Recovery of whey

In a nutshell

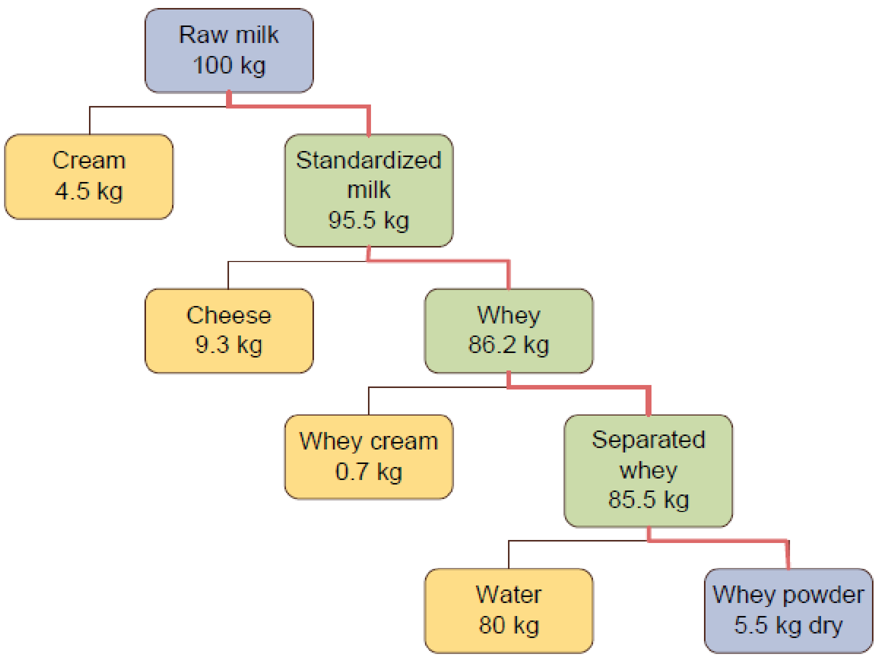
Summary				
Best practice is to recover all the whey from the production of cheese and to use it in new applications, according to the following priority list: • concentrate, filter and/or evaporate the whey to produce whey powder, whey protein concentrate (WPC), lactose and other by-products, • manufacture whey products intended for human consumption such as whey cheeses or whey drinks, • feed the whey to animals, use it as a fertiliser or process it in an anaerobic digestion plant.				
Target activities				
All food and beverage manufacturing	Processing of coffee	Manufacturing of olive oil	Manufacture of soft drinks	Manufacture of beer
Production of meat products	Manufacture of fruit juice	Cheese making	Manufacture of bread, biscuits and cakes	Manufacture of wine
Applicability				
This best practice is applicable to all cheese producers, provided that local conditions (e.g. sufficient generation of whey for the implementation of a whey concentration system, market demand for whey-based products, and availability of local livestock to feed) allow the implementation of the options listed above.				
Environmental performance indicators				
• Percentage (% weight) of the total dry matter weight of generated whey recovered for use in products intended for human consumption, in animal feed and as feed for anaerobic digestion. • Percentage (% weight) of the total dry matter weight of generated whey recovered for use in products intended for human consumption.				
Benchmarks of excellence				
• Whey is recovered and further treated in order to obtain other products for human consumption based on market demand. Excess whey is employed instead for animal feed or for anaerobic digestion.				

Description

Introduction

In the manufacture of most cheeses, typically less than 10% by weight of the original raw milk is used to make the cheese, leaving behind substantial quantities of a liquid known as ‘whey’ (Figure 1). The whey is largely comprised of water (more than 90% by weight) although it also contains valuable nutrients, especially serum proteins and lactose.

Figure 1: Milk and whey distribution



Source: Smith (2014)

The significance of whey, its use and disposal practices lies in three main factors:

1. Up to 55% of milk’s total nutrients are retained in whey during cheese processing. This includes lactose, minerals, vitamins and 20% of milk proteins (Banaszewska, 2014).
2. Whey is a highly polluting substance due to its high BOD content, reported to be approximately 175 times higher than the average sewage effluent (Smithers, 2008). The disposal of whey can cause an excess in oxygen

consumption, eutrophication and toxicity (Prazeres, 2012).

3. Large amounts of whey are produced annually. It is estimated that worldwide production of whey is around 180 to 190 million tonnes per year (Baldasso, 2011). According to Eurostat, 67 million tonnes of milk were processed to obtain 9 million tonnes of cheese in the EU-27 in 2011 (Marquer, 2013). For every litre of milk used in cheese production, approximately 85 to 95% results in whey (Guimarães, 2010). Therefore, it can be estimated that perhaps 60 million tonnes of whey were produced in the European Union alone.

Given its excellent nutritional properties, whey can be used in a number of food applications. However, according to the European 'WheyLayer' project, which seeks to develop new bioplastics from whey, half of the whey produced annually in Europe is left unprocessed and is simply flushed into municipal drains (King, 2014). Anecdotal evidence suggests that it is the smaller and medium-sized cheese-makers in particular that tend to do this. This practice not only wastes valuable nutrients but can also be expensive. Local sewage treatment companies and environmental protection agencies require that the effluent from factories, including dairies, meets stringent limits on dissolved organic content. These limits are costly for cheese-makers to achieve if whey is included in their waste water and often dairies have to install their own on-site water treatment equipment, in order to 'pre-clean' the effluent (FACE network, 2014), or pay higher rates to the waste water companies. These rates vary significantly with locality.

This BEMP describes how frontrunners, especially among small and medium-sized cheese producers, avoid these financial and environmental impacts by recovering the whey for use themselves, or by others, in new applications.

For the purposes of this report, the following definitions of company size are used, as suggested by ACTALIA, the research and technology institute for the French dairy sector:

- **Large**: industrial producers, processing 40 million litres of milk per year, with a highly automated process.
- **Medium**: small industrial or larger artisanal producers, processing 2 to 40 million litres of milk per year, often with an automated process.
- **Small**: artisanal and/or farmer producers, processing less than 2 million litres of milk per year using a traditional, manual process.

The preferable option is to concentrate, filter and/or evaporate the whey to produce whey powder, whey protein concentrate (WPC), lactose and other by-products. By doing this, the nutritional value of the whey is fully exploited; and the market for such whey-derived products is large and growing. Where this option is not feasible, however, perhaps due to low production volumes, the manufacture of whey products intended for human consumption such as whey cheeses or whey drinks should be considered; these latter applications, though, suffer from low market demand and may exploit only a small proportion of the whey's constituents. This best practice also briefly explores other options, which can be implemented when the previous two are not feasible, such as feeding the whey to animals, using it as a fertiliser or processing it in an anaerobic digestion plant to generate energy.

Production of whey powder and isolation of components

As discussed, whey contains a number of valuable components, especially a variety of proteins (e.g. ?-lactoglobulin, ?-lactalbumin, lactoferrin, lactoperoxidase) and the sugar lactose. Other constituents include fats (i.e. phospholipids), non-protein nitrogen (e.g. urea, ammonia) and minerals (e.g. calcium phosphate) (Smith, 2014). Whey powder, simply a dried version of whey is used as an ingredient in a variety of processed food products. However whey's value is maximised when the individual constituents, particularly the protein and lactose, are isolated or fractionated from the liquid whey. The proteins in particular are highly versatile and can be used in products from baby milk powders and ice cream to fortified yogurt and bodybuilding supplements as well as as an egg substitute in baked goods. The whey-derived lactose meanwhile is often polymerised and used for applications such as bioplastics and foams.

Production of whey cheeses and drinks

The production of 'whey cheeses' such as ricotta (Italy), or 'brown cheeses', e.g. brunost (Scandinavia) or sérac (France) is a method of extracting some value from the protein contained in whey. However, it may not exploit the full value of the protein as a source of human nutrition while continuing to incur sewage treatment costs. For instance, in ricotta production, a significant proportion of the protein is lost in effluent, although some producers supplement the whey with small quantities of raw milk, the casein content of which helps to extract more of the protein (Wisconsin Center for Dairy Research, 2014 pers. comm.).

In some parts of Europe, cheese-makers will produce 'whey drinks' to meet local demand. These beverages are created by first removing any residual fat from the whey by skimming, pasteurising, adding flavourings and packaging it (Wisconsin Center for Dairy Research, 2014 pers. comm.). The most successful whey drink is made by the Swiss company **Rivella** with annual domestic sales of approximately 80 megalitres (Rivella, nd.), although a proportion of the nutrients in this product are removed during manufacture so, again, this does not fully exploit the whey's true potential. By contrast, **Wei4All**, produced by a micro business in Holland, does use the full nutritional content of whey (Wei4All, 2014 pers. comm.). The product can be made of both 'acid' and 'sweet' whey (see below) and from most kinds of cheese-making; however, no preservative such as saltpetre (potassium nitrate) can be present in the whey.

It should be clarified that the whey drinks discussed in this report are those derived directly from the whey with minimal processing. Another class of whey beverages to be considered are those made with whey protein concentrate (WPC) as a key ingredient. Sometimes called 'protein drinks', these were originally targeted at body-builders but are becoming more universally popular (Walker, 2013). Due to the high costs of producing WPC discussed below, small and medium-sized cheese-makers are very unlikely to be in a position to manufacture this type of product.

Other options

Traditionally, smaller cheese-makers have either fed their whey to livestock (e.g. pigs, goats, sheep), either their own or those of other farmers, or have spread their whey directly onto the land as a fertiliser. This practice is still very common and may be a viable option in certain circumstances, however, it is unlikely to attract a revenue and fails to directly exploit the true value of the whey as a source of human nutrition. A perhaps more promising avenue is processing the whey in an anaerobic digestion plant to release a 'biogas' for use as a fuel, as well as a 'digestate' used as a fertiliser or soil conditioner. As well as the production of methane, whey can also be used to make other fuels such as alcohol (Smith, 2014). This end use may be most appropriate application for the so-called 'acid whey' produced in the manufacture of certain cheeses, yoghurts and other dairy products (see below). The French technologies firm Utilities Performance, in conjunction with a Japanese company, is among those currently trialling a biogas system which runs on acid whey (Utilities Performance, 2014 pers. comm.).

Environmental benefits

The production of whey powder offers the greatest environmental benefit of all the options for recovering whey in that large quantities of polluting effluent are avoided. This in turn reduces the substantial chemical, water and energy inputs which would have been required to treat the whey (either by the manufacturer or the waste water treatment company). Whey powder also offers hidden environmental benefits in that the nutrients can be used to substitute 'virgin' ingredients in a wide variety of food products and which themselves would have been responsible for environmental impacts through their growing, transportation and so on.

Membrane processes result in high contaminant removal, with COD reductions of between 74% and 98%. In addition, these result in protein and lactose recovery in the ranges of 87-100% and 89-100% respectively. Limiting factors in the use of these technologies are the by-products generated during the process: concentrates, membrane fouling and the pollutant permeate production (Prazeres, 2012).

The production of whey drinks could offer comparable benefits assuming these drinks contain all the whey's nutrients and have not had some removed during production. Indeed, whey drinks theoretically offer the greatest benefit because the energy-intensive heating and filtration processes needed for whey powder production are avoided. However, the tiny market for whey drinks means that these are not a realistic option to 'solve the whey problem'. The environmental benefit of producing whey cheeses, versus discharging the whey to thr drains, is also considerable and the market is strong for certain products, although, as noted above, in some cases only a small proportion of the nutrients are exploited and an effluent still results.

The use of whey as feedstock in biogas production (through anaerobic digestion) offers the advantage of generating renewable energy. COD reductions of 36% to 99% can be achieved; at the same time the gas resulting from the digestion contains between 53% and 79% methane (Prazeres, 2012).

The environmental benefits of the other options are likely to be substantially lower and are not further discussed here.

Side effects

The production of whey powder can be highly energy intensive due to the evaporating and filtering of the whey; detailed analysis on a case by case basis may be necessary to understand whether these impacts potentially outweigh the benefits of recycling the whey versus disposal to drains (or alternatives such as feeding to animals). To minimise the energy demand, the evaporation is carried out in a vacuum (Wisconsin Center for Dairy Research, 2014 pers. comm.). In addition, transportation of the whey concentrate in liquid form has a significant environmental impact in terms of greenhouse gas emissions due to the water content when compared with competing dry ingredients such as corn (Wisconsin Center for Dairy Research, 2014 pers. comm.). Some dairies, including relatively small ones, have invested in equipment to concentrate the whey (from 5% to 15% solids content) in order to reduce these impacts (Wisconsin Center for Dairy Research, 2014 pers. comm.).

Certain whey cheeses also require considerable amounts of energy to produce. For instance, the Scandinavian brunost is produced by simmering the whey until almost dry to leave a viscous caramelised product whose texture resembles that of peanut butter (Wisconsin Center for Dairy Research, 2014 pers. comm.).

Cross-media effects are significant for some of the other less recommended uses of whey. For instance, as with any fertiliser, whey spread on the land may run off fields into watercourses – especially when improperly applied or when the ground is frozen - and with its naturally very high BOD, it may impact negatively on aquatic biota.

Applicability

Although the production of whey powder maximises the value of the material, significant investment may be required which can only be justified when threshold volumes of production are met. This barrier is discussed in the 'Economics' section below. Another constraint is that the type of whey normally used to make whey powder is known as sweet whey. This material is recovered relatively early on in the fermentation process and is typically generated in the production of cheeses such as cheddar or mozzarella. However, the manufacture of certain products such as cream cheese and cottage cheese (actually curds rather than 'true' cheese) requires that the whey is drawn off significantly later in the process; by this point, bacterial action has lowered the pH of the whey (by converting lactose in the whey to lactic acid) and has also begun to brown the sugars (Wisconsin Center for Dairy Research, 2014 pers. comm.). Producers of whey protein concentrate and other whey-derived products tend to avoid acid whey because (Smith, 2014):

- it has a lower lactose content (due to conversion to lactic acid);
- it causes evaporator problems due to greater calcium;
- the permeate has an undesirable brown colour, and;
- sweet whey is readily available.

Acid whey is therefore still largely fed to animals, spread on the land or, in more recent years, used as a feedstock for anaerobic digestion plants (Arla Foods, 2014 pers. comm.).

It is worth noting that in the USA, projects are now underway to develop new specialised membranes able to ‘sweeten’ the acid whey by removing some of the acid (Wisconsin Center for Dairy Research, 2014 pers. comm.). Much of the research is being conducted on the acidic whey produced in the making of Greek-style yogurt but any findings should be applicable to whey from cheese-making.

For other whey products, market factors are critical. The markets for certain whey cheeses are already long established, for instance, the Italian ricotta, French sérac and the brunost of Scandinavia. However, new entrants with new cheese products may find it difficult to interest consumers in new and unfamiliar products without significant investments of time and money in marketing campaigns. Also, the production of the established whey cheese products is often geographically constrained in the consumer’s mind. Even traditional whey cheeses offer limited scope since they are usually produced from the milk of certain animal species only. In Scandinavia, goat’s milk alone is used to make brunost, with the whey from sheep’s or cow’s milk usually fed by the cheese-maker back to the animal providing it, or to pigs (FACE network, 2014).

Despite these difficulties, the option to make whey cheeses has a key benefit for smaller producers in that large economies of scale or substantial investment in new equipment are not needed. This is evidenced by the fact that cheeses such as brunost are manufactured in very small dairies (FACE network, 2014). With other end uses, such as the evaporation of whey to make powder, this may not be the case.

Consumer demand for whey drinks is generally more limited. Although **Rivella** is popular in Switzerland and parts of Italy and Germany, it has so far failed to break into other markets, notably North America. **Wei4All**, a whey drinks microbusiness based in the Netherlands, reports that marketing the drink domestically is a challenge due to lack of consumer awareness of the product and its nutritional benefits (Wei4All, 2014 pers. comm.). Wei4All sells only about 2,500 litres per year.

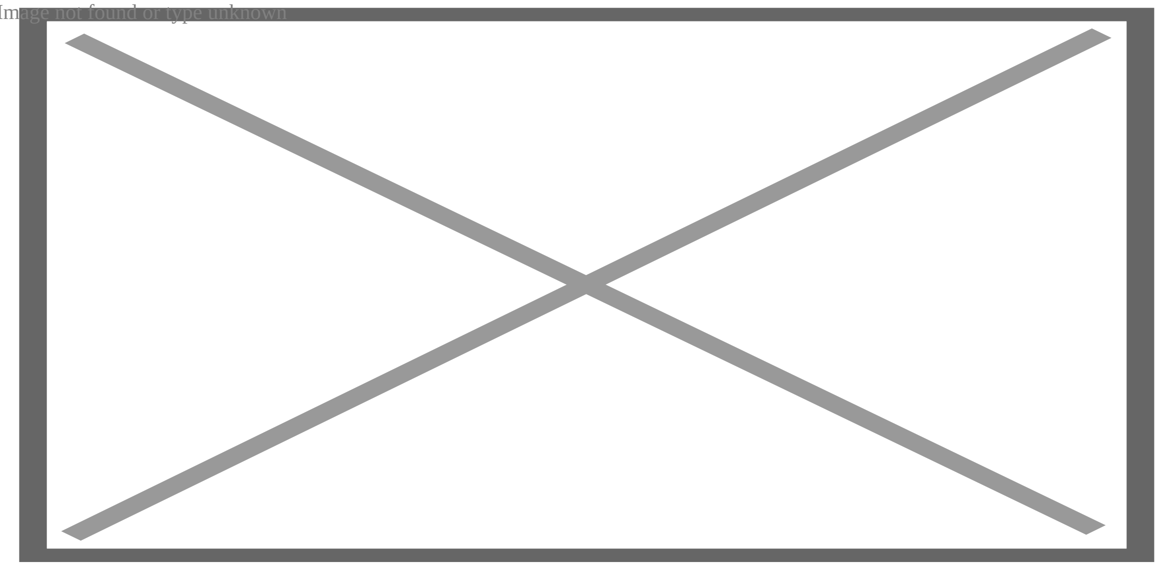
Applicability issues are important for the less recommended whey recovery options. For instance, feeding whey to animals or spreading on land may not be feasible for cheese-makers based in non-rural locations (Barbers Farmhouse Cheesemakers, 2014 pers. comm.). In addition, land spreading of whey may be prohibited in specific regions due to the risks of run-off.

Economics

Regardless of the end use, recovering and recycling the whey offers significant cost savings because disposal to the drains can be expensive (Wisconsin Center for Dairy Research, 2014 pers. comm.). Furthermore, given the large and growing worldwide demand for whey powder, WPC and other by-products, this option offers frontrunners the greatest financial opportunity. The trading prices for whey powder have risen markedly in the last 10 years, from an EU wholesale price of EUR 400/tonne in 2004 to approximately EUR 1000/tonne in July 2014 (Figure 6)

Part of the reason for this rising price is thought to be an increasing demand from China for whey powder used in infant feed (Wisconsin Center for Dairy Research, 2014 pers. comm.).

Figure 6: EU wholesale prices for whey powder, EUR/tonne

a. 

Source: DairyCo website. Available at: http://www.dairyco.org.uk [Accessed 12 September 2014]

While standard whey powder sells for approximately EUR 1000/tonne, whey protein concentrate (WPC) attracts higher prices. For instance, at the time of writing, WPC with a 34% protein content sold for USD 1.55/lb (around EUR2,638/tonne), and for yet more concentrated WPC - and for 100% protein ‘isolate’ - the prices climb higher still. Similarly, the permeate (containing lactose and minerals) attracts a modest USD 0.40/lb (about EUR680/tonne) but the price for extracted lactose (which is highly volatile depending on prevailing demand) was at the time of writing, approximately USD 0.50/lb (about EUR 1191/tonne[1]). Although lactose has found use as a precursor to biopolymers, the demand is low due to its high cost relative to competing materials derived from corn starch. Further processing to make WPC and lactose adds more value but substantial additional investment is needed, perhaps more than EUR 1 million, in machinery (Wisconsin Center for Dairy Research, 2014 pers. comm.) and so it will be beyond the scope of most SMEs.

Currently, anecdotal evidence indicates that in Europe at least, smaller cheese-makers tend not to exploit these opportunities. According to dairy experts in Italy and the Netherlands, SMEs are unable to produce whey powder due to the perceived need for large quantities and the costs of transport; instead these companies spread the whey on the land or feed it to animals such as pigs. The Dutch interviewee was aware of only one cheese-maker in their country that was making whey powder, and this firm was processing approximately 10,000 litres of milk per day, or approximately 4 million litres annually, putting it in the ‘medium’ category according to the size definitions presented in the Introduction to this report (Wei4All, 2014 pers. comm.). In Italy, however, large cheese manufacturers processing at least 50 000 litres of milk per day produce whey powders and concentrates (CNR - Istituto di Scienze delle Produzioni Alimentari, 2014 pers. comm.).

This finding is surprising because the production volume threshold at which it becomes cost-effective to recover whey for use in whey powder, either by the manufacturer themselves or for passing on to other larger manufacturers, is reportedly low. For instance, according to one American dairy expert, “as soon as you can fill a tanker, it’s worth it” (Wisconsin Center for Dairy Research, 2014 pers. comm.). However, this information may not be applicable to companies operating in Europe. The threshold quoted by this American expert is approximately “10,000 lbs of whey per day” which equates to 5000 litres per day or 1.8 million litres per year. This is therefore applicable even to small artisanal cheese-makers, and in the USA at least, even for the smallest producers who cannot meet this threshold, options remain to pool the whey with others in the area, for instance through cooperatives. According to the same American expert, small cheese-makers may get paid for their whey, although the amount will vary widely.

Although the threshold at which it makes financial sense to recover the whey is low, substantial investment in equipment is needed to process the recovered whey into powder and ingredients for human consumption. For instance, a single evaporator machine may cost GBP 500 000 (about. EUR 600 000), reverse osmosis membrane equipment may cost GBP 250 000 (about EUR 300 000) and a large whey drying operation may cost up to GBP 10 million (about EUR 12 million) (Barbers Farmhouse Cheesemakers, 2014 pers. comm.). Thus, this next step in the whey powder supply chain may only be feasible for the larger cheese-makers. The threshold at which it becomes worth making such investments will vary with factors such as prevailing market prices. However, one leading UK cheese-maker suggests that when more than 2000 tonnes per year of cheese is being produced at a site (roughly equivalent to 20 million litres of raw milk being processed per year – or a 'medium' sized cheese-maker in the definitions above) - then it becomes a viable proposition; indeed, according to this UK interviewee, a 'whey strategy' is 'essential'. Should on site generation of whey fall below this threshold, those who have invested in the equipment will seek to source additional whey from other smaller local cheese-makers (Barbers Farmhouse Cheesemakers, 2014 pers. comm.).

The alternative uses for whey discussed above (e.g. drinks, cheeses) may generate a modest revenue in some niche products with limited markets. However, as mentioned, the production of whey cheese is not thought the best way to exploit the full value of the protein content of whey given that a sizeable proportion of the protein is still lost in by-products, and that additional milk is sometimes needed to maximise the proportion of protein recovered (e.g. in ricotta production) (Wisconsin Center for Dairy Research, 2014 pers. comm.). But the use of whey for alternative products means the liquid does not have to be disposed of or treated further before disposal. According to an expert in Italy, disposal costs amount to EUR 10 000 per month for a dairy company processing 100,000 litres per day. Thus, significant monetary savings can be achieved by reducing the need to dispose of whey (CNR - Istituto di Scienze delle Produzioni Alimentari, 2014).

Uses such as passing the whey to farmers to feed animals or for landspreading typically attract no revenue, but these fates at least avoid the disposal costs. The use of whey as a feedstock in biogas production or the production of alcohol (fuel) may yield a revenue depending on local renewable energy incentive schemes or subsidies and whether the energy generated is sold on; in some cases, however, the energy may instead be used internally by the dairy itself. It should be noted that fuels such as methane and alcohol derived from whey are less competitive in the biofuels marketplace than those made from other raw materials such as corn (Smith, 2014).

[1] Conversions from USD/lb to euros/tonne performed using Google on 12 September 2014.

Driving forces for implementation

The key driver for recovering the whey and using it in any of the ways described above is to avoid the steep costs associated with disposal of the whey to the drains. For the frontrunners, the additional motivating factor is to maximise the value from the whey by producing highly marketable products, such as whey powder.

Reference organisations

Whey powder production: The following are examples of companies maximising the economic value of their whey, and minimising the environmental impacts (especially those associated with sewage treatment), by evaporating, filtering and fractioning their whey into desirable protein- or lactose-based precursor ingredients for re-use in the production of new food products:

- Arla Foods (Sweden, Denmark, UK)
- Barber's (UK)
- DMK Deutsches Milchkontor GmbH (Germany)
- FrieslandCampina (Netherlands)
- Groupe Lactalis (France)
- Kerry Group (Ireland)
- Müller Wiseman Dairies (UK)

Whey cheeses: leaders in the field are found especially in Italy (for ricotta) and Scandinavia (for brunost and other 'brown cheeses').

Whey drinks: Rivella (Switzerland) exploits whey for producing a popular beverage. Wei4All (Netherlands) is an SME producing a whey drink that uses 100% of the nutritional content of the whey.

Biogas generation: A number of cheesemakers produce biogas from whey which can be used to generate energy. These include Abbaye de Tamié (in the Savoy region of France) and BV Dairy (in the UK).

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