systems

Session 1, Topic: From cow to raw milk

Moderator: Frans Kampers

Problem to be solved	**Parameter to be improved**
Detection of residues (organic farming)	Cost of sensors
In-line measurements of cell count or biological contamination (bacteria)	
Uptake by users (education level of farmers, connected to economy, low cost tests)	

Opportunities / benefits / drivers for user (food industry / consumer)

If you can detect cows that have contaminants (bacteria, residues) in the milk soon enough you will be able to increase the value of the milk in the collection tank. Both for the farmer and for the dairy industry.

Screening for cows that are in the process of developing a health problem.

Challenges / problems / barriers in the realisation

- from user (dairy industry point of view):

Cost

How do you know that the organic milk is really from an organic farm?

- from Microsystems supplier / research point of view:

Provide a sensor that can measure certain parameters (somatic cell count, bacteria, residues) in the teat cup) during the milking (10-15 min).

Urgency / expectations on availability (3, 5, 10 years)

No clear answer

Key parameters / specification range

Time of measurement (10-15 min for the in-line measurement)

Cost (depending on application: in-line screening: very low; test of recovery of cows: 1 €)

Sensitivity (depends on regulation)

Reliability (less for screening, but no false negatives; for checks the reliability needs to be higher)

It is very difficult at this stage to specify more ranges

Other issue / discussion items

What is missing during the discussions is the knowledge of the end users (farmers, quality control organisations and dairy industry)

Fig. A2.1.5 Break-out session 1: From cow to raw milk (Quality, contamination)

Problems in the Dairy supply chain that might (possibly) be solved with new Micro technologies or Smart Systems

Session 2, Topic: Measurements during the process (on-line)

Moderator: Olivier Chartier

Problem to be solved	**Parameter to be improved**
Non-destructive analysis	Acidification +++
In situ	Temperature ++
Non-intrusive (better) : problem for cleaning	Humidity (cheese)
No by-pass	Density
Continuous measurements are better	Products (≠ environment) :
Fast measurement	Microbio parameters
	Physical parameters
	Chemical parameters
	Protein, fat, lactose, dry matter
On-line : don't take a sample,	Residue previous batches
In-line : sample, multi-parameters very important	Residue detergent batches
Off-line : in laboratory	We have to make a difference between :
	Cheese - solid
	Milk – liquid
	Microbio quality (not today in continuous)
	Raw milk quality : protein, count somatic cells

Opportunities / benefits / drivers for user (food industry / consumer)

Better control of processing parameters of the product for increase yield and decrease waste.

Challenges / problems / barriers in the realisation

- from user (dairy industry point of view):

- Not much regulatory constraints (linked with cleaning – foreign bodies)
- Cost : depends on benefits
- Competing with simple/existing sensors
- Reliability
- Calibration
- Standardisation is not hot topic
- Specific case of Infant Formula
- Environment constraints: humidity, temperature, salt, biocompatibility
- Food contact material regulation

- from Microsystems supplier / research point of view:

--

Urgency / expectations on availability (3, 5, 10 years)

As soon as possible

Solution that do not exist -> priority

Key parameters / specification range

Other issue / discussion items

Fig. A2.1.6 Break-out session 2: Measurement in process (on-line, in-line)

Problems in the Dairy supply chain that might (possibly) be solved with new Micro technologies or Smart Systems

Session 3, Topic: Quality control (analysis of final product)

Moderator: Arnout Fischer

Problem to be solved	Parameter to be improved
we need online knowledge on mineral protein	know quicker than now final composition, often

Fig. A2.1.7 Break-out session 3: Quality control (analysis of final product), page 1

Problems in the Dairy supply chain that might (possibly) be solved with new Micro technologies or Smart Systems

Session 3, Topic: Quality control (analysis of final product)

Moderator: Arnout Fischer

(page 2)

Fig. A2.1.8 Break-out session 3: Quality control (analysis of final product), page 2

Problems in the Dairy supply chain that might (possibly) be solved with new Micro technologies or Smart Systems

Session 5, Topic: Cleaning efficiency

Moderator: Olivier Chartier

Problem to be solved	**Parameter to be improved**
Alarm to indicate when/how to clean	Biofilm thickness/composition

Fig. A2.1.9 Break-out session 5: Cleaning efficiency

Problems in the Dairy supply chain that might (possibly) be solved with new Micro technologies or Smart Systems

Session 6, Topic: Packaging / transport / tracking

Moderator: Arnout Fischer

Opportunities / benefits / drivers for user (food industry / consumer) and challenges / problems /

Fig. A2.1.10 Break-out session 6: Packaging / transport / tracking

List of Participants

first_name	last_name	company	country
Maud	Lambert	Fromageries Bel	France
Nathalie	BONDU	LACTALIS	France
Edwige	JARDIN	LACTALIS R&D	France
Jean-René	Kerjean	Actilait	France
Alain	MIMOUNI	CTCPA	France
Laura	MARLEY	ANIA	France
Ariane	VOYATZAKIS	OSEO, Maisons Alfort	France
Aliénor	Liogier de Sereys	Spectralys Innovation	France
Jerzy	Radecki	Institute of Animal Reproduction and	Poland
Hanna	Radecka	Institute of Animal Reproduction and	Poland
Anna Grazia	Mignani	CNR IFAC	Italy
Stephan	Karmann	HSG-IMIT	Germany
Dag	Ilver	Acreo, Sensor Systems	Sweden
Leandro	Lorenzelli	Fondazione Bruno Kessler	Italy
Arndt	Steinke	CiS Forschungsinstitut für Mikrosens	Germany
Eric	Moore	Tyndall National Institute	Ireland
Eleni	Makarona	NCSR Demokritos	Greece
Clémentine	Bouyé	TEMATYS, Dep. "Biophotonics"	France
Roland	Lartigue	TOPPAN Photomasks France	France
Julien	Arcamone	CEA-LETI	France
Henne	van Heeren	enablingMNT -Netherlands-	Netherlands
Mariann	Nõlvak	Tartu Biotechnology Park	Estonia
Luis	Fonseca	IMB-CNM (CSIC)	Spain
Patric	Salomon	4M2C / enablingMNT Germany	Germany
Frans	Kampers	DLO	
Elisabeth	Delevoye	CEA	
Christophe	Cotillon	ACTIA	
Olivier	Chartier	Euroquality	
Hélène	Bourgade	Euroquality	
Matthieu	Alric	ACTIA/ADIV	
Stéphane	Gavoye	ACTIA/ACTILAIT	
Dalal	Werner	ACTIA/AERIAL	
Catherine	Sauvageot	ACTIA/LNE	
Arnout	Fischer	WUR	
Katrin	Schmitt	Fraunhofer	

Break-down of Participants

21 external participants (from 8 countries), amongst them:

- 7 representing the Food Industry,
- 14 technology suppliers (representing the Microsystems community)

14 partners of the FoodMicroSystems project, amongst them:

- 5 representing the Food Industry,
- 2 technology suppliers (representing the Microsystems community)
- 3 specialists in Microsystems AND Food
- 4 project management / consulting

A2.2: Roadmapping Workshop "Micro Technologies for the Dairy Processing Industry" 18th Jan 2013 in Wageningen

International Roadmapping Workshop

Micro Technologies for the Dairy Processing Industry

Towards a Roadmap for Micro Technologies and Smart Sensors to help the Dairy Industry to improve food quality, reduce cost, and strengthen consumer confidence.

(invitation text)

This workshop is a follow-up to the two workshops already organised by the FoodMicroSystems project (7 Jun 2012 Wageningen, 25 Sep 2012 Paris) and will specifically discuss opportunities & challenges and drivers & barriers for the use of micro technologies and smart systems in the dairy industry. The workshop aims at a roadmap that will help the dairy industry and the technology companies to focus their research on joint goals, ensuring that technology push and dairy pull align. The roadmap can serve as a coordination mechanism for the near future, ensuring that demands of the dairy sector are met by technological developments and will help future innovations in the sector. By participating in the workshop you can direct the roadmap to goals that are of interest to your company and you will be able to join a collaboration that really can benefit your competitiveness.

Fig. A2.2.1 Workshop announcement on website (18th Jan 2013)

Tentative topics for parallel workshops / break-out sessions

(4-6 out of these topics will be selected, depending on the interest and qualification of participants; please select your favourites during on-line registration):

1. From cow to raw milk (measuring quality, contamination)
2. Measurements during the dairy processing (on-line, in-line, off-line)
3. Quality control (analysis of final dairy product)

4. Specific sensors/analysis for liquid dairy products (e.g. yoghurt, milk)
5. Specific sensors/analysis for creamy to solid airy products (e.g. cheese, butter, cream)
6. Cleaning of processing equipment (when to clean, cleaning efficiency, contamination by detergents)
7. Packaging / transport / tracking
8. Quality check throughout retailing sector / consumer
9. Process innovations, e.g. micro sieves for pasteurisation / sterilisation / fractionation
10. New / innovative processing steps that require completely new (micro) technologies

Programme

09:00 Registration, Coffee and Networking
09:30 Overview on the FoodMicroSystems Project, Funding Opportunities, and Objectives of this Roadmapping Workshop
Patric Salomon, 4M2C/enablingMNT, Germany
09:50 Round the table introduction of all participants and their background
10:30 Microsystems in Dairy Processing - Results from initial workshops (7 Jun 2012 Wageningen, 25 Nov 2012 Paris)
Frans Kampers, Wageningen University, The Netherlands
Patric Salomon, 4M2C/enablingMNT, Germany
11:00 Coffee Break and Networking
11:30 Three parallel workshops / break-out sessions "Micro technologies for the Dairy Processing Industry" (see list of topics)
12:30 Lunch Break and Networking
13:30 Summary and discussion of results from 1st set of parallel workshops
14:00 Three parallel workshops / break-out sessions "Micro technologies for the Dairy Processing Industry" (see list of topics)
15:00 Coffee Break and Networking
15:30 Summary and discussion of results from 2nd set of parallel workshops
16:00 Overall summary and conclusions from this Roadmapping Workshop, follow-up activities, and recommendations for the European Commission.
16:30 End of Workshop

Contacts

(local organiser)
Dr. Frans Kampers, Wageningen UR
Yvonne Blom, Wageningen UR
Wageningen/The Netherlands
Tel.: +31 317 487279
E-Mail: yvonne.blom@wur.nl

(international contact)
Patric Salomon, 4M2C/enablingMNT

Berlin/Germany
Tel.: +49 30 24357870
E-Mail: patric@enablingmnt.com

All presentations, the flyer, and notes have been made available at www.foodmicrosystems.eu.

Fig. A2.2.2 Workshop Invitation/Flyer (18th Jan 2013)

In addition to introductory presentations by Patric Salomon and Frans Kampers from the FoodMicroSystems project, all participants had the opportunity to give a short introduction about their organisation's activity, their relation to dairy processing and to raise comments and questions for discussion. These presentations are also available from www.foodmicrosystems.eu.

Break-out sessions

Participants were asked to vote for their favourite topics for the break-out sessions with the registration process. From the 10 proposed topics the voting was as follows (the second column shows the number of votes):

topic	how many	proposed Topics for Dairy workshop Wageningen January 2013
1	6	From cow to raw milk (measuring quality, contamination)
2	**12**	**Measurements during the dairy processing (on-line, in-line, off-line) - Process Control**
3	**8**	**Quality control (analysis of final dairy product) - measure the "wanted"**
4	**13**	**Specific sensors/analysis for liquid dairy products (e.g. yoghurt, milk) - measure the "unwanted"**
5	**11**	**Specific sensors/analysis for creamy to solid airy products (e.g. cheese, butter, cream) - measure the "unwante**
6	6	Cleaning of processing equipment (when to clean, cleaning efficiency, contamination by detergents)
7	4	Packaging / transport / tracking
8	3	Quality check throughout retailing sector / consumer
9	**11**	**Process innovations, e.g. micro sieves for pasteurisation / sterilisation / fractionation**
10	**12**	**New / innovative processing steps that require completely new (micro) technologies**

Fig. A2.2.3 Voting for break-out session topics

From this, it was proposed to discuss topics 2,3,4,5,9,10 within 6 break-out groups; 2 sessions with 3 parallel groups each.

2- Measurements during the dairy processing (on-line, in-line, off-line)
3- Quality control (analysis of final dairy product)
4- Specific sensors/analysis for liquid dairy products (e.g. yoghurt, milk)
5- Specific sensors/analysis for creamy to solid airy products (e.g. cheese, butter, cream)
9- Process innovations, e.g. micro sieves for pasteurisation / sterilisation / fractionation
10- New / innovative processing steps that require completely new (micro) technologies

It was then decided to merge topics 4 and 5, as they might have a lot of overlap and discuss both together within a double-length session.
As one of the break-out groups finishes much faster, it was later decided to add another topic to the group discussion:

6- Cleaning of processing equipment (when to clean, cleaning efficiency, contamination by detergents)

Each break-out group had a moderator, who took notes and reported back to the overall workshop later.

Fig. A2.2.4 Photo from the workshop

Notes from Break-out sessions

Micro Technologies for the Dairy Processing Industry (18 January 2013 in Wageningen)

2. Measurements during the dairy processing (on-line, in-line, off-line)

Sensor Priorities

1. In-line
2. Cleanable
3. Contact-less
4. Wireless

Performance indicators/ specification range

1. Dry matter.
2. Record temperature time-history.
3. Humidity.
4. Density (commercial equipments might be good enough?).

Developments Needs/missing technologies

1. Water activity: linked water vs free water.
2. Measuring native protein vs denatured protein.
3. Dry matter (quantity) with microwave technology or electrically through ohmic heating.
4. Fouling sensors (pressure and temperature) during pasteurization.
5. Viscosity measurement before separation (not clear if Microsystems can be used).

Problem to be solved / driver for development

1. Possible alternatives to stainless steel.
2. Good encapsulation for needed electronics in wireless sensors, to avoid both contamination and degradation.
3. Obtain inner temperatures for semi-solid products (cheese).
4.
5.

State of the art

1. Wired Pt100 temperature sensors.
2.
3.
4.
5.

Main players

1. Sensor suppliers and Plant building companies.
2. Usually big companies. It's difficult for SMEs to get in the game.
3.
4.

Other comments about offline / online / inline, etc.

One of the most important problems in dairy processing is that as general rule nothing which is not stainless-steel is allowed to touch the substance. Any material in contact with it must be thoroughly tested, for possible contamination of substance, as well as possible degradation of material during cleaning. Glass, for example, is not allowed. Special food-graded Pt100 and electrodes are used. It could be interesting to explore materials used in medical-pharmaceutical industry and use them for inline sensors (Teflon, polyimides,...).

Micro Technologies for the Dairy Processing Industry (18 January 2013 in Wageningen)

3. Quality control (analysis of final dairy product)

Sensor Priorities

1.
2.
3.
4.

Performance indicators/ specification range

1. Aromatic quality (electronic noses).
2. Texture, hardness.
3. Voids (holes) inside the cheese: distribution, uniformity, size, ...
4. Temperature, humidity, ...
5. Bacteria activity inside the cheese.

Developments Needs/missing technologies

1. Traceability (RFID) would help identifying the origin of the product and fight counterfeiting.
2. Temperature monitoring during distribution (application for high value products).
3.
4.

Problem to be solved / driver for development

1. Proteolysis is the highest priority.
2. Amount of water present in the final product.
3. Quality of water.
4.
5.

State of the art

1. Aromatic quality measured by human experts.
2. Texture and hardness are measured with destructive methods.
3. Voids (holes) inside the cheese are also measured with destructive methods. Some literature about ultrasound methods.
4. Bacteria activity monitored through volatile free acid measurements.
5.

Main players

1.
2.

Other comments about offline / online / inline, etc.

Bacteria activity data could be interesting for R&D groups or industry, but is not much interesting for quality control. Despite the amount of bacteria needs to be precisely controlled to get the right cheese, as well as temperature and humidity during the ripening process in the final product there is no need. And in any case microsystems do not give a real benefit.

Final product control in milk is not that important as a lot of effort is already made during the process control. On the other hand, cheese needs some final product quality analysis to check how bacteria acted on your cheese.

There seems to be no high priority application for MEMS in cheese and milk analysis of the final product.

Break-out sessions 4/5: **Testing for unwanted content in the dairy logistic chain**

Not all tests in dairy need to provide fast results; for instance for testing milk for cheese production, a 24 hr time frame is allowed for the total test procedure.
A visionary product is a printed sensor in a milk package for pathogen detection. Such a sensor might test for secondary effect of pathogen presence instead of direct measurement. This application will profit from ongoing work in the area of roll to roll production, RFID, printed electronics, etc. Such a sensor should be able to detect one pathogen in a liter of milk, and make no use of bioreceptors/antibodies. Read out on the other hand is relative simple: only a good or bad response is needed.
Baby food: Cronobacter has been linked to the use of baby formula. Cronobacter ends up in powdered formula because it is well adapted at surviving in very dry environments. The bacteria may grow rapidly if the powdered product, with even small amounts of cronobacter, is reconstituted in water that's not hot enough to kill it. Therefore absolutely no cronobacter is allowed in baby food. Current tests are PCR or culture based.
In general it makes sense to put a test as early as possible in the supply chain; for instance a sensor in the milking robot. That doesn't mean there will be no tests needed later in the logistic chain as new contaminants might have been introduced during processing.
NXP worked on a protein sensor in blood; it achieved to detect femtogram level. It was based on a CMOS capacitance sensor. The main difficulty was the fact that such a sensor was sensitive to a lot of other effects, like temperature for instance.
It might be sensible to divide the test "wish lists" in four groups: 1) pathogen 2) organic material 3) inorganic material 4) physical effects. Regarding pathogens, a division between a) zoonotic bacteria, i.e. the ones that cause diseases: not a single one is allowed and b) those that cause spoilage and which need to be quantified.
There are lessons to be learned from the detection of pesticides in wine and orange juice. Testing orange juice is relatively easy after dilution; for wine one needs first to remove tannins. In research it has been proved that the detection at picomolar level is possible?
The R&D community is in need for clearer specification from the user (dairy) community for a) what there has to be improved and b) what specific performance indicators need to be met.
It was mentioned that IMB-CNM worked on a capacitive sensor that was able to check for residues after cleaning.
Milk is a rather difficult matrix; it seems to be necessary that the fat and casein is removed before any testing is possible. This is common problem for all tests of milk.
Global Life & Science is in the business of risk avoiding. This company claims that it can detect if certain batches of milk have a higher risk of pathogen growth than others. This might be another approach.
PCR is a time consuming activity, but the throughput can be substantially increased by using microfluidics: 2 hr compared to 24 hr in conventional systems. The particularity of PCR is that is leads to the detection of life pathogens. With direct sensing dead and living organisms are detected. Detecting RNA could overcome this problem as RNA has a short life and therefore an indication of living organisms.

Increasing the sensitivity of the system can be done by pre-concentration, for which there are several options:

- Adhesion to fixed structures like pillars or herringbone structures covered by antibodies and washing. (Note: three dimensional structures can also be used to increase sensor sensitivity)
- Magnetic beads
- Filtering & washing

Innosieve uses a filtering technique, but the read out is still manually, and the whole set up makes it a lab technique; it is not suitable for use in-line or on-line. But the time to result is shorter than conventional systems.
There is a specific request for sensors to detect leakage of lubricants or cooling water.
Pesticides/herbicides/antibiotics have a specific problem. There are a huge number of them around. The only way to detect them effectively is by using an array based concept.
The main driver for microsystems in the dairy chain is the need for shorter time to result. Faster tests could minimize product loss by early removal of suspected batches. Secondly it could enable early response to production problems. Thirdly tests could optimize the use of the equipment by optimising maintenance procedures.
It makes sense to do the control as early as possible in the chain. If you do it at the farm, it is possible to isolate suspected batches from the good ones. It should be possible to do this at the farm or at the entrance of the dairy factory. Besides pathogen detection, also the quality of the milk (fat, protein, cell etc.) should be measured. Pathogen detection needs to be as fast as possible, while the batch will only be released after the results are known. There is no hurry for the content test. If the dairy company can guarantee that there are no pathogens in the milk, sale of unpasteurized milk might become possible.
It might even be of interest to integrate a sensor in the milking robot. That way even milk from suspected cows can be separated from the others. To detect mastitis, conductivity measurement or cell count might be an option. In-line detection of pathogens should do the trick too, but this idea faces a number of practical problems in terms of robustness, cleanability, etc. In-line detection of pathogens has been investigated by one company at least, but this technology is far from being ready for the market. Introduction in the water supply chain will be earlier then in the food supply chain.
A detection system that can be used by the driver of the van that transports the milk must be preferable handheld or at least desktop. It should be able to do the test during the loading or during transport. If it is a fast system, it could also be done at the entrance of the dairy company. Essential is that the device is fully automatic and robust. We are therefore looking for a disposable cartridge based system. The cartridge should cost less than 5 € (based on the following rough calculation: there is a wide range of farm sizes in Europe; supposed a "high end" farm with 200 cows @

100 l /cow/day @ 20 ct per liter, the value of a batch is 4000 €). The lower the price of the cartridge, the higher the number of potential users.
A critical point is the sensitivity, i.e. which concentration should be detected according to the rules and what concentration is realistically detectable in the near future.
Bacteria that spoil the cheese making process: The current method requires a first sterilisation to kill the bacteria and a second step for spores germination and bacteria growth detection. The analysis equipment is bulky, inaccurate and old. A new technology is overdue and requested by the industry.

Summary / conclusions (break-out sessions 4/5: Testing for unwanted content in the dairy logistic chain)

Top three needs are
1) pathogens
2) pesticides
3) antibiotics and hormones.
It must be said that there are also many more unwanted chemicals and parameters that the dairy industry wants to test. As the absolute number of test positions might not be that high, it would help if the tests can detect for several markers simultaneously. An approach would be to have a generic instrument with application specific cartridges.

In terms of performance indicators:
Number one: the suitability to detect for several items simultaneously. This goes for all three top priority items.
Secondly, the time of result should fit to the logistic schedule.
Thirdly ease of use, cost and robustness.

It can be expected that introduction of new tests and technologies will be seen first for the production of those products that have a high added value or products for consumers with a strong risk avoiding attitude (i.e. medical food, baby milk, etc.). For these products it might even be realistic to talk about handheld sensor systems for point of use or even integrated in the package. A requisite for a sensor in a package should be that it would operate without the need for an antibody/receptor.

There are three approaches to pathogen detection:
1) detection of the pathogens
2) detect for effects caused by the presence of the pathogens
3) detect batches that have a constitution that makes them sensitive for pathogen detection.

Micro Technologies for the Dairy Processing Industry (18 January 2013 in Wageningen)

6. Cleaning of processing equipment (when to clean, cleaning efficiency, contamination by detergents)

Sensor Priorities

1.
2.

Performance indicators/ specification range

1. Bacteria.
2. Organic compounds.
3. Fouling.
4. Biofilms.
5. Proteins on the pipes.
6. Water conductivity to ensure proper rinsing.

Developments Needs/missing technologies

1. Improved external electrical measurements to determine fouling layer thickness.
2. Magnetic measurements could be an alternative (not yet explored).
3.

Problem to be solved / driver for development

1. Involve some objective measurement to decide when a cleaning is needed.
2. Improve cleaning efficiency.
3. During cleaning the whole production is stopped.

State of the art

1. No measure is involved in the decision of cleaning. It's simply made every day.
2. Electrical measurements determine fouling layer thickness inside the pipe.
3. Proper rinsing measured at the end of the line monitoring water conductivity.
4.

Main players

1.

Other comments:

In 99% of the cases, cleaning is over killing. We need tools to decide if it's clean or not and if a clean process is needed. Being able to determine precisely when cleaning is needed would improve productivity. In addition, there is a need to determine when the detergents have been eliminated and production can start again.

Possible methods are electrical to determine the layer thickness inside the pipe. If this layer grows thicker than a certain value then the cleaning is needed. There are (*according to Stephan*) some companies which measure this thickness but we have no clues about the methods or techniques involved. It could be resonant sensors or electrical impedance measurements. Magnetic measurements could be useful but it's not clear at this stage.

Even though Microsystems do not have a clear application in this topic, some technology needs have been identified which could be helpful for cleaning efficiency.

Micro Technologies for the Dairy Processing Industry (18 January 2013 in Wageningen)
Session 9, Topic: Process Innovations

Moderator: Verena Eisner
Notes: Arnoud Togtema

Problem to be solved **Parameter to be improved**

Opportunities / benefits / drivers for user (food industry / consumer)
Packaging: Cheese Ripening in the package / less influence of lack of knowledge in supply chain to prevent waste/spoilage, more flexible shelf life (sensors)
Improved Drying: - Maintaining protein functionality / Bio Activity towards nutriceuticals
- Energy efficient: low denaturation / loss of proteins & vitamins: improved bioactivity

Improved Preservation: Bactofuge (spills ±2% milk) / Micro Filtration
Separation: - Micro Filtration with active coating: inactivates spores, microorganisms etc.
- Specific/selective removal of unwanted microorganisms
- Selective / Specific á la Bio refinery: Sum of individual components have higher value
- Free of Antibiotics / Bad microorganisms
- Product diversification: for example lactose free milk

Challenges / problems / barriers in the realisation
Better to split in two roadmaps: Bulk & Specialities / Niches

- from user (dairy industry point of view):

- from Microsystems supplier / research point of view:
Who will pay for R&D? In general the one who has the benefit. But with less spoilage due to longer shelf-life for the consumer there is less volume to produce for both the farmer as well as the dairy industry.

Key parameters / specification range
Lack of industry interest makes it hard to develop a roadmap towards process innovations! But outcomes will be shared with industry where they can add their comments / visions.

Priorities

Developments Needs

Missing Technologies

Key Performance Indicators
{N.B.: Last 4 issues no remarks / lack of time within session}
Main Players

Micro Technologies for the Dairy Processing Industry (18 January 2013 in Wageningen)

Session 10,

Topic: New & Innovative processing steps that require new (micro) technologies

Moderator: Verena Eisner

Notes: Arnoud Togtema

Problem to be solved | **Parameter to be improved**

Opportunities / benefits / drivers for user (food industry / consumer)

- Pack of milk: for consumer quality visible. Should be cheap: only shelf life visible or more fancy: fits best with my diet (personalised nutrition)
- Sensors on large scale – possibly inside the package. Waste disposal (incineration) should be no problem (no metals): sensors out of polymers.
- More sensors in one package: more accurate / less drift (signal to noise ratio).
- Zwitter ionic layers on membranes: less fouling. Should "survive" harsh CIP-conditions.
- Functional foods with a card: smart shopping in supermarket / personalised functional foods.
- Separation of milk into individual components: personalised reblending in shop.
- Better quality of live for the animal (welfare): sensor for continuous monitoring the health of the cow.
- Sensors in packaging should also send the price – so at till total cost directly available.
- Consumers should be smarter: not only price as parameter.
- Multiple biodegradable biosensors: add to the system (milk!). Homogenisation?
- Concentration @the farm: less transport of water.

List of Participants

Alessia	**Mortari**	**Fondazione Bruno Kessler**	Italy
Alienor	**Liogier**	**Spectralys**	France
Andre	**Veskioja**	**Bio-Competence Centre of Healthy Dai**	Estonia
Andrei	**Bratov**	**IMB-CNM, CSIC**	Spain
Arnoud	**Togtema**	**Food & Biobased Research, Wagening**	Netherlands
Arnout	**Fischer**	**WU**	Netherlands
Cees	**van Rijn**	**Aquamarijn**	Netherlands
Cristina	**Rusu**	**Swedish ICT Acreo AB**	Sweden
Didier	**Mauroy**	**Global Life+Sciences SA**	Switzerland
Elisabeth	**DELEVOYE**	**CEA**	France
Geertje	**Huijs**	**Danone Research Center for Specialis**	Netherlands
hans	**bouwmeester**	**RIKILT- Wageningen UR**	Netherlands
Henne	**van Heeren**	**enablingMNT**	Netherlands
Henri	**Jansen**	**MESA+ Institute for Nanotechnology**	Netherlands
Marc	**Salleras**	**IMB-CNM, CSIC**	SPAIN
Patric	**Salomon**	**enablingMNT GmbH**	Germany
Romano	**Hoofman**	**NXP Semiconductors**	Belgium
Sébastien	**Guerrault**	**Spectralys**	France
Stéphane	**Gavoye**	**Actilait**	France
Verena	**Eisner**	**Food & Biobased Research, Wagening**	Netherlands
Frans	**Kampers**	**Wageningen UR**	Netherlands

Break-down of Participants

21 participants (from 9 countries), amongst them:

- 5 representing the Food Industry and its research environment,
- 7 technology suppliers (representing the Microsystems community),
- 7 specialists in Microsystems AND Food,
- 2 project management / consulting

Evaluation of the workshop feedback forms

An evaluation from the workshop has been taken place; the feedback form was filled by > 50% of external participants (project partners were not asked). Recommendations have been discussed in detail at the February 2013 internal project meeting of FoodMicroSystems and will be taken into account for future workshops.

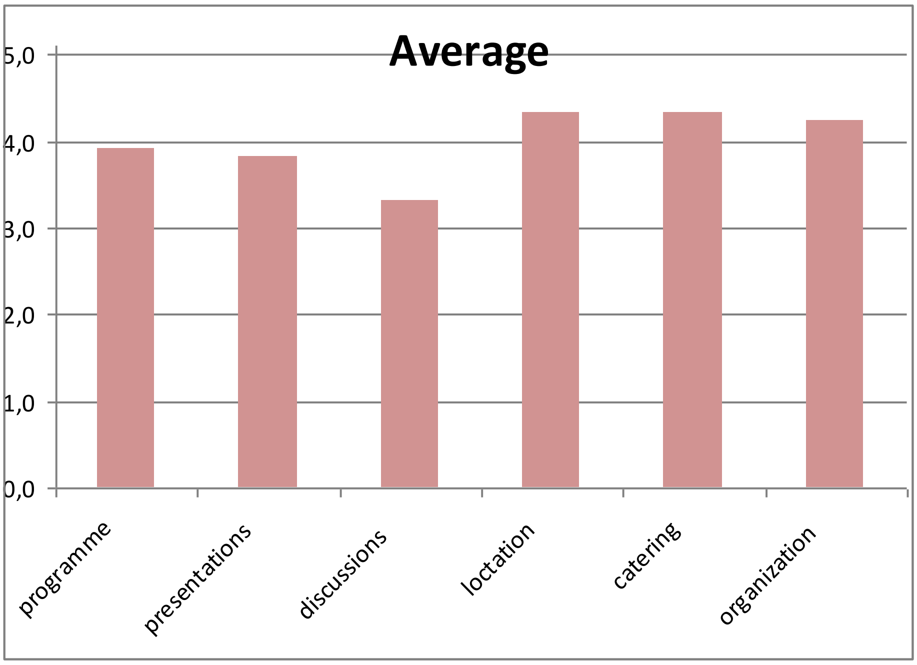


Fig. A2.2.5 Evaluation results from workshop

The evaluation shows an average evaluation rating of 4 out of 5.
Overall, participants appreciated all items like programme, presentations, discussions, location, catering and organisation.
The major issue that was criticised was the low industry participation from the user community (dairy industry). Only one dairy company was present and participants from dairy related research organisations and suppliers to the dairy industry were not fully confident to represent the complete needs of the dairy industry.