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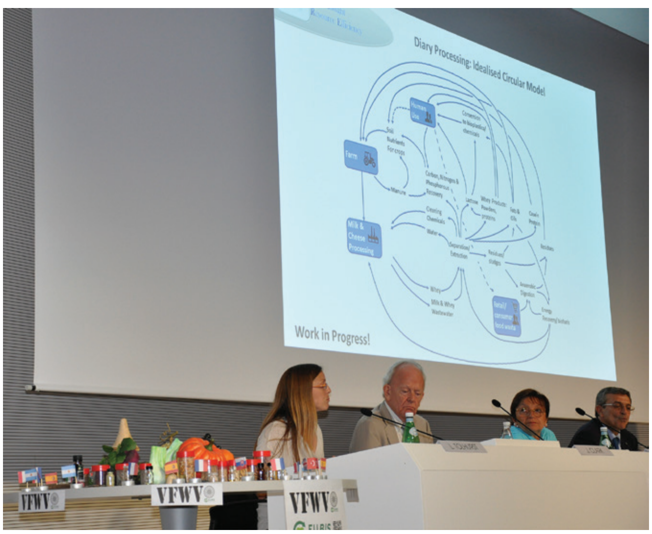
FROM DAIRY ‘WASTE’ TO PROFITS

The dairy processing industry provides a remarkable example of food ‘waste’ utilisation. Large scale cheese manufacturers have transformed whey from a costly effluent into an innovative range of over 100 products, with further developments underway to find new uses for other dairy by-products.



Background

The large scale cheese processing industry has undergone a huge transformation from a “supply chain” towards a “supply cycle”. The majority of industry in the 1900’s was formulated around a linear supply chain, whereby raw materials enter the chain at one end, undergo processing to manufacture the product, which is then distributed for retail and utilised by the end-user. In many instances the materials were disposed of at the end of life without further thought. In addition, many material losses were, and still are, seen at each stage of the supply chain, as by-products and wastes were sent to landfill, and effluent discharged to watercourses. This represents a huge waste of resource, not just of the physical material being disposed of, but also the energy and other resources required to produce that material in the first place.

However, with heightened awareness of materials scarcity, environmental impacts and tightening regulation there has been a movement to return towards a “supply cycle”, whereby all resources entering the system are utilised and kept in circulation, as outlined in Fig. 1. This is not a new concept and is closely related to various other terminology in use: circular economy; cradle to cradle; closed loop; and industrial symbiosis all have similar ideology of diverting material from landfill and keeping resources in use. There are three key enablers to reclaim materials that might otherwise be disposed to landfill:

1. *re-use and recycling*: use of the material in its original form or with similar chemical composition;
2. *extraction*: the separation of components to extract valuable materials and bulk materials, and utilisation of each component for different applications. This is often used for generating flavour and fragrance compounds or active ingredients;
3. *transformation*: the conversion of the resources into other materials, including fuels and chemicals, or construction materials and other applications.

The dairy processing sector provides an interesting example of the evolution of an industry to adapt to changing pressures, involving utilisation of by-products.

In the 1900’s the industry underwent significant consolidation with considerable resource consequences. For example, by the early 2000’s in the UK 80% of the total milk production was controlled by only six dairies and similarly ten companies controlled over 80% of the cheese produc-

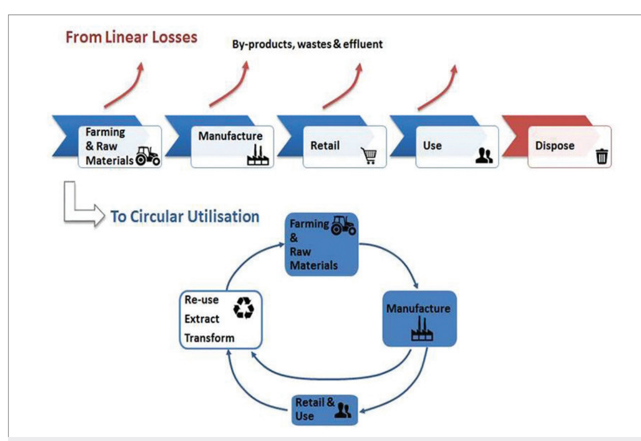


Fig. 1 - Transformation from a Linear “Supply Chain” to a “Supply Cycle”

tion [1]. The result of this was the unprecedented production of whey and dairy wastewaters at single locations, making traditional spreading to the surrounding land or provision to local animals unfeasible due to the vast quantities. The material is extremely bulky, being composed predominately of water, and quickly spoils, making it uneconomic to distribute more widely for these lower value uses. With increasing regulations on discharge of untreated dairy processing wastewaters due to the high biological content and polluting effect, the dairy industry sought to identify alternative solutions, particularly for the liquid effluent from cheese production known as whey, and in the 1970's the first whey processing pilot was developed by the dairy co-operative that is now known as Arla [2].
Today, the manufacture of products from whey is a huge industry in its own right. The USA is the largest producer, accounting for 32% of the market share and according to Research and Markets was estimated to be worth $1,776.6 million in 2014 and is expected to reach $2,709 million by 2020 [3]. In addition to whey powder production, methods to extract value from whey have been developed using a cascade of processes, as can be seen in the simplified schematic below (Fig. 2) [4]. For example, ultrafiltration of raw whey separates the proteins from a liquid permeate. The proteins can be sold as whey protein concentrate or further separated out by microfiltration to generate whey phospholipids and whey protein isolates. Meanwhile, the whey permeate contains lactose, a valuable material that can be crystallized out of the permeate and used in the food industry and as an excipient in pharmaceuticals. This leaves a 'delactosed permeate' which can be more challenging to utilise, although there are developments in this space, as outlined later.
The success of these developments is such that dairy experts have reported that it is possible for cheese producers to generate more revenues from whey than from cheese products and in Europe demand now outstrips supply for whey products [5].
A particularly well developed circular approach has been employed by Arla, and their site in Jutland processes whey into over 100 different products, including 80 protein and 25 lactose based derivatives. In addition to the extensive whey processing facilities, the site opened a new lactose factory in 2014 to process 80,000 tonnes of the material each year [6]. Their current focus for the site is development of a new protein hydrolysate factory for infant, sports and clinical nutrition products [7].

Challenges

Utilisation of whey is a great success story, but there still remains a number of resource issues for the dairy processing industry. There are certain residues from whey processing that have been described by experts as "very challenging" to manage [8]. For example, delactosed whey permeate is very high in salt which can be damaging to freshwater systems, and is not suitable for microbial fermentation routes such as anaerobic digestion, as it does not contain sufficient carbon to make a good feedstock. Another significant resource consideration in the dairy industry is water usage, with disposal particularly high during cleaning of equipment and from the manufacture of powdered milk. In theory both the water and cleaning chemicals can be recovered for re-use, but it is not always economically viable, especially where these resources are in cheap supply.
In addition, material recovery processes have their own environmental impact, including energy input for processing and logistics and often further material input, such as equipment and chemicals or biologics. Outputs must also be considered: creating more hazardous waste materials through the process may be a worse option than disposal, whereas creating a chemical that can replace a petrochemical (for example bioplastics) provides a double benefit. Therefore the options need to be evaluated within a wider context that simply keeping materials in the economy.

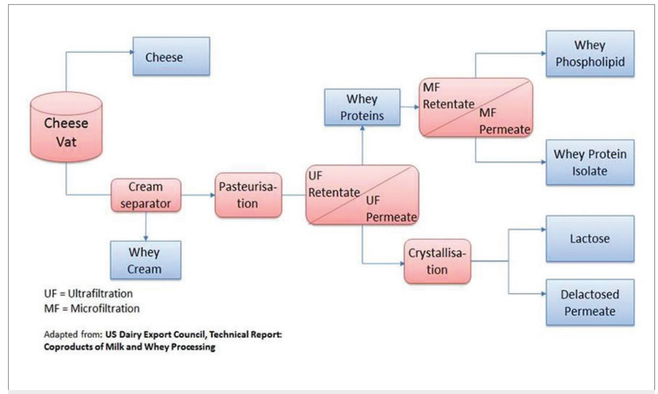


Fig. 2 - Whey and whey by-product processing

Recent innovation

There are a number of innovative developments globally that are providing solutions to untapped effluents and waste streams from dairy processing, and some of these are described in the examples below. There is huge variation within the industry and every dairy is unique, therefore there is no one single solution that will suit every situation. Specific issues such as the effluent type, material flows and composition variability, the regional logistics and markets for products, water availability and effluent discharge fees, to name just a few, need to be considered to find the right approach for any one site. Therefore a range of technologies are required across the industry to cater for this variation. However, the following examples demonstrate some of the options available.
The huge market demand for whey protein products has resulted in a deproteinized lactose whey by-product commonly known as 'whey permeate'. This is the liquid left over once the proteins have been filtered out, and it contains a relatively high level of the milk sugar, lactose. There is a large market for crystallised lactose from whey permeate, but production of lactose is not appropriate for all sites. In these cases, the lactose rich permeate can make an excellent carbon source for fermentation processes such as anaerobic digestion (AD). This has been exploited by a number of companies, such as Clearfleau in Europe and Lacteos & Energia (L&E) in Chile.
L&E initiated their whey permeate AD programme in 2010 for whey protein facilities. The process generates biogas and energy as electricity and heat for on-site utilisation, and they have their third plant under construction with Dairy Osorno [9]. However, although a good solution for some sites, energy from waste is low down on the waste hierarchy, and other companies have been looking at higher value utilisation of whey permeate. UK based Cellulac is one such company, and in 2014 they announced what they claimed to be the world's first industrial scale continuous production of lactic acid from whey permeate. Their optically pure D-lactic acid, produced from a combination of biological processes, hydrolysis and pressure, can be used to make poly lactic acid (PLA) for biodegradable plastics. The Italian award winning start-up company, EggPlant, which focuses on wastewater-to-bioplastics, has also considered conversion of lactose

from whey permeate to lactic acid [11]. Another innovative group in Italy, Dr Matteo Mariani and colleagues based at ISTM-CNR in Milan, have found a way to break the glycosidic bond in lactose and simultaneously reduce the resultant glucose and galactose sugars to produce sorbitol and dulcitol in a single step [12]. Sorbitol is already widely used in industry, such as in sugar-free foods, medical laxatives, cosmetics and toothpaste. More recently Mitsubishi Chemical have developed a bio-based isosorbide plastic from sorbitol, which has been used in the new Aquos Crystal 2 smartphone screens. Dulcitol is thought to have similar properties, but currently has very limited availability therefore requires further research regarding potential applications.

The above examples are potential approaches to utilise whey permeate in the cases where the lactose is not being extracted for products such as excipients in pharmaceuticals or the food industry. In these cases lactose is crystallised out of the whey permeate, and this process results in a delactosed permeate (DLP), which is an even more salty liquid but now with insignificant carbon content for growing microbes and so not suitable for any fermentation transformation processes. Dr Rena Barry-Ryan, from the Dublin Institute of Technology in Ireland, has taken advantage of this property and investigated the antimicrobial activity for the potential use of DLP as a food preservative [13]. They studied the effects of coating tomatoes and strawberries and found reduced decay, reduced growth of microbial populations, as well as improved overall quality and antioxidant properties. They suggest in their paper that there may be anti-microbial peptides involved in this effect, although others have suggested that the very high osmotic pressure is likely to be playing a significant part in this [14].

There has been a great deal of emphasis on deriving value from whey processing, but what about milk processing effluent? A Milchunion dairy plant in Germany has installed a system from NuReSys for recovering phosphorous and nitrogen from their wastewater [15]. The plant will treat 120 m^3 per hour to produce 600 kg/day of magnesium ammonium phosphate in a granular product called BioStru™, which can be harvested and converted to a ready-to-use fertiliser. Meanwhile, a group at Wageningen University in the Netherlands has proposed that bioactive peptides could be recovered, particularly peptides from ß-casein, which they found to inhibit oxidant activity related to various conditions such as asthma, atherosclerosis and cancer [16]. However, this is a long way away from commercialisation and potential issues over the public perception of consumption of these materials from a waste stream would need to be addressed.

There are also developments to recover chemicals that are used to clean the processing equipment, so that the chemicals can be recycled within the system. This is particularly beneficial environmentally as the cleaning chemicals are often high in salts and/or phosphorus, which are polluting to the environment. In water restricted regions, such as the Middle East, the salt concentrations of effluent and materials spread to land are strictly controlled to prevent contamination. One dairy in Israel has partnered with Envirochemie to install their Envopur Nanofiltration system which can separate out up to 80% of the chemicals in a pure format for re-use [17]. This means that the resultant effluent is clean enough to be used to irrigate the surrounding land for agriculture. Meanwhile in Mexico, Nestle has also taken a water recovery approach, and has built a 'zero discharge plant' for their milk powder facility [18]. They have employed a series of technologies to purify the effluent from the factory including: reverse osmosis; activated carbon filtration; UV light; and chlorination. The system reportedly saves 1.6 million litres of water each day, enough to supply the average consumption of 6,400 people. The water is recycled on site and this means that they no longer draw water from the local groundwater supply.

Discussion and conclusions

Given the complexity of the composition of dairy products there is, in theory, a large array of products that can be generated from the by-products. Indeed, the industry has already demonstrated some excellent innovative successes, and continues to strive to expand upon these. As can be seen in the Fig. 3 below, the potential supply cycle is hugely complex if industry is to valorise every component, and although this suggests great opportunity, it also gives a sense of the scale of the input required for any single company to accomplish complete valorisation. Implementation of by-product utilisation often requires new knowledge, new skills, collaborations, development of new products and potentially entry into new markets, for example bioplastics, or at least forming new supply chains. Companies require clear motivation, and must see the benefits, in order to invest in these changes.

Idealised dairy by-product supply cycle

The dairy processing industry, particularly the story around whey products, provides an excellent example of how an industry can be transformed by valorisation of by-products. Continuing in this manner, there are many current activities and opportunities to extend this even further, including improved water efficiency, through to finding new ways to valorise the effluents from whey processing and milk effluents (Fig. 3).

However, for these innovations to spread more broadly across the industry there needs to be a supportive framework to make it economically

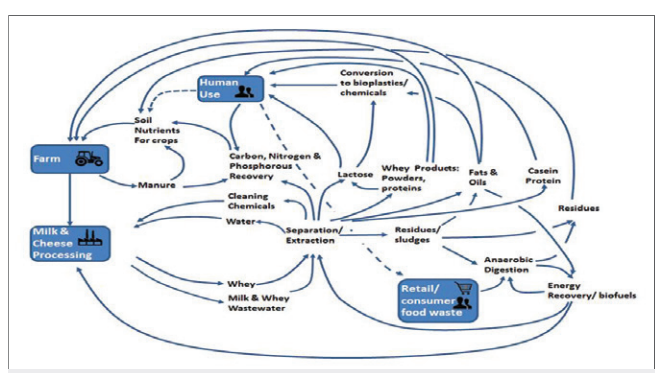


Fig. 3

viable for companies to invest in the technologies and systems required. In addition, from an environmentally sustainable point of view it is necessary to consider the inputs and outputs required for further processing of by-products in order to determine whether there is an overall sustainable benefit from implementing additional resource recovery facilities.

Please contact Lucid Insight for a copy of a more detailed review of these case studies: lucinda@lucid-insight.com or visit www.lucid-insight.com/publications

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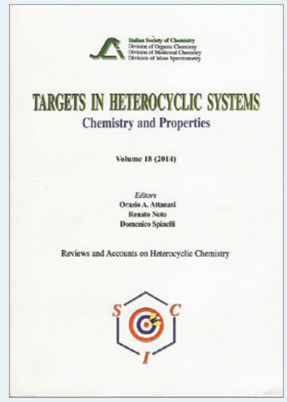

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