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The Characterisation of Dairy Waste and the Potential of Whey for Industrial Fermentation

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Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

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ENVIRONMENTAL PROTECTION AGENCY

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- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
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- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiological Protection
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA Research Programme 2014–2020

The Characterisation of Dairy Waste and the Potential of Whey for Industrial Fermentation

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EPA Research Report

Prepared for the Environmental Protection Agency

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The agri-food sector makes a substantial contribution to the Irish economy. In order to promote growth within this sector, the Irish government has adopted the Food Harvest 2020 and, subsequently, the Food Wise 2025 strategies. Along with the abolition of dairy quotas in 2015, these strategies offer scope for significant growth, particularly within the dairy sector, and the aim of Food Harvest 2020 is to increase milk production by 50% overall. An increase in primary production will inevitably lead to an increase in the generation of processing waste.

This project focused on (1) the identification/quantification of dairy processing wastewater process streams of environmental significance that are likely to be characteristic of the year 2020; (2) the evaluation of current and emerging technologies in order to determine which are best suited to the treatment of the most significant pollutants identified; (3) the evaluation of the potential of whey (a potentially major pollutant produced as a by-product of cheese manufacture) as a growth medium for industrially important microorganisms; and (4) the minimisation of water usage in dairy plants.

Standard indicators of polluting potential include biological oxygen demand, chemical oxygen demand, suspended solids, fats, oils and greases, and outputs of nitrogen and phosphorus. The wastewater outputs that were generated between 2008 and 2013 by Irish dairy processers were profiled using the annual environmental reports available on the Environmental Protection Agency (EPA) website. All wastewater outputs reported were within the annually allowed limits. A survey related to processing activity and the wastewater streams generated (both current and projected for 2020) was distributed to 22 Irish dairy processing facilities. The low response rate (only four companies responded) and the incomplete nature of the data returned did not provide a sufficiently comprehensive dataset from which firm conclusions pertaining to the first two project aims could be drawn. However, the processors that did reply believed that the 50% increase in milk production projected as part of Food Harvest 2020 will not lead to similar increases in their intakes or processing activities; dairy processors expect increases of approximately 25–40%. All of the companies contacted expect that, as milk production and processing increase, it will become necessary to include reviews of pollution outputs in their Industrial Emission/Integrated Pollution Control Licences. These licences are documents that set out a company's (or, within a relatively large company, a single facility's) environmental responsibilities in relation to their emissions to air and water.

The waste treatment systems (for wastewater) currently used in the context of Irish dairy processing were profiled using Industrial Emissions Directive/Integrated Pollution Control Licence data and through direct contact with industry. The majority of processing facilities rely upon aerobic waste treatment processes (i.e. the microbiological breakdown of organic waste in the presence of oxygen) and utilise standard secondary treatment techniques such as bio-towers and activated sludge aeration (which are forms of aerobic, microbiological waste treatment). In most facilities (68%), tertiary treatment consists of chemical removal of phosphorus. A review of the international literature indicates that few breakthrough technologies, related to dairy wastewater treatment, are under development, and current research appears to be primarily focused on phosphorus removal and recovery, as well as microbial fuel cell technology and hydrogen generation. These technologies allow electricity to be generated from wastewater treatment processes; this electricity can then be used to power plant activities.

An increase in the production of dairy products, primarily casein powders and cheese, is expected to lead to an associated increase in the amount of process waste, particularly whey. Potentially, this could be a significant environmental concern, as an increase in the amount of whey produced will lead to an increase in the amount of processing required and, therefore, an increase in the amount of waste generated.

According to the information obtained from industry and the international literature, the minimisation of water usage has become a core focus of the dairy processing sector; this issue was highlighted in the Food Wise 2025 report. A consequent investigation of the literature indicated the potential for significant water savings, generally via straightforward practical steps, including the development of a detailed water usage model,

"cleaning-in-place" water reuse and leak detection testing.

The large-scale growth of microorganisms in order to produce a range of medical or industrial products (e.g. antibiotics, amino acids, organic chemicals, etc.) represents a multi-billion euro industry. Laboratory-based studies were undertaken to investigate the use of waste whey as a means of growing industrially relevant microorganisms. Both traditional (non-genetically engineered) and recombinant (genetically engineered) microorganisms were studied for their potential to grow in waste whey. This could lead to potential cost savings related to both the treatment of the whey and the use of the whey in growth media. The majority of fungal, yeast and bacterial strains tested failed to grow on whey as their major nutrient (primary carbon) source. However, two fungal strains, namely *Penicillium chrysogenum* DSM1075 (which produces penicillin and secondary metabolites) and *Aspergillus flavus* DSM1959 (which produces secondary metabolites), did grow relatively well on whey, although not to commercially viable levels. Preliminary studies, however, showed the potential technical feasibility of the utilisation of whey in the manufacture of some industrial products. Future work on this topic should focus upon further optimisation studies in an attempt to achieve levels of whey-based microbial growth equal to those achieved using current industrial fermentation media constituents, such as glucose. A full comparative economic analysis would also be required.

Many modern industrial bioprocesses are based upon the growth (fermentation) of genetically engineered (recombinant) microorganisms. Examples include the production of therapeutic proteins, such as insulin (biopharmaceuticals), and enzymes such as cellulase (used in biofuel manufacture, the textile industry, animal feed preparation, etc.). A model genetically engineered bacterium was generated (namely *Escherichia coli*, into which a gene coding for a cellulase enzyme was inserted). Cellulase is an enzyme capable of breaking down cellulose (the major sugar found in plants) and is of potential use for biofuel production.

Growth studies of this model *E. coli* and assessments of cellulase production levels showed that nutrient-supplemented whey can support the production of cellulase quantities corresponding to 70% of those achieved using a control "gold standard" medium. This indicates that a whey-based medium can support the production of appreciable levels of the model cellulase enzyme, although not quite to commercially viable levels. It is recommended that future work focuses upon the further optimisation of the composition of whey-based growth media and that an economic analysis is performed in order to ascertain the commercial viability of a fully optimised process.

1 Introduction

1.1 General Overview of the Agri-food and Dairy Processing Sectors

1.1.1 The agri-food sector in Ireland

The agri-food sector makes a substantial contribution to the Irish economy. It is estimated that, in 2013, the primary agriculture, fisheries and forestry sectors together accounted for approximately 2.4% of gross value added (GVA), and the agri-food sector accounted for approximately 7.1% of GVA. Approximately 175,300 jobs or 8.6% of total employment in Ireland was accounted for by the agri-food sector at the end of the first quarter of 2014. The industry also contributed 11% of Ireland's exports in 2013 (DAFM, 2014). In 2013, Irish agri-food and drink exports increased by an estimated 9% to circa €9.9 billion compared with 2012 (An Bord Bia, 2014; DAFM, 2014).

Irish agriculture can be divided into three main activities: meat production (from cattle, sheep and pigs), small tillage production, and dairying. In 2011, 296,200 hectares of land were under cultivation for cereals and approximately 2.5 million tonnes of wheat, oats and barley were produced (An Board Bia, 2014). In 2013, there were an estimated 1.14 million dairy cows in Ireland, and the total milk output was estimated to be 5.8 billion litres (5.6 billion litres in 2011) (An Bord Bia, 2014). There were 6.9 million cattle in Ireland in 2013 according to the Central Statistics Office (CSO) June 2013 livestock survey, with an estimated 518,000 tonnes of beef (to the value of €2.09 billion) and 160,000 live cattle (€217 million) being exported in that year. The Irish sheep flock was estimated at 5.08 million animals in 2013, with 45,000 tonnes of lamb (to the value of €220 million) being exported. Irish pig population was estimated to be 1.55 million, with 185,000 tonnes of pig meat (to the value of €525 million) being exported in 2012 (An Board Bia, 2014).

1.1.2 Food Harvest 2020 and Food Wise 2025

The Irish government is pursuing a policy of increasing both primary agriculture and the agri-food sector in Ireland and, to this end, has developed the strategy "Food Harvest 2020" as a blueprint for the expansion of the agricultural sector. This strategy focuses upon both primary production (targeted increase of 33% by 2020) and value added/processing activities (targeted increase of 40% by 2020). The strategy projects that there will be a 50% increase in milk production by 2020 using the average of the outputs of the years from 2007 to 2009 as a baseline. This equates to an approximate increase of 2.75 billion litres in production and will increase the primary output value of the sector by about €700 million. This is possible because of Ireland's low-cost grass-based system (which accounts for 85% of Irish dairy cows) (Woulfe, 2012). This is expected to increase dairy product values, export earnings and employment (DAFF, 2011).

It is hoped that this increase in productivity will span all sectors of Irish agricultural activity, both established and developing. It also foresees that pig meat production will increase by 50%, beef and lamb output will increase by 20%, poultry production will increase by 10% and farmed-fish production will increase by 78% (DAFF, 2011).

Food Wise 2025, a report published by the Department of Agriculture, Food and the Marine (DAFM) towards the end of 2015, as the present report was being finalised, provides a vision and strategy for the future development of the sector. It envisages an 85% increase in the export value of the agri-food industry between now and 2025, projecting that this value will reach €19 billion by 2025. It is anticipated that increases in dairy production, along with beef and seafood production, will be at the forefront of this growth. Importantly, the report also recognises that increases in food production systems must be as focused upon sustainability and environmental protection as they are upon increasing production per se (DAFM, 2015).

1.1.3 The dairy processing industry in Ireland

In 2013, Ireland's total milk output was estimated to be 5.8 billion litres (An Bord Bia, 2014), and Irish milk processors produced in excess of 480 million litres of whole and skimmed milk, 152,000 tonnes of butter and 180,000 tonnes of cheese; dairy product exports have been valued at approximately €3.05 billion for

2013 (Irish Dairy Board, 2013; An Bord Bia, 2014). The quantities of dairy products processed between 2010 and 2013 are shown in Table 1.1.

The dairy industry accounts for approximately 30% of Irish agri-food exports, and provides employment for approximately 18,500 farmers (Ask about Ireland, 2014), 9000 people in the processing industry and an additional 4500 people in support and ancillary services (National Dairy Council, 2008). The Food Harvest 2020 Committee's report proposes the target of a 50% increase in milk production by 2020 (DAFF, 2011).

1.2 Pollution Risks Associated with Dairy Products

The overall vision of Food Harvest 2020 highlights the need to prioritise environmental protection (DAFF, 2011). Within the agri-food processing sector, the industry with the largest polluting potential is the dairy industry, with milk wastes (before treatment) having a biological oxygen demand (BOD) value of ~2700 mg/L, whereas poultry processing waste has a BOD of 1306 mg/L and meat packing waste has a BOD of 1433 mg/L (UNIDO, 2014); whey from cheese manufacturing is one of main and most difficult pollutants to treat (Ghaly *et al.*, 1988; Marwaha and Kennedy, 1988).

Different types of milk products (e.g. cheese and butter) create different types and amounts of waste. The typical quantities of wastewater associated with different milk products are shown in Table 1.2. It is important to note that the quantity of wastewater does not relate to the BOD or chemical oxygen demand (COD). The types of waste will be discussed in greater detail below.

1.2.1 Milk

The first step in the production of milk powders is the creation of milk condensate. This involves the evaporation of water and the creation of a large amount of condensate, which is normally clean but can be contaminated with milk residues. If contaminated, this condensate must be treated.

1.2.2 Cheese

A large proportion of the milk used in cheese manufacturing ends up as whey (~90%). Whey consists of approximately 55% of the total nutrient content of milk. The main nutrients in whey are lactose (4.5–5.0% w/v), soluble proteins and peptides (0.6–0.8% w/v), lipids (0.4–0.5% w/v), and mineral salts (8.0–10.0% w/v of dried extract) (Kosikowski and Wzorek, 1977; Kosikowski, 1979). In general, to make 1 kg of cheese about 9 L of whey is generated (Kosikowski, 1979). Based on cheese production figures, this suggests that approximately 1.5 billion litres of whey is produced annually in Ireland. Different types of whey are produced depending on the type of process used to create the cheese. The cheese making process starts

Table 1.1. Dairy product production in Ireland between 2010 and 2013 (Irish Dairy Board, 2013)

Product	Quantity produced (1000s of tonnes)			
	2010	2011	2012	2013
Butter	135	146	145	152
Cheese	161	165	174	180
Whole milk powder	34	38	40	35
Chocolate crum	35	35	40	34
SMP (including BMP)	74	81	52	49
Proteins	40	44	45	N/A

BMP, buttermilk powder; N/A, not available; SMP, skimmed milk powder.

Table 1.2. Quantities of wastewater produced during milk processing in Austria in 2002 (EC, 2006)

Types of product	Wastewater volume (L/kg of milk processed)
White products (milk, cream and yoghurt)	3
Yellow products (butter and cheese)	4
Special products (milk/whey concentrates and dried milk products)	5

with the creation of curds through the addition of either rennet and/or lactic acid to the milk. The process used to create these curds affects the properties of the whey. Sweet whey is created by the action of rennet (a complex of enzymes produced in any mammalian stomach that consists mainly of chymosin) during the production of hard cheeses (Figure 1.1), while acid whey is created through the actions of lactic acid bacteria, which create lactic acid through their metabolic activities (Todar, 2014). This process is used to make cheeses such as cottage cheese and cream cheeses, or can be used to produce acid casein. Salt whey is created by the addition of salt to the curd to remove additional liquid (Tommaso *et al*., 2012).

Because of the high level of organic constituents (mostly lactose) in cheese whey, whey can have high BOD values, ranging from 30,000 to 60,000 g/L depending on the cheese-making process utilised (Ghanadzadeh and Ghorbanpour, 2012). In the past, this cheese whey was sent to landfill (a practice that has been discontinued because of newly developed markets for whey proteins and regulatory requirements based upon the EU Landfill Directive 1999/31/EC), and used as a fertiliser (also largely discontinued), as a feedstuff for animals, as a food supplement, in the production of mitzithra cheese and in baby foods (Bylund, 1995).

The effects that whey has on the polluting potential of the waste outputs from cheese production are shown in Table 1.3. To place the figures in context, most pristine rivers/water bodies will have a 5-day BOD level that is below 1 mg/L, while moderately polluted rivers can have 5-day BOD values ranging from 2 to 8 mg/L (Sawyer *et al*., 2003). The allowed limits of treated urban wastewater are also given. In this context, wastewater constitutes "cleaning-in-place" (CIP) water, leftover product (liquid milk, cheese curds, whey, cream, buttermilk, etc.), washing water, etc.

Whey can be treated to give three different whey protein types: whey isolate, whey concentrate, and whey hydrolysate. These can be used as supplements to help bodybuilding and muscle recovery, and have various health-associated effects.

Whey protein concentrate (WPC) is approximately 50–85% protein. These concentrates are created by ultrafiltration. Whey protein isolate (WPI) has a high

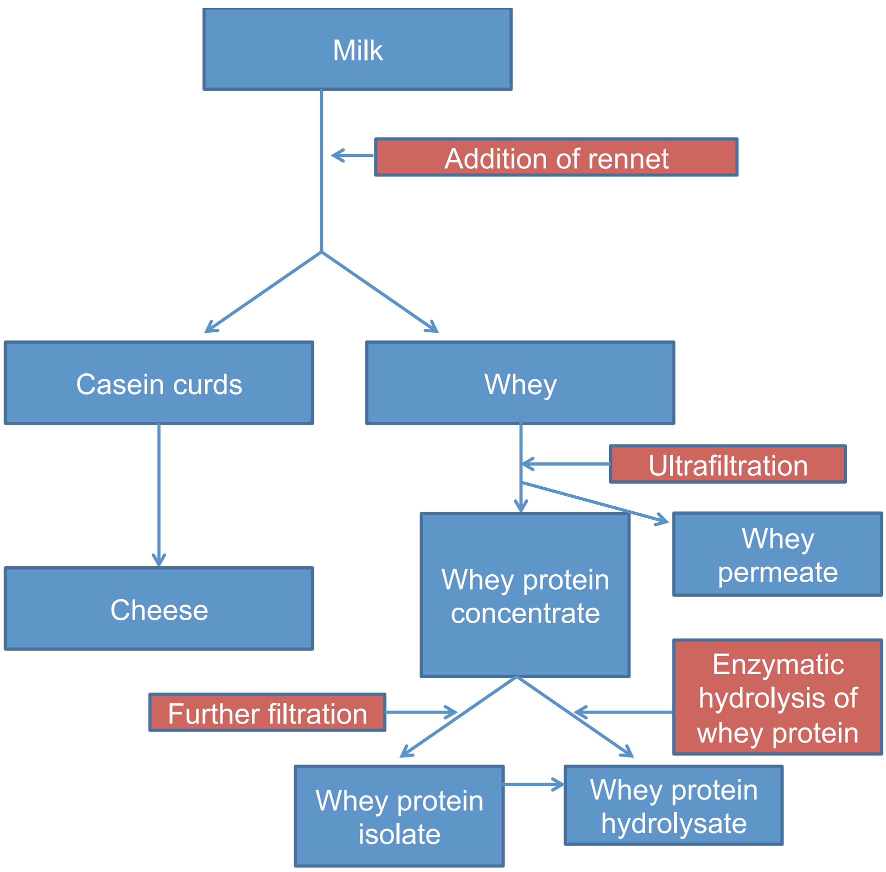

Figure 1.1. An overview of the creation of different classes of whey powders.

Table 1.3. Composition of cheese manufacturing wastewater (adapted from EC, 2006)

	Processing plants with whey recovery	Processing plants without whey recovery	Urban wastewater treatment regulation limits
BOD (mg/L)	2397	5312	25
COD (mg/L)	5312	20,559	125
Fats (mg/L)	96	463	35
Nitrogen (mg/L)	90	159	N/A
Phosphate (mg/L)	26	21	N/A

N/A, not available.

level of protein (> 90% protein) and is almost completely devoid of lactose and fats. It is created from the further refinement of WPC. Whey hydrolysate is created by the enzymatic hydrolysis of WPC or WPI. The creation of WPC leaves a secondary liquid stream, whey permeate, as a residue (Mollea *et al.*, 2013). Whey permeate has nearly as high a BOD value as whole raw whey fluid (this is because it contains most of the lactose present in whey) and, therefore, potentially poses just as significant a disposal problem. An overview of this process is shown in Figure 1.1.

The Carbery Group, which converts 90% of its annual milk intake (35,748,792 L) into cheese, uses this whey permeate to create alcohol for use as both a fuel and potable alcohol for alcoholic beverages, including several varieties of Irish cream liqueur (Ling, 2008; Leslie, 2013). This group is the only dairy processer in Ireland to use whey permeate in this way.

1.2.3 Butter

The process of creating butter creates large amounts of buttermilk (the liquid left over after fats have been removed from the cream). This buttermilk can then be used in animal feed or be incorporated into dairy or bakery products as an emulsifying agent (Vanderghem *et al.*, 2010). CIP also contributes to the waste generated during butter creation, as described below.

1.2.4 Cleaning in place

The majority of wastewater from dairy processing is generated by cleaning operations. Most of these cleaning operations are CIP methods. The definition of CIP in the context of the dairy processing industry is the circulation of cleaning (and sanitising) liquids through the milk processing equipment under conditions of increased turbulence and flow speed (Boyce *et al.*, 2010). The wastewater comes from the washing of lines, holding tanks at start-up and shut down and batch pasteurisation units. The protein and fat content of milk can cause fouling deposits to be formed on holding tanks and the other equipment used to process the milk. The removal of these deposits increases the organic load of the wastewater. CIP during dairy processing involves several steps: the recovery of any residual product (if practical); a pre-rinsing step with water (usually heated); cleaning with detergent(s); rinsing with clean water to wash out any residual detergent; and sanitation.

The pre-rinsing with water step is performed as quickly as possible after the recovery of all possible residual products. The water used for pre-rinsing is usually heated to help remove milk fat residues. The aim of this step is to remove all lightly bound material. This step can reduce the amount of detergent that is needed in the subsequent cleaning steps, with effective pre-rinsing adding to the effectiveness of the overall CIP process. Pre-rinsing is carried out until the return water runs clear (Bylund, 1995; Reinemann, 2002).

The deposits mentioned above are insoluble in water. The protein content of these deposits is soluble in alkaline and slightly soluble in acidic solutions, while the lipid content is soluble only in alkaline solutions. The mineral content of the deposits is variably soluble in water, but is soluble in acidic solutions (Bylund, 1995; Fryer and Christian, 2005). Consequently, cleaners are usually based upon either acidic or alkaline compounds. These solutions are usually heated to 70–80°C. Sodium hydroxide (NaOH), also known as caustic soda, is the most commonly used alkaline compound. It leads to the fast hydrolysis of proteins and breakdown of lipids, and is partially bactericidal (Purnell, 1993; D'Souza and Mawson, 2005). Other alkaline solutions that can be used in CIP include potassium hydroxide (KOH), sodium carbonate (Na_2CO_3) and alkaline silicates and phosphates (Purnell, 1993). Nitric and phosphoric acid are the most

commonly used acids for detergent applications in dairy CIP, with CIP solutions containing approximately 0.5% (w/w) acid (Chisti, 1999). Nitric acid is less expensive than phosphoric acid and has also been shown to have passivating effects (a chemical process that strengthens metals and preserves their appearance) on the stainless steel of the processing equipment. Sulphuric and hydrochloric acids can also be used but these can have corrosive effects on piping (Purnell, 1993). Organic acids, including acetic acid ($C_2H_4O_2$), hydroxyacetic acid ($C_2H_4O_3$), lactic acid ($C_3H_6O_3$), gluconic acid ($C_6H_{12}O_7$) and citric acid ($C_6H_8O_7$) (Reinemann, 2002), and mixes of these different types of acids can also be used (Bremer *et al*., 2006). However, these solutions can also increase the phosphate and nitrate content, and alter the pH of the wastewater. This can lead to difficulties in treatment if pH adjustment and phosphorous removal are necessary.

If cleaning is performed with detergents, certain considerations must be taken into account. These include the concentration of the detergent being used, the temperature of the solution and the duration of cleaning. The detergent solution has to be circulated for an adequate amount of time to remove deposits; this time can depend upon the level of fouling and the temperature of the detergent solution. CIP with both alkaline and acidic detergents occurs at approximately 70°C (Bylund, 1995). Several factors must be considered when deciding on the duration of cleaning, including optimum cleaning, the usage and cost of electricity, heating, water and labour, as well as the associated downtime, and these factors can vary from plant to plant. After cleaning, the system is flushed through with water in a final rinse step to remove any suspended soils and wash out all remaining traces of CIP chemicals (Bylund, 1995; Reinemann, 2002). The final CIP step is disinfection. The disinfection step is carried out using either thermal or chemical means, and is performed in order to reduce microbial numbers within the system to an acceptable threshold (Eide *et al*., 2003). Thermal-based disinfection can be carried out through the circulation of either hot water (>80°C for 5 minutes) or steam (condensate temperature of >80°C for 15 minutes) through the system. Chemical disinfection is carried out using chlorine, iodophors (iodine-containing compounds) and quaternary ammonium sanitisers (Reinemann, 2002.

Minimising the impact of CIP on the environment is becoming an area of interest for the dairy processing industry. This minimisation could potentially be achieved using enzymes. Enzymes are biodegradable and can operate at relatively low temperatures (<40°C), and the use of enzymes could replace the conventional high-temperature caustic-based CIP procedures discussed above. Enzyme-based CIP approaches would lead to a reduction in the use of CIP chemicals and energy, because of the lower operating temperatures involved. The pH of enzyme-based cleaning solutions would also be more compatible with the ensuing wastewater treatment processes meaning that lower levels of chemicals (or possibly no chemicals) would be necessary for the neutralisation of CIP wastewater. Enzyme-based cleaning has also been shown to reduce water consumption and the volume of wastewater produced because of the reduction in the rinsing volumes required (Boyce *et al.*, 2010; Boyce and Walsh, 2012).

1.2.5 Water usage

Water usage, either the use of municipal supplies or on-site wells, is a major expense for dairy processors. The typical amount of water used by dairy processors to process a litre of milk varies worldwide. A typical dairy processer in the UK uses 1.3 L of water for every 1 litre of milk that is processed. Water consumption in the rest of Europe has been reported to range from 0.2 to 11 L water/L of milk processed (Daufin *et al*., 2001). In Australian dairy processing plants, water consumption varies for mixtures of white milk products, cheese, powders and yoghurts, ranging from 0.07 L water/L milk (for milk powders) to 2.90 L water/L milk (for yoghurts), with the average being around 1.5 L water/L milk (Prasad *et al*., 2004). For most US dairy plants, 0.5 L water/kg milk equivalent processed is reported to be the lowest achievable water consumption value. North Carolina Department of National Resources and Land-of-Sky Regional Council (2009) consider this amount to be obtainable in most dairy plants. In 2012 in an Irish setting, the Aurivo Co-Operative Society Ltd used 0.75 L water/L milk. Reducing water usage as much as possible can provide great savings: dairy processors in Lidcombe, Sydney, Australia, were able to save nearly AUS $300,000/year with initial capital costs of AUS $150,000 and ongoing maintenance and running costs of AUS $26,000/year. National Foods Ltd in Penrith, Sydney, Australia, reduced water use at its plant by 22% (110,000 L/day) saving AUS $104,000/year, with implementation costs of AUS $86,000

(Prasad *et al*., 2004). Water saving measures are discussed further in section 2.4.

1.3 Aims of this Study

The initial aims of this project were to (1) identify/ quantify dairy processing wastewater process streams of environmental significance that are likely to be characteristic of the year 2020; (2) evaluate current and emerging technologies in order to determine which are best suited to the treatment of the most significant pollutants identified; and (3) evaluate the potential of whey (a major potential pollutant produced as a by-product of cheese manufacture) as a growth medium for industrially important microorganisms.

2 Research Approach, Actions and Results

2.1 Wastewater Outputs of the Irish Dairy Processing Industry

2.1.1 Wastewater outputs from Irish dairy processers

Allowable emissions (to both air and water) are determined by the Industrial Emission Licences (IELs)\ Integrated Pollution Control (IPC) Licences that are granted by the Environmental Protection Agency (EPA) to each individual dairy processing facility. The Industrial Emissions Directive (IED)/IPC licensing process is based on the Best Available Techniques (BAT) principle. In order for an industry to determine what constitutes BAT, a series of sector-specific guidance documents have been developed. BAT documents from individual Member States (drafted by the EPA in Ireland) and BAT reference documents (BREFs) from the European Commission provide guidance on complying with IED/IPC Licences. The licence lays out the parameters (temperature, flow, pH, BOD, COD, etc.) that must be tested in wastewater, the methods that must be used to test these parameters and how often these tests must be carried out. The licence lays out the maximum volumes that can be released per hour and per day in any one day (e.g. 500 L and 12,000 L, respectively, in the case of the Kerry Ingredients processing plant at Listowel, and 250 L and 6000 L, respectively, in the case of the Carbery plant in Cork). The amounts of pollutants that can be released are set as amounts per litre (i.e. BOD: 16 mg/L; COD: 125 mg/L; suspended solids: 30 mg/L). In the case of the Kerry Ingredients processing plant at Listowel, for example, this means that up to 8 g of BOD can be released per hour and up to 192 g of BOD can be released per day. This would equate to 70,000 kg per year if the plant were active 24 hours per day, 7 days per week. In practice, however, this does not occur, as plants are not active for 24 hours per day and often shut down for periods during the winter.

Six outputs were examined – (1) BOD, (2) COD, (3) suspended solids, (4) total nitrogen, (5) total phosphate, and (6) total oils, fats and greases – as these outputs provide a good indication of polluting potential and values were (in most cases) available for all sites. The output values show fluctuations from year to year as expected because of differences in the quantity of milk produced yearly (mainly as a result of weather conditions) and, therefore, the quantity of milk processed. Differences between plants are due to the differing amount of milk processed and the different products manufactured at each plant. CIP procedures take place at every plant. The waste values are presented in kilograms, and an average (with standard deviation) was calculated based on all outputs between 2008 and 2013. The theoretical yearly output limits (based on activity 24 hours per day, 365 days per year) are also included. As Food Harvest 2020 projects a 50% increase in milk production using the average of the years from 2007 to 2009 as a baseline, 2008 and 2009 are especially relevant. Annual output figures for all wastewater outputs show fractions of the total allowable amounts for the years considered in this study. However, if considered in isolation, these values are misleading, as total annual allowable amounts are based on output for 24 hours a day, 7 days a week, 52 weeks per year, as stated above, whereas plants under IED/IPC licensing have hourly and daily output limits. Full figures can be seen in the full final report, available on the EPA website.

2.1.2 Contact with the Irish dairy processing industry

Contact was made with 19 different dairy processing facilities (14 different companies) and four of these companies (six facilities, i.e. 31% of those contacted) responded. Questions were asked about the waste outputs from the processing activities of the plant, the difficulties (if any) in complying with wastewater output limits, and the projected effects of Food Harvest 2020 on milk intake and wastewater outputs. All of the questions asked are shown in Table 2.1.

The low response rate to these questions, despite repeated requests by email and/or follow-up phone contact, was disappointing. Moreover, the replies received were characterised by the provision of incomplete answers, particularly to questions 7 and 8 (Table 2.1). The poor and incomplete response profile does

Table 2.1. Questions for dairy processors

Question number	Questions
Q1	What types of processing activities take place at the plant (e.g. cheeses, milk powders, etc.)? In what quantities is milk processed and what are the quantities of end products produced?
Q2	What are the constituents of the waste streams from your facility's dairy processing activities (e.g. waste from CIP, whey waste from cheese making, etc.)?
Q3	What type of waste treatment systems do you use (e.g. bio-towers, membrane bioreactors, phosphorus removal, etc.)? How does your facility dispose of waste sludge (if any)? What are the costs associated with running your facility's waste treatment system?
Q4	How much does seasonality affect your waste outputs?
Q5	How often (if ever) would your plant fall outside of the emission limits (to water) set forth in your IPPC [integrated pollution and prevention control] licence?
Q6	What are the (projected) effects of Food Harvest 2020 on dairy intake and product and waste outputs for your plant/ company?
Q7	What are the (projected) effects of Food Harvest 2020 on processing activities (new equipment, new staff, etc.) at your plant?
Q8	What are the (projected) effects of Food Harvest 2020 (or future plant activities) on statutory responsibilities?
Q9	Are any future activities (new products, new processes, etc.) planned that may affect the waste profiles of the plant?

not provide a sufficiently robust and comprehensive dataset from which overall conclusions can be reliably drawn. This, in turn, limited the ability to meet two of the project's main aims: (1) to identify/quantify waste process streams of environmental significance that are likely to be characteristic of the year 2020; and (2) to evaluate current and emerging technologies in order to determine which are best suited to the treatment of the most significant pollutants identified.

However, some indications of expectations in the industry can be drawn from the replies received. The companies that replied believe that the 50% increase in milk production projected by Food Harvest 2020 will not lead to an equivalent increase in their milk intake or processing activities: the Kerry Group estimates a 25% increase in milk intake and processing activity; Arrawbawn expect a 40% increase in milk intake, but they do not expect this to equate to a 40% increase in processing activity; and the Carbery Group expect an increase in milk intake (by an amount not specified), but they expect to decrease the amount of whey they take from other processors and this will offset the extra production. The processers expect that the wastewater types produced by the Irish dairy processing industry are likely to be unaffected by Food Harvest 2020. However, it is expected that waste quantities will increase in line with increases in dairy product types (i.e. the production of more cheese will lead to the production of more whey and milk powders, which, in turn, will result in the production of more condensate, etc.); however, no figures were provided to quantify these expected changes. Arrabawn, for example, expect that the manufacture of acid casein will increase with a corresponding increase in the levels of acid whey. It is expected that, in some instances, greater capacity will be required for milk processing and the wastewater treatment operations of plants, and that a review of allowable emissions in the IED/IPC licences may take place. However, as stated above, this information is based on only a few responses and may not represent an accurate picture of the entire Irish dairy processing sector. Given the low response rate to the survey undertaken, industry co-operation should be agreed prior to the commencement of any similar survey in the future.

2.1.3 Legislation that may be affected by Food Harvest 2020

Large-scale activities that fall within the scope of the Environmental Protection Agency (EPA) Act 1992 as amended and regulated by the EPA under the terms of an IEL or an IPC Licence. Dairy processing is covered by Class 7.2.1, "The treatment and processing of milk, the quantity of milk received being greater than 200 tonnes per day (average value on a yearly basis)", and Class 7.2.2, "The manufacture of dairy products where the processing capacity exceeds 50 million gallons of milk equivalent per year not included in paragraph 7.2.1". Licences granted to operators for these classes

of activities by the EPA set out mandatory requirements for the environmental management of the facility; the necessary emission control and abatement infrastructure; the handling of waste materials on site; the emission levels to air, water and sewer, and the monitoring of these emissions; the accident prevention and emergency responses; plant decommissioning; record keeping and reports; and any financial charges and future provisions. Smaller activities that fall below the threshold specified in the EPA Act 1992, as amended, are regulated by local authorities or Irish Water under the terms of a single media permit issued under the Water Pollution Act 1977, the purpose of which is to control the volume and quality of effluent to waters/sewers.

Two other documents establish the best practice that should be adhered to when managing and processing dairy waste: the EPA's 2008 *BAT Guidance Note on Best Available Techniques for the Dairy Processing Sector* (EPA, 2008) and the European Commission's *Reference Document on Best Available Techniques in the Food, Drink and Milk Industries* (EC, 2006). Other relevant statutory instruments include the "European Union (Good Agricultural Practice for Protection of Waters) Regulations 2014" [Statutory Instrument (S.I.) No. 31 of 2014] (Nitrates Regulations), and the "Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998 (S.I. No. 148 of 1998), which control the disposal and recovery of waste sludge on lands. The Nitrates Regulations control the spreading of fertilisers (including dairy sludge) in nitrate-vulnerable areas. A requirement of these regulations is that there are nutrient management plans in place for the application of fertilisers onto land.

2.2 An Overview of Dairy Processing Wastewater Treatment

Information was identified for this section by interrogation of a number of different sources including the EPA website; the *Reference Document on Best Available Techniques in the Food, Drink and Milk Industries* (EC, 2006); internet search engines (using terms such as "wastewater treatment technologies", "dairy wastewater treatment", "sewage treatment technologies", etc.); and articles and special reports published in the standard academic literature. A patent search was also carried out using the Google Patent search tool.

2.2.1 *Primary, secondary and tertiary wastewater treatments in the dairy processing sector*

The treatment of wastewater in the dairy processing sector typically consists of primary, secondary and tertiary treatments. An overview of these processes is shown in Figure 2.1. Primary treatment usually involves a number steps including sedimentation/screening to remove debris; balancing to create a steady flow and concentration in the wastewater; dissolved air floatation (DAF) to remove fats, oils and greases; and pH control. Secondary treatments are directed towards the removal of organic material and suspended solids using biological methods. Pollutants, including non-biodegradable materials such as heavy metals, can be adsorbed into the organic sludge. Secondary treatments can also partially remove organic nitrogen and phosphorus from the wastewater. Secondary treatment options can be used by themselves or in combination/sequence with other secondary processes. There are three types of secondary treatments based on the metabolic processes employed: aerobic processes, anaerobic processes and anoxic processes. Aerobic processes are carried out using dissolved oxygen, anaerobic processes are carried out without oxygen, and anoxic processes are carried out using the biological reduction of oxygen donors (EC, 2006). The type of treatment used (aerobic, anaerobic or a combination of the two) can vary based on a number of factors including climate, cost, regulatory emission output limits, etc. Aerobic techniques that are routinely used internationally in the treatment of dairy processing wastewater can involve activated sludge, sequencing batch reactors (SBRs), aerobic lagoons and trickling filters/bio-towers or membrane bioreactors (MBRs). Tertiary treatment potentially includes phosphorus removal through the use of chemicals (e.g. ferric sulphate or aluminium chloride) and polishing steps before releasing treated wastewater to water bodies or municipal wastewater treatment systems.

2.2.2 *Treatment systems used in the Irish dairy processing sector*

The majority of processing facilities in Ireland (20 out of 22) use aerobic processes for the treatment of wastewater (only 2 facilities out of 22 use anaerobic treatment processes; however, these processes are combined with aerobic processes such as bio-towers). Most of the

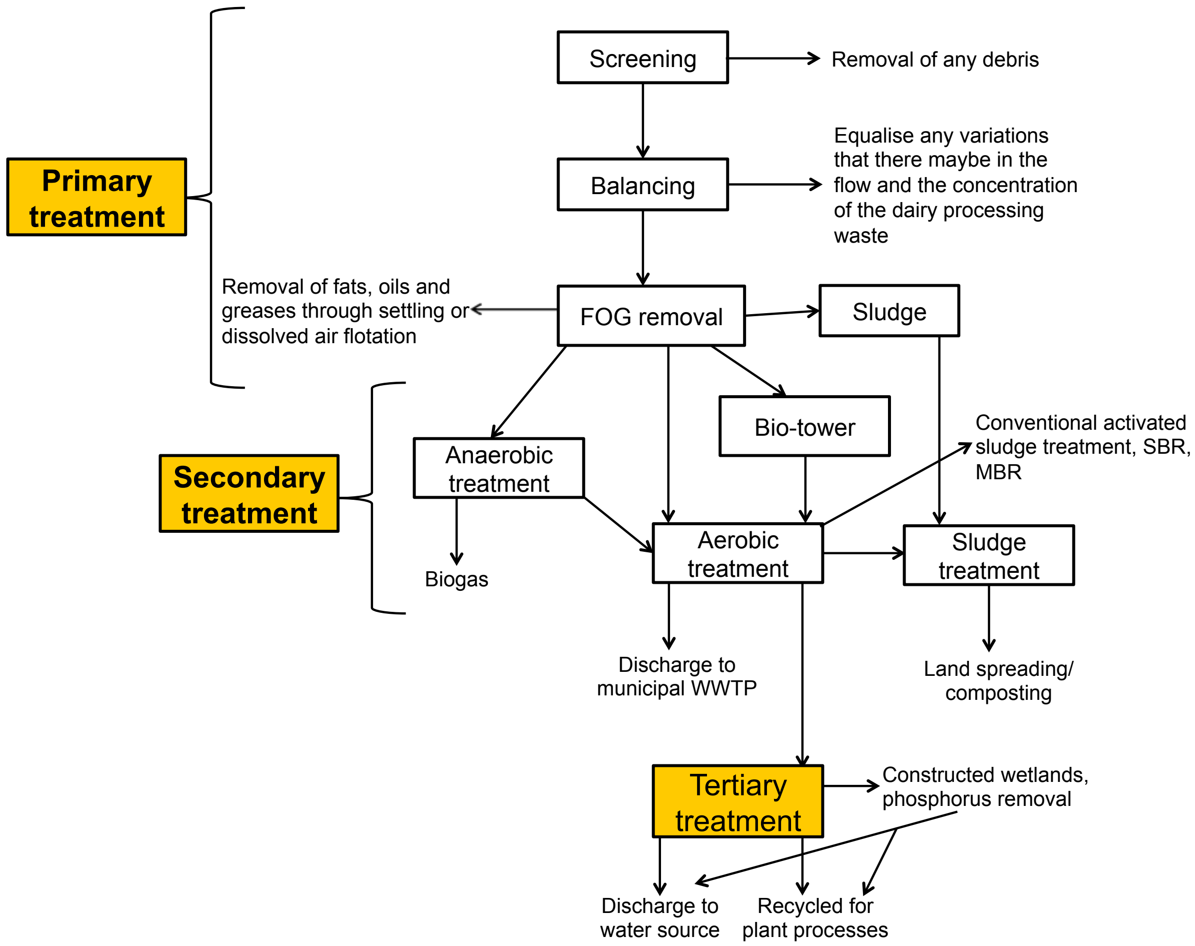

Figure 2.1. A generalised overview of the treatment of dairy processing wastewater (based on information in EC, 2006).

processing sites use more traditional secondary treatment techniques, such as bio-towers, oxidation ditches and activated sludge aeration, to treat wastewater. The more traditional aerobic processes are well suited to treating dairy wastewater and are also suited to the Irish climate. They are also very cost effective for the treatment of dairy wastes as these are highly biodegradable. Microorganisms in the mixed liquor can get oxygen from either the surface of the liquid or from air diffusers that are submerged in the wastewater. Surface injection of oxygen/air is carried out by either surface aerators or oxygenation cages.

Two facilities (Abbott Ireland and Pfizer Nutritionals Ireland Limited) use SBRs and one facility (Dairygold in Mitchelstown) uses a MBR (in combination with a bio-tower and an anaerobic digestion system). Several facilities also use an anoxic tank to reduce nitrogen content. Tertiary treatment involves chemical phosphorus removal in most facilities (15 out of 22) and constructed wetlands (2 out of 22). Waste sludge from the 22 facilities is disposed of by land spreading, composting or by licensed contractors. Sludge (organic waste/organic material are the regulator-/industry-accepted terms) is disposed of on land by land spreading in accordance with the Waste Management Act 1996, as amended, the “European Union (Good Agricultural Practice for the Protection of Waters) Regulations 2014” (S.I. No. 31 of 2014) (the Nitrates Regulations) and the “Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998” (S.I. No. 148 of 1998). A breakdown of the types of wastewater treatment processes used in an Irish context is shown in Figure 2.2.

2.3 Future Wastewater Treatment Technologies

In the future, treatments for dairy wastewater should be more efficient in their use of water, electricity and chemicals than the previous and current technologies used to treat dairy processing wastewater. Such new treatment

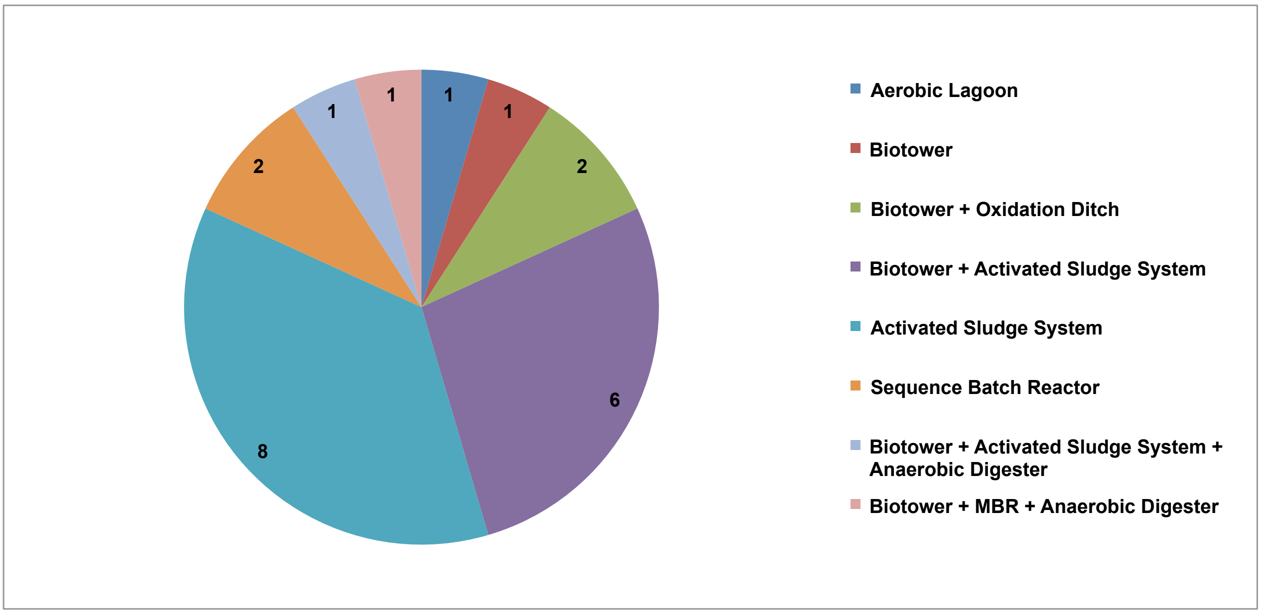

Figure 2.2. Breakdown of secondary treatment processes used by the Irish dairy processing sector.

systems should, if possible, have an output that can help reduce the costs associated with operating the treatment plants. An overview of the recently developed processes considered in this report is given in Table 2.2. In some cases, these technologies are already in limited use. Few breakthrough technologies appear to be in development; therefore, traditional treatment technologies will continue to dominate, certainly in the near and intermediate future. The information used for this section of the report was identified by interrogating a number of different sources, including articles and special reports published in the standard academic literature, and the Google Patent search tool.

2.3.1 REPHATER

The REPHATER ("electrochemical water treatment pilot plant in the dairy industry with phosphate recovery") project was funded by the Eco-Innovation Programme of the Executive Agency for Competitiveness and Innovation (EACI) (Brussels, Belgium).

The aim of this project was to develop a pilot wastewater treatment plant that is based on the combination of two state-of-the-art technologies for which prototypes already exist: electrocoagulation and electrooxidation. The treatment plant also includes a process for the recovery/recycling of phosphate using an eco-innovative integrated approach.

The aims of the novel prototypes developed by the REPHATER project were to improve the existing electrocoagulation and electrooxidation methodologies and bring an effective solution to the market that is also environmentally friendly. Potentially, this system could be used in many different industrial sectors, not just the dairy processing sector. The recovery of phosphate from dairy waste not only removes a highly polluting substance from the waste, but also allows the recovery of phosphate, which can then be used for different agricultural (e.g. fertiliser) and industrial applications (REPHATER, 2014).

Electrocoagulation works by generating coagulants in the wastewater vessel by electrically dissolving either aluminium or iron ions from aluminium or iron electrodes. Metallic hydroxides are formed that flocculate organic and colloidal material. The materials can be in the form of aluminium or iron plates, or can be packed material made up of scrap metal waste such as steel turnings and millings. Laboratory-scale studies have shown that electrocoagulation can remove 98.84% COD, 97.95% 5-day BOD and 97.75% total suspended solids (Bazrafshan *et al.*, 2003). Preliminary estimates indicate that a REPHATER plant could reduce operational costs by 25% compared with traditional plants.

Table 2.2. Future wastewater treatments for the dairy processing industry

Name	Technology	Oxygen use	Useful output	Operation stage	Contact details
REPHATER	Electrocoagulation and electrooxidation	Not available	Phosphorus recovery and water reuse	Pilot plant in operation	http://leitat.org/projectes/rephater/
The Pearl process	Phosphorus removal from wastewater through the formation of struvite crystals	Aerobic	Phosphorus for use as a fertiliser	Commercial process available	http://www.ostara.com/nutrient-management-solutions/pearl-process
REWAGEN	Electrocoagulation, electrooxidation and hydrogen recovery technologies	Not available	Water reuse and electricity	Research stage	http://www.rewagen.eu/
Microbial fuel cell (MFC)-based treatment system	MFC	Anaerobic	Electricity	Research stage has finished; no commercial process available	Dr Bruce Logan Pennsylvania State University Hydrogen Energy Center 231Q Sackett Building University Park, PA 16802 Telephone: 814–863–7908 Email: blogan@psu.edu
Anaerobic migrating blanket reactor (AMBR)	Granular biomass	Anaerobic	Biogas	Has reached operational stage with a plant in Costa Rica that has since been shutdown	Largus (Lars) Angenent Department of Biological and Environmental Engineering Cornell University Telephone: 607–255–2480 Fax: 607–255–4080 Email: la249@cornell.edu
Anaerobic membrane bioreactor (An-MBR)	Membrane technology similar to MBRs	Anaerobic	Biogas	Has been used in the food industry in the USA including in dairy processing plants	Veolia Water Solutions and Technologies Biothane Americas 2500 Broadway Camden, NJ 08104 Telephone: 856–541–3500 Fax: 856–541–3366 Email: sales@biothane.com ADI Systems Inc. P.O. Box 397 7 Pointe Sewall Road Wolfeboro, NH 03894 Telephone: 603–569–0955 Fax: 603–569–0957 Email: systems@adi.ca Website: www.adisystemsinc.com

2.3.2 *Phosphorus removal from wastewater through the formation of struvite crystals*

The basis of this phosphorus-removal process is much the same as that of chemical precipitation with compounds like ferric sulphate, the only difference being that this process allows the crystallisation of phosphorus into a usable product. The sludge liquor is sent to an upflow fluidised bed reactor along with the chemicals added to generate a precipitate. A common additive is magnesium in order to generate a magnesium ammonium phosphate ($MgNH_4PO_4$) precipitate, which is also called MAP or struvite. The controlled addition of magnesium and the manipulation of upflow rate causes crystals of MAP to be efficiently formed and suspended in the flow until they grow to the necessary size. After this, the crystals settle to the bottom of the reactor and can be collected. This also removes nitrogen as MAP includes 0.2 kg of nitrogen for every 0.45 kg of phosphorus.

Recovery of up to 85% of the initial sludge phosphorus has been reported by Ostara Technology (the company that created this technology). The Ostara Pearl process is controlled to produce pellets of 1–3.5 mm diameter; these pellets are marketed by Ostara Technology as CrystalGreen fertiliser (Ostara Technology, 2014).

2.3.3 REWAGEN

The European Union Framework 7 project REWAGEN ("electrochemical water treatment system in the dairy industry with hydrogen recovery and electricity production") was launched in June 2012 with the aim of creating a new type of dairy-related wastewater treatment process. The project is expected to end in June 2016.

The objective of this project is to develop a water treatment system that is founded upon the combination of three technologies: electrocoagulation, electrooxidation and a new recovery technology for the hydrogen produced by electrocoagulation and electrooxidation. The goal is to create a process that closes the water cycle by integrating energy and water management, and in which the electricity generated through hydrogen conversion is used to power the system, and the residues extracted from wastewater treatment are reused in the food and dairy production process for various needs (REWAGEN, 2014).

The aims of the REWAGEN process are to treat dairy effluents (wastewater and whey) through the coupling of electrocoagulation and electrooxidation upgrading systems; to reduce water consumption at dairy sites through the reuse of treated water (the aim is to reuse 80–95% of treated water); to recover and purify hydrogen from electrocoagulation and electrooxidation processes; to recover energy through hydrogen combustion in a fuel cell system; to study waste management through electrogenerated sludge valorisation; and to reduce chemical consumption (REWAGEN, 2014). Such a system is highly attractive as it could provide power not only to run the system itself by potentially other plant process as well as also providing clean water that could be used in processes such as CIP.

This proposed technology, however, is highly novel and no work focusing on the recovery of generated hydrogen from electrocoagulation or electrooxidation systems for the production electricity has been reported in the scientific literature. According to the first published summary, released in January 2014, from the project, work is progressing well (REWAGEN, 2014).

2.3.4 Microbial fuel cell-based treatment system

A microbial fuel cell (MFC) is a device that produces electricity from the metabolism of organic matter by bacteria (Logan and Rabaey, 2012). During the last stage of bacterial metabolism, electrons are passed along the bacterial membrane and passed onto a terminal electron acceptor. Under conditions of aerobic respiration, this electron acceptor is oxygen. However, under anaerobic conditions (i.e. no oxygen present), bacteria must use another electron acceptor. Examples of alternative electron acceptors include sulphates or nitrates. In MFCs, bacteria are grown under anaerobic conditions and their electrons are transferred externally to an anode. These electrons flow from the anode to a positively charged cathode through an external circuit. This creates an electrical current. The cathode is exposed to oxygen and protons (H^+) that chemically react with the incoming electrons to form water.

Research into using MFCs for wastewater treatment has mainly concentrated on the design of the fuel cell, for instance the number of chambers and their layout; the size (surface area), spacing, materials and quantity of electrodes; the composition of the proton exchange membranes; and affordable cathode catalysts.

Research to identify the best bacterial species to use in the process and to better understand how electrons can be transferred externally is also underway. An adapted MFC process that creates pure hydrogen gas, which can be used with hydrogen fuel cells to create electricity, is also being studied. Under the conditions used for this approach, no oxygen is supplied at the cathode. Instead, a small amount of voltage is added to the circuit to facilitate the chemical formation of hydrogen gas. Advances in MFC research and design have achieved substantial increases in electricity production compared with previous designs. The technology is still at laboratory level; however, it is thought that, with further developments, MFCs could be capable of producing enough electricity to run a wastewater treatment plant and possibly even produce an excess of power that could be used to run other activities at the processing plant (Liu *et al*., 2004; Fan *et al*., 2012).

2.3.5 Anaerobic migrating blanket reactor

An anaerobic migrating blanket reactor (AMBR) is an anaerobic wastewater treatment process that uses granular biomass and produces biogas. The granular biomass permits very long solid retention times. This allows the AMBR process to be operated at lower temperatures than required for standard, non-granular, anaerobic processes that operate with shorter solid retention times. Laboratory studies carried out with the AMBR process on dairy wastewater have shown a 59% removal of COD from non-fat milk at 15°C, and the removal of 80% to 95% COD at 20°C (Angenent, 2001a,b). Trials of the AMBR process have been carried out at a full-scale installation for remediation of dairy wastewater; however, there are currently no full-scale installations are in operation. An aerobic process of some kind would be needed for effluent polishing (US EPA, 2013).

2.3.6 Anaerobic membrane bioreactor

Another potential type of wastewater treatment that could be applicable in an Irish setting is the use of an anaerobic membrane bioreactor (An-MBR). The An-MBR process is comparable to that of the MBR process, except that the biological process takes place under anaerobic conditions instead of aerobic conditions. The An-MBR process needs less energy and generates biogas (which can be used to power plant processes), the system (as with aerobic MBR) does not take up as much space as classical treatment systems, such as activated sludge systems, and it produces less sludge than the standard MBR process. The system can also be operated at lower temperatures (the system was shown to work at 15°C under optimal conditions) than other standard anaerobic processes (operated at >25°C) because of the inclusion of a membrane. The ability of this system to operate at lower temperatures than normal for an anaerobic process is attractive in an Irish context. The membrane (microfiltration grade membrane of >0.1 µm) allows the system to operate at high solid concentrations and with high solid retention times to compensate for the low growth rate. Laboratory-based experiments have shown that the system can remove up to 92% of COD (Raskin *et al.*, 2012). The system has been installed in food processing facilities in the USA, including in cheese manufacturing sites such as Valley Queen Cheese, Milbank, South Dakota (US EPA, 2013).

2.4 Water Usage and Savings in the Dairy Processing Sector

While investigating the major waste streams associated with dairy processing activities, it quickly became apparent that water usage, specifically the minimisation of water usage, has become a core focus within the dairy processing sector. The increasing focus on water conservation is driven not only by obvious environmental concern, but also by economic factors (Forfas, 2014). Consequently, although not specified as an initial project aim, it was considered appropriate to consider water conservation as part of the overall project.

To achieve water savings, it is essential to understand how much water enters and exits the plant and where and for what exactly the water is being used. Understanding water flows within the processing plant will allow the identification of the greatest opportunities for savings. This can be accomplished by developing a detailed water usage model for the site using dedicated software [e.g. Pinch analysis (Oliver *et al.*, 2008)] or through a simple spreadsheet. Other steps include the fitting of flow meters to measure and monitor water use directly; flow meters can also be used to measure "standing still" water consumption during non-operational periods to detect leaks. Another step is the use of manufacturer's specifications to estimate water use for equipment and to then carry out a comparison with the actual amounts used. Any manual operations, as well as the equipment used in these operations, should be monitored carefully (e.g. the amounts of water needed for washing down floors and equipment), as should staff behaviour, which could include things such as leaving taps running, leaving hoses unattended, leaving taps or hoses dripping, etc.

Once all of this information has been collected, it will be possible to develop a water conservation programme that involves steps such as creating new procedures, purchasing new equipment and carrying out regular water audits (Box 2.1).

The first step that should be carried out in a water conservation programme is to check for leaks on all taps, valves, pipes, etc. Equipment that is left leaking over lengthy periods can waste significant amounts

of water (or potentially product). A regular leak-check schedule (weekly checks, monthly checks, etc.) should be instituted.

Trigger-operated controls for hoses, combined with high-pressure water cleaners, can potentially use up to 60% less water than hoses directly attached to the water mains (Prasad *et al.*, 2004). Such hoses are typically used to clean floors and some equipment, and also for cleaning areas such as those around wastewater treatment plants, cooling towers and some floor areas.

Fine-tuning/redesign of CIP systems can also lead to water savings. Pauls Ltd, Stuart Park, Darwin, Australia, instituted a new CIP regime that saves the company AUS $40,000/year (resulting from the chemical and water saving paybacks in a year). The previous single-use system (i.e. all water and chemicals were used once and were then discharged to the wastewater treatment system) was replaced with a multi-use CIP system. This system recycles the final rinse water for use in the pre-rinse cycle. The chemicals that are used in the system are also returned to holding vats, in which temperature and conductivity are monitored, and are automatically adjusted to meet specifications for reuse (Australian Government Department of the Environment, 2001). Simple adjustments in CIP regimes, such as the reviewing of flush timings for cleaning, can also save large amounts of water. National Foods in Penrith, Sydney, Australia, was able to save approximately 12,000,000 L of water per year by reducing the flush time of their pasteurisation unit by 12 minutes/day (Prasad *et al.*, 2004).

The recovery and reuse of condensate water can also potentially allow water savings. Condensate water is generated from two processes in dairy processing plants: the drying and evaporation processes used to concentrate milk products or produce milk powders (vapour condensate); and the boiler and steam supply system processes. Condensate water from drying and evaporation has the potential to supply a large quantity of the needs of the plant; however, the opportunity to use the condensate could be affected by its quality [i.e. what was being condensed (e.g. full-fat or skimmed milk, whey, etc.)] and in some instances treatments, such as reverse osmosis (RO), may be required before reuse. Significant savings in energy costs can also be gained by recovering heat energy from the condensate (Prasad *et al.*, 2004; Vourch, *et al.*, 2008).

Another potential means of saving water is through the reuse of wastewater treatment effluent. ELGA Process Water carried out a pilot study with Robert Wiseman Dairies in the UK. In this study, the processing plant's wastewater was first treated by DAF and then using a MBR. The quality of the MBR effluent was found to be high enough to be directly fed into a RO system (the ELGA Process Water MegaRO™ system in this case). The process allowed the recovery of up to 200,000 L of water per day for use in CIP. The RO process removes the residual COD, dissolved salts and bacteria from the treated process wastewater. This produces water that is of equal or better quality to the mains supply. The operating costs of the RO system are low and the recovered water costs less than mains water (based on UK prices). The system can recover its capital costs after 2.5 years (again based on UK prices) (Fairman, 2012). This type of water recovery system requires high-quality effluent from the wastewater treatment system so would be viable for only systems such as MBRs.

The ancillary use of water in amenities and kitchens/cafeterias can contribute a small percentage to a plant's overall water use [e.g. approximately 3% of water use in Australian dairies (Prasad *et al.*, 2004)], but large water savings can still be made. The fitting of water-minimising features, such as push taps, water flow regulators/restrictors, toilet cistern displacement devices, low-flush toilets and sensor flushing controls on urinals, can minimise unnecessary water use (Envirowise, 2007).

In an Irish context, Aurivo Dairy (formerly Connacht Gold) has achieved a 34% reduction in water use on site since 2010, while, during the same period, the amount of milk processed increased by 47%. It achieved this by improving wash cycle control, reusing condensate, promoting water awareness, and monitoring water use using key performance indicators (KPIs) and other metrics (Daly, 2013). As a result of these measures, for every 1 L of milk that is processed, the company uses only 0.75 L of water. Box 2.1 lays out several steps that can be taken by dairy processors to conserve and reuse water.

Box 2.1. Water conservation in the dairy processing sector [adapted from various sources, including Prasad *et al.* (2004) and Rausch and Powell (1997)]

- Water should be treated as a raw material with a cost.
- Water conservation should be made a priority.
- Specific water conservation targets should be set for a plant.
- Water meters to monitor use should be installed and checked regularly.
- Employees should be trained on how to use water efficiently (on the use of hoses etc.).
- Automatic shut-off nozzles should be used on all water hoses.
- Spills of ingredients, raw materials and finished products should be prevented.
- Spills should always be cleaned up (e.g. using a floor squeegee) before washing.
- High-pressure, low-volume cleaning systems should be used.
- The use of water hoses as brooms should be avoided.
- Water should be reused if possible (condensate, CIP water, etc.).

2.5 Use of Whey as a Means of Growing Industrially Relevant Microorganisms

While opportunities for the use of whey for various industrial and other applications have increased in recent decades, the production of excess waste whey and waste whey permeate remains a potential environmental hazard. In order to ascertain if waste whey could be put to an additional use, a laboratory-based study was undertaken using both synthetic and dairy-derived waste whey to assess if these could be used as media to grow industrially important microorganisms (such as bacteria, fungi or yeast that are used to create enzymes or industrial chemicals). If successful, this could provide an additional outlet for excess whey in the fermentation industry. Microbial fermentation, which is used to create biomolecules of industrial or medical uses, remains one of the main activities within the biotechnology industry (Demain and Vaishnav, 2009).

2.5.1 The growth of industrially relevant (classical, non-recombinant) microorganisms in whey

A panel of industrially relevant fungi, bacteria and yeast were screened for their ability to grow in whey-based media. Two fungal strains, *Penicillium chrysogenum* DSM1075 [which produces penicillin and secondary metabolites (Deacon, 2005)] and *Aspergillus flavus* DSM1959 [which produces secondary metabolites (Ariff *et al*., 1997)], showed growth in both synthetic whey media (SWM) (0.35% w/v WPI; 4.5% w/v lactose) and in waste whey (sourced from a local dairy processor) and were therefore selected for further study. Waste whey was found to support the production of higher levels of biomass than potato dextrose broth (PDB) (the recommended growth medium for both strains), whereas the SWM supported the production of lower levels of biomass of *P. chrysogenum* DSM1075 than PDB, but higher levels of biomass of *A. flavus* DSM1159 (Figure 2.3). In 2010, penicillins (both natural and semi-synthetic) accounted for around 20% of the total antibacterial sales worldwide ($8.7 billion) (Business Insights, 2011). PDB is a common microbiological growth medium that is made from potato infusion and dextrose (glucose). It is very widely used for the growth of fungi and was chosen for this study as it is the medium suggested by the DSMZ (Deutsche Sammlung von Mikroorganismen und Zellkulturen) for the growth for both *P. chrysogenum* DSM1075 and *A. flavus* DSM1959.

The whey was then supplemented with 3% yeast extract (YE) to ascertain whether or not this would further increase biomass levels compared with those in industrial fermentations.

Supplementation with 3% YE was found to increase biomass production by 351% for *P. chrysogenum* DSM1075 ($n=3$) compared with SWM alone, and by 165% compared with whey alone. For the whey waste, supplementation with 3% YE was found to increase biomass production by 226% for *A. flavus* DSM1959 and by 165% for *P. chrysogenum* DSM1075 ($n=3$ for both) when compared with whey alone. For comparison, Kluge *et al*. (1992) showed biomass levels of up to 40 ± 4 g/L for penicillin-producing *P. chrysogenum* after 170 hours (approximately 1 week) of growth at 25°C, while growth of *P. chrysogenum* DSM1075 in the SWM supplemented with 3% YE and whey supplemented

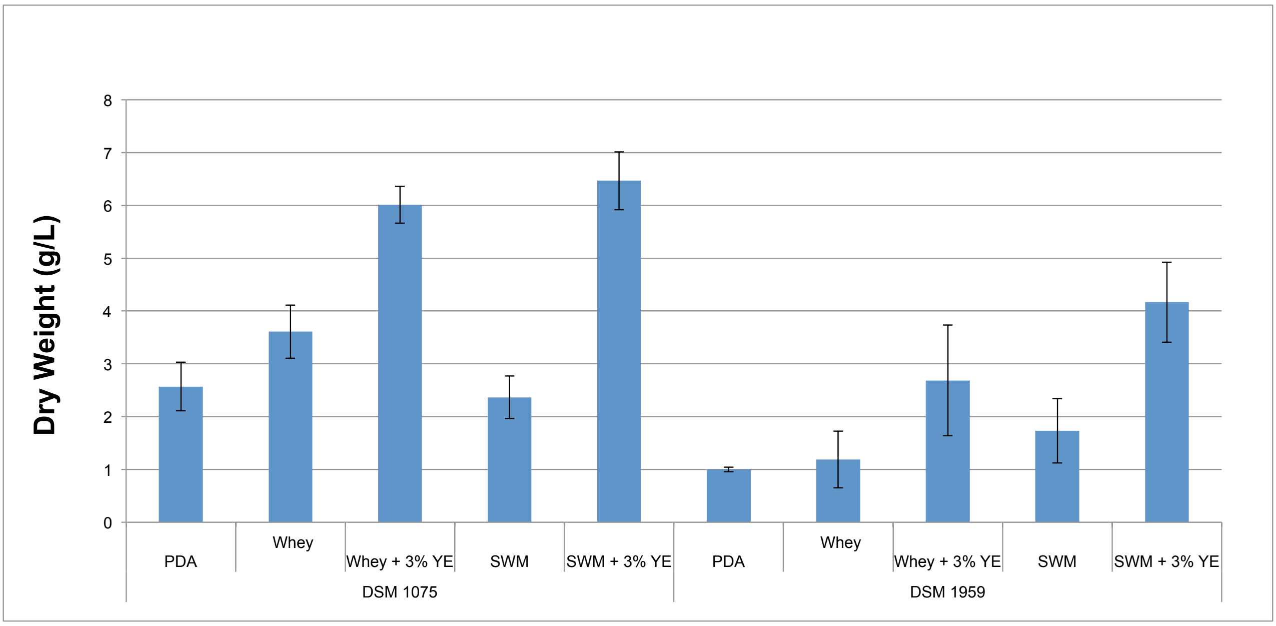

Figure 2.3. Microbial biomass of selected fungal strains in 100 mL of various growth media [mean values (n = 3) ± standard deviations (SDs) are shown]. PDA, potato dextrose agar.

with 3% YE gave biomass levels of 6.65 ± 0.56 g/L and 6.02 ± 0.35g/L, respectively, after 72 hours of growth.

Supplementation with 3% YE was found to increase biomass production by 226% for *A. flavus* DSM1959 when compared with whey alone (n = 3 for both). Ariff *et al*. (1992) showed biomass levels of 11.8 g/L for kojic acid-producing *A. flavus* after 200 hours (approximately 8 days) of growth at 30°C, while growth of *A. flavus* DSM1959 in the SWM supplemented with 3% YE and whey supplemented with 3% YE gave 4.17 ± 0.76 g/L and 2.69 ± 1.05 g/L, respectively, after 72 hours of growth.

YE is a complex hydrolysate of yeast. It provides nitrogenous compounds, carbon, sulfur, trace nutrients, vitamin B complex and other important growth factors, which are essential for the growth of diverse microorganisms. It was chosen for this study as it is widely available and has been used to supplement both solid state fermentations and submerged fermentations (Couto and Sanromán, 2006). The values achieved in the (preliminary) study were 5- to 10-fold lower than those achieved by Kluge *et al*. and Ariff *et al*.; however, the results of these published studies were achieved using media that had been specially adapted to the task and using longer fermentation times (5 days for *P. chrysogenum* and 6 days for *A. flavus*). Process optimisation would be expected to abrogate this difference. There is, therefore, potential scope for the limited application of whey for industrial fermentation. However, this would be subject to satisfactory process optimisation and economic analysis on an industrial scale.

2.5.2 *Whey as a medium for the growth of recombinant microorganisms*

A separate study was undertaken to ascertain if whey waste could potentially be used as a medium for the growth of recombinant microorganisms and therefore be of potential use in the genetic engineering-based biotechnology sector. *Escherichia coli* strain MC1061 was used as the model recombinant organism. This is a well-established recombinant expression system that has been used in many research laboratories around the world. The recombinant model *E. coli* strain was designed to express a test industrial enzyme (a cellulase from *Bacillus subtilis* was chosen for this purpose) to determine if a whey-based medium could be used to obtain recombinant enzyme levels comparable to that of media normally used in expression studies, such as Luria–Bertani (LB) broth. Cellulase was chosen as the test enzyme as the industrial-scale production of recombinant cellulases for the purposes of 2nd generation biofuel production is currently the subject of much research.

Preliminary studies were carried out to determine what growth conditions/media composition would give the best growth as ascertained by absorbance at 600 nm, plate counts of colony forming units (CFU)/mL and biomass yield. For these preliminary investigations, the model recombinant system (*E.coli* MC1061) without the plasmid expressing cellulase was used.

Growth in whole whey was poor, and a density of only 11×10^7 CFU/mL [optical density (OD) of 0.277 at 600 nm] was achieved after 24 hours [compared with 240×10^7 CFU/mL (OD of 2.199 at 600 nm) in the LB broth]. Because of these low levels of growth, it was decided that nutrient supplementation of the whey medium with YE was required. The addition of 3% YE to whey allowed high levels of growth after 24 hours, resulting in 165×10^7 CFU/mL (OD of 1.86 at 600 nm). However, it took 10 hours to reach an OD of 0.6, which is the OD at which the induction of expression [by the addition of IPTG (isopropyl β-D-1-thiogalactopyranoside)] of recombinant genes is generally performed in standard expression experiments. This compares unfavourably with LB broth, for which an OD of 0.6 was reached after 4 hours. This relative lag in growth would render whey-based media much less industrially attractive. The full results of these experiments are shown in Figure 2.4 and Table 2.3.

After these initial experiments, it was decided to supplement the treated whey with LB broth. This nutrient supplementation was carried out in order to achieve high levels of growth (as with the addition of YE) and to reduce the time taken to reach an OD of 0.6 to the target of 4 hours. A nutrient mix comprising 50% LB broth and 50% whey was tested first. This gave similar results to those obtained with 100% LB broth: 212×10^7 CFU/mL (OD of 2.1 at 600 nm) was achieved after 24 hours. An OD of 0.6 was reached after approximately 4 hours with both types of media. The growth curve profile was also similar for both media.

Testing was carried out on various mixes of LB- and whey-based media to determine if lower concentrations

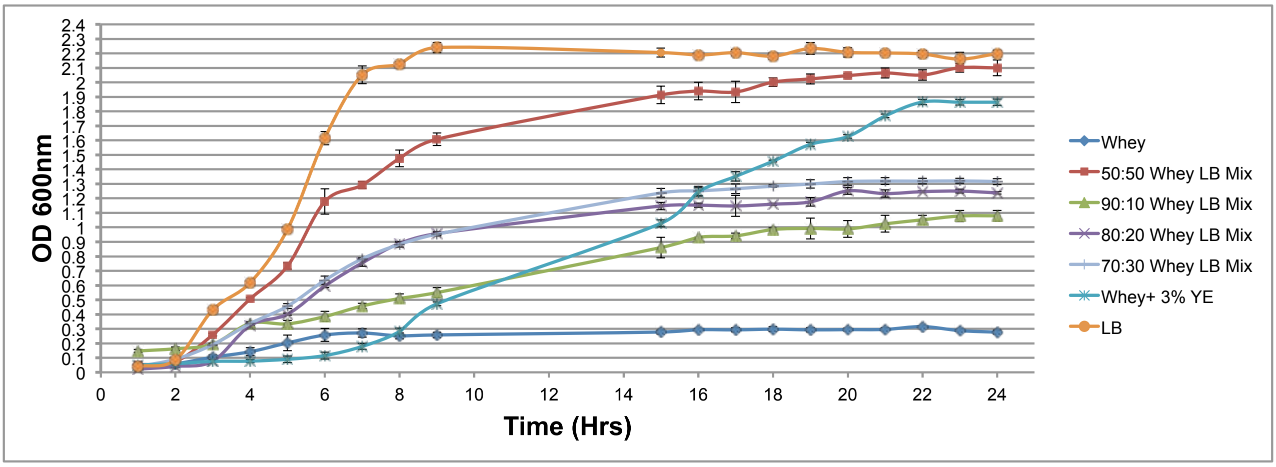

Figure 2.4. The OD of *E. coli* MC1061 in various whey/LB mixes [mean values (*n* = 3) ± SD].

Table 2.3. Growth of *E.coli* MC1061 in various different media

Media	No. of CFU/mL	Standard deviation	Dry weight biomass (mg/L)	Time to reach an OD of 0.6 (hours)
LB	240×10^7	10×10^7	319	4
50:50 (whey to LB)	212×10^7	14.7×10^7	283	4.2
70:30 (whey to LB)	195×10^7	18×10^7	233	6
80:20 (whey to LB)	137×10^7	25.4×10^7	221	6
90:10 (whey to LB)	100×10^7	7.1×10^7	198	10
Whey	11×10^7	4×10^7	47.3	N/A
Whey + 3% YE	165×10^7	15×10^7	243	10

N/A, not available.

of LB could be used to achieve similar results. The full results of these analyses are shown in Figure 2.4 and Table 2.3.

As shown in Table 2.3, media containing 20% LB and 80% whey, and 30% LB and 70% whey produced similar results: 195×10^7 CFU/mL (OD of 1.3 at 600 nm) and 137×10^7 CFU/mL (OD of 1.2 at 600 nm), respectively, were achieved after 24 hours. The time to reach an OD of 0.6 was approximately 6 hours for both (this compares favourably with the 4 hours it takes to reach an OD of 0.6 in LB broth). The biomass levels obtained using these mixtures were also more than two-thirds of the biomass levels obtained with LB broth.

These results for the 80:20 and 70:30 mixes merited further study, because they gave the best results overall [in terms of growth levels (CFU/mL and biomass) and time to reach an OD of 0.6] for the least amount of nutrient supplementation.

The model system was then used to ascertain if the levels of expression and activity of a recombinant protein achieved using only LB broth could also be achieved using the chosen whey-based medium. The 80:20 whey to LB mix was chosen as it gave the best all round results (in terms of growth levels and time to reach an OD of 0.6) for the least amount of supplementation. An endoglucanase (a cellulase) was chosen as the model product because these enzymes are well studied and are becoming commercially important in the context of 2nd generation biofuel production. The market for cellulases was US$155.8 million in 2011 and is expected to grow rapidly in the future because the goal of the US Department of Energy is to produce 170 billion litres of ethanol from cellulose per annum starting in 2030. The projected yearly cellulase market is expected to be approximately US$9 billion (BCC Market Research, 2013; Zhang and Zhang, 2013). This demonstrates that it is an area with huge potential for growth.

The BSCel cellulase was chosen for the study as it has previously been shown to have high levels of activity at relatively high temperatures (> 50°C), the temperature at which the industrial processes necessary to create ethanol would take place at (Santos *et al*., 2012).

A model system was created using the genes encoding BSCel from *B. subtilis* DSM402 and BSFUL2. The amplification of the predicted 1450-bp DNA fragment housing the endoglucanase gene from the selected *B. subtilis* genomic DNA was successfully achieved using polymerase chain reaction (PCR); the PCR product was inserted into an expression plasmid (pProEx-Htb); and subsequent protein expression was successfully achieved. Expression studies in a standard LB medium were used to maximise the production of soluble endoglucanase gene product, while also minimising non-soluble recombinant protein inclusion bodies. The optimal conditions were determined to be an expression temperature of 37°C for 4 hours and an IPTG concentration of 100 µM. The production of recombinant protein was determined by activity assays for the desired enzyme. Negative controls were carried out (using *E. coli* MC1061 containing pProEx-HTb with no insert) and showed no activity (Figure 2.5).

The conditions stated above were replicated using the 80:20 whey to LB mix, an 80:20 water to LB mix, to act as a control (to ensure that the presence of the whey was having an effect on expression levels), and an 80:20 whey to LB mix in which no IPTG was added, in order to control for the effects of the ITPG.

The overall results of these experiments are encouraging: the activity of the enzyme obtained using the 80:20 whey to LB mix was 66.2% and 73.8% of the activity levels obtained using the BSFUL2 and DSM402 constructs, respectively, in LB alone. The 80:20 water to LB mix yielded activity levels of 27.6% and 33.8% (i.e. half of the expression levels obtained using the whey to LB mix) with the BSFUL2 and DSM402 constructs, respectively. This indicates that the whey in the media affected the expression levels of the enzyme.

An experiment was also undertaken to determine the effects of having no ITPG in the 80:20 whey to LB mix. This was possible as the pProEx-HTb plasmid has a *lac* promoter (a promoter that is "turned on" by exposure to lactose) and lactose is present in the whey/LB mix. These results were also positive as the activity of the enzyme in the 80:20 whey to LB mix with no ITPG resulted in 58.6% and 64.6% of the activity levels obtained from the expression of the BSFUL2 and DSM402 constructs, respectively, in LB. This result is significant as ITPG can be toxic to bacterial cells at high concentrations and is expensive (Donovan *et al*., 1996).

These results show that it is technically feasible to produce a recombinant protein in a largely whey-based medium, although the practicalities of using whole whey in an industrial setting will be difficult to overcome. Growth media must be sterile to prevent contamination;

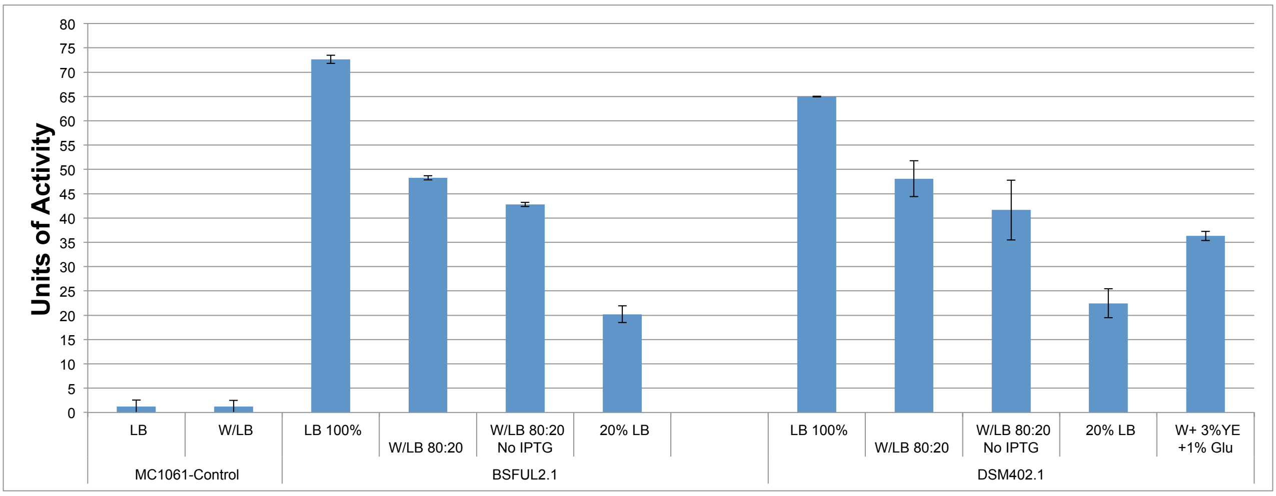

Figure 2.5. Units of activity of recombinant cellulase expressed using various media [mean values ($n = 3$) ± SD; units are μmol/minute/mL]. W, whey.

however, autoclave sterilisation of whey leads to the precipitation of the protein portion of the whey. In an industrial setting, time may not be available to filter out the denatured protein. Filtering with 0.22-μm sterilising filters may be possible in an industrial setting; however, this is expensive and companies prefer to use media that can be autoclaved. A possibility for overcoming this problem is through the use of whey permeate, which already has the protein portion of the whey removed meaning that autoclaving would be much easier. Further refinement of both the make-up of the media and the conditions of expression are required, but these results show promise. It should, however, be stated that while these laboratory-scale studies are a useful indicator of potential suitability, pilot- and industrial-scale studies are necessary to confirm actual industrial suitability as well as economic feasibility.

3 Project Conclusions and Recommendations

3.1 Project Conclusions

The Irish government's Food Harvest 2020 strategy projects a 50% increase in milk production by 2020. The focus of the initial research undertaken in this study was to ascertain the amounts and profiles of the types of waste currently generated by the 22 major Irish dairy processing facilities, in order to facilitate projections for 2020, and also to look at the potential of using waste whey as a nutrient source for the growth of industrially relevant microorganisms. Methods for water saving were also considered, in line with Food Wise 2025.

3.1.1 Dairy wastewater in Ireland

Standard indicators of wastewater polluting potential include BOD, COD, suspended solids, and nitrogen and phosphorus outputs The main liquid waste types (e.g. product residue and waste from CIP) and the quantities of their key pollution indicators (BOD, COD, suspended solids, total nitrogen, total phosphate, and total oils, fats and greases) currently generated by the processing of milk and other dairy products by the major Irish dairy processing facilities were identified by using the Annual Environmental Reports or the Annual Environmental Return Workbooks available on the EPA website. The output values show fluctuations from year to year, as expected because of the differences in the amount of milk produced (mainly as a result of weather conditions) and therefore the amount processed. Differences between plants are due to the differing amounts of milk processed and the different products manufactured at each plant.

A second key focus of initial research activity was the design, and distribution to dairy processing facilities, of a survey seeking to identify, in more detail, the processing activities and consequent waste streams generated, both currently (for the purposes of this project, current is treated as 2008–2013) and projected for 2020. The low response rate (four companies), despite follow-up contact via email and/or by phone, as well as the incomplete nature of the data returned do not provide a sufficiently comprehensive dataset from which firm conclusions can be drawn. However, the processors who did reply believe that the 50% increase in milk production projected by Food Harvest 2020 will not lead to an equivalent increase in their intake or processing activity, with industry estimates of the increase in intake and processing activity ranging from 25% to 40%. However, even so, the significant increases in processing activity that will occur will necessitate the review of pollution outputs in dairy companies' IELs and IED/IPC Licences.

3.1.2 Dairy wastewater treatment in Ireland

The wastewater treatment systems currently used in the context of Irish dairy processing were profiled. The majority (77%) of processing facilities rely upon aerobic wastewater treatment processes and utilise secondary treatment techniques, such as bio-towers and activated sludge aeration, to treat wastewater. Few facilities (14%) use technologies such as MBRs or anaerobic treatment systems, and waste sludge derived from the treatment process (the greater reuse of whey would not lead to lower levels of sludge) is currently disposed of by land spreading (63%), composting (13.6%) or by contractors licensed to dispose of sludge (22.7%). The most common form of tertiary treatment consists of chemical phosphorus removal (68% of plants) followed by constructed wetlands (9%). Overall, therefore, the majority of dairy processing sites rely upon standard wastewater treatment approaches.

3.1.3 Potential future dairy wastewater treatment technologies

In line with the principle of sustainable intensification enunciated in Food Wise 2025, potential future dairy wastewater treatment technologies were identified. These include An-MBR technology, MFC technology, hydrogen generation and recovery (through the breakdown of waste) technology, and phosphorus recovery technology. These technologies strive to be more efficient in their use of water, electricity and chemicals, and to have outputs (e.g. electricity, biogas, phosphorus for fertilisers) that could help reduce the costs associated with operating treatment plants. While some of these technologies have reached at least pilot-scale assessment (e.g. An-MBR technology), several remain at an

earlier stage of development (e.g. an electrochemical water treatment system with hydrogen recovery and electricity production). Therefore, the extent to which these technologies will have an impact on a larger scale (i.e. be used in actual dairy processing plants), internationally and nationally, remains to be seen.

3.1.4 Waste whey in microbial growth media

Traditional studies

The ability of a range of traditional (non-genetically engineered) microorganisms of industrial value to grow on whey was assessed, in order to ascertain if excess whey (a by-product of cheese manufacture of high polluting potential) could be of potential use within the industrial fermentation sector. Only 2 of the 17 microorganisms tested, the fungi *P. chrysogenum* DSM1075 and *A. flavus* DSM1959, grew on whey to an appreciable extent. Strains of both of these fungi are used to produce penicillins (antibiotics) and kojic acid (used in cosmetics). In these two cases, preliminary growth optimisation studies further increased microbial yield two- to three-fold. It is likely that a further 5- to 10-fold yield increase would be required to achieve current industrial norms, although such further increases would not be beyond typical, detailed process optimisation studies.

Recombinant studies

Many modern industrial bioprocesses are based upon the growth of genetically engineered (recombinant) microorganisms. Genetically modified strains of *E. coli* are used to produce 70 biopharmaceutical products (pharmaceutical drugs), equating to sales worth in excess of US$40 billion per annum. A genetically engineered bacteria strain was generated in the laboratory as a model organism to assess whether or not such organisms could be grown in waste whey. The model was *E. coli* into which a gene coding for a cellulase enzyme (of potential use for biofuel production) was inserted. The model *E. coli* grew well on nutrient-supplemented whey and supported the production of cellulase levels corresponding to 70% of those achieved when a control "gold standard" medium was used.

Overall, therefore, whey-based fermentation media do show promise for the growth of some microorganisms (i.e. the fungi *P. chrysogenum* DSM1075 and *A. flavus* DSM1959, which are used to produce penicillins and kojic acid, respectively, and recombinant *E. coli*, which can be used to produce a wide range of medically and industrially useful proteins) that are used for industrial biotechnology purposes. An appraisal of actual industrial potential would require further growth optimisation studies and comparative economic analyses.

3.1.5 Water savings in the dairy processing industry

Based on feedback from industry and the international literature, it was established that the minimisation of water usage is a core focus within the dairy processing sector, and is very much linked to waste stream generation and composition. Although not one of the original project aims, in line with the importance it assumes in Food Wise 2025, it was considered appropriate to incorporate the consideration of international approaches to water conservation as a supplementary project work package.

A consequent investigation of the international literature indicated the potential for significant water savings, generally via straightforward, low-technology practical steps, including the development of a detailed water usage model, CIP water reuse and leak detection testing. These strategies have been profiled in the report. The majority, if not all, are applicable to an Irish setting, and it is likely that some are already pursued in at least some Irish processing plants.

3.2 Project Recommendations

- Wastewater technologies identified as being in current development should be re-profiled in a few years with a view to identifying those successfully introduced at process scale in any world region.
- Further growth optimisation studies and associated comparative economic analyses should be undertaken for the microorganisms of industrial relevance that this project found to be capable of growing on whey-based media.

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Abbreviations

AMBR	Anaerobic migrating blanket reactor
An-MBR	Anaerobic membrane bioreactor
BAT	Best Available Techniques
BOD	Biological oxygen demand
CFU	Colony-forming units
CIP	Cleaning in place
COD	Chemical oxygen demand
DAF	Dissolved air floatation
DAFM	Department of Agriculture, Food and the Marine
EPA	Environmental Protection Agency
IED	Industrial Emissions Directive
IEL	Industrial Emission Licence
IPC	Integrated Pollution Control
IPTG	isopropyl β-D-1-thiogalactopyranoside
LB	Luria–Bertani
MAP	Magnesium ammonium phosphate
MBR	Membrane bioreactor
MFC	Microbial fuel cell
OD	Optical density
PDB	Potato dextrose broth
REPHATER	Electrochemical water treatment pilot plant in the dairy industry with phosphate recovery
REWAGEN	Electrochemical water treatment system in the dairy industry with hydrogen recovery and electricity production
RO	Reverse osmosis
SBR	Sequencing batch reactor
SD	Standard deviation
S.I.	Statutory Instrument
SWM	Synthetic whey media
WPC	Whey protein concentrate
WPI	Whey protein isolate
YE	Yeast extract

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL

Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú

Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:

- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha);*
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce

- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol

- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn

- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil

- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta

- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas

- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol (*m.sh. Timpeall an Tí, léarscáileanna radóin).*
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta

- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:

- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- An Oifig um Cosaint Raideolaíoch
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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The Characterisation of Dairy Waste and the Potential of Whey for Industrial Fermentation

Michael P. Ryan and Gary Walsh

Identifying Pressures/ Informing Policy

The Irish government is pursuing a policy of increasing both primary agricultural output and the agri-food sector in Ireland. To this end, two key strategic documents have been developed over the past number of years; Food Harvest 2020 and Food Wise 2025.

Food Harvest 2020 projects for a 50% increase in milk production using the average output of the years 2007 to 2009 as a baseline. This will equate to an approximate 2. 75 billion litre increase in production and will raise the primary output value of the sector by about €700 million annually.

Foodwise 2025 envisages increasing dairy production/processing activity as a core driver towards achieving an 85% increase in agri-food industry export value by 2025, and explicitly recognizes that increases in food production/processing systems must be as focused upon sustainability and environmental protection as it is upon increasing production. An increase in primary produc-tion will inevitably lead to increases in processing waste generated. Foodwise 2025 also recognizes that increased processing activity renders desirable further efficiencies in process water usage. Upscale in the manufacture of certain types of products, primarily casein powders and cheese, will lead to an increase in the amount of whey waste being produced, which is potentially of significant environmental concern.

The research informs current policies such as Harvest 2020 and Foodwise 2025, and noted that Irish Dairy processers also expect that as milk production and processing increases, reviews of the pollution outputs in their IPC licenses will become necessary.

Developing Solutions

The research identified several water saving measures that could be utilised in an Irish dairy processing setting. The research team noted that the majority of waste/wastewater treatment technologies currently used in the Irish dairy processing are traditional technologies and identified future treatment technologies that have potential for use in the Irish dairy processing industry.

One potential option for the management of whey, a key waste arising from diary production, was the growth of fungal strains in whey-based media which could have industrial potential.

The project found that an adapted whey media could to be used to grow recombinant *Escherichia coli*, which is used to produce various protein products in the biotechnology sector.

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