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MOVING TOWARDS A ZERO ENVIRONMENTAL FOOTPRINT DAIRY PLANT

Katrina Bukauskas (Jacobs), Richard Greenwood (Jacobs), John Poon (Jacobs)

ABSTRACT

This paper sets out a vision for a fully integrated and systems approach to the recovery of water, nutrients, carbon, energy and waste streams within the footprint of a dairy plant. The Zero Environmental Footprint Plant (ZEFP) moves beyond the Zero Liquid Discharge (ZLD) model to one of resource recovery and closing the resources loops.

A ZEFP has minimal to zero measurable air, liquid and solid emissions into the environment by optimising the recovery and reuse of solids and liquids and use of renewable energy to reduce carbon emissions. In doing this, water and energy imported from sources outside the plant are minimal or avoided. Within a ZEFP model all waste streams are considered resources that can be recovered and reused within the dairy plant or by external stakeholders, with minimal to zero environmental consequences.

The concept for ZEFP incorporates:

- Biogas and co-generation of electricity
- Use of renewable energy
- Carbon neutrality
- Zero liquid discharge treatment of water and recovery of salts
- Biosolids and nutrient recovery to produce a fertiliser or soil improver product
- Minimal to zero production of intractable residuals

The benefits of a ZEFP are long-term reductions in water extraction, potential cost savings in energy use and waste disposal, regulatory compliance with more stringent environmental consent limits and recovery of resources such as nutrients, carbon and water. Other benefits include meeting increasing customer desire to minimise carbon emissions and the environmental impacts of the products they use.

A Zero Environmental Footprint Plant is a paradigm shift in how resources are viewed and used within the industrial food manufacturing setting. By applying available, proven technologies with a systems approach to optimise resource recovery, it eliminates or significantly minimises discharges and emissions to the environment and reduces the importation of energy and water.

This paper will outline case studies to demonstrate the technologies and systems available which can be used to achieve a Zero Environmental Footprint Plant. A current and future scenario is presented demonstrating the changes in processing required to achieve this paradigm shift.

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KEYWORDS

Wastewater, Energy, Footprint, Closed Loop, Dairy, Circular Economy

PRESENTER PROFILE

Katrina Bukauskas is a civil and environmental engineer with 10 years' experience having worked in multiple industries including industry, not-for-profit, government and consulting in Australia, Cambodia and New Zealand. Katrina is passionate about drinking water quality and minimising environmental and health impacts of water and wastewater.

1 INTRODUCTION

1.1 APPROACH

This paper sets out a vision for a fully integrated and systems approach to the recovery of water, nutrients, energy and waste streams within the footprint of a dairy plant. The Zero Environmental Footprint Plant (ZEFP) moves beyond the Zero Liquid Discharge (ZLD) model to one of resource recovery and closing resource loops. There are now many proven technology applications within the industrial manufacturing, wastewater, desalination, reuse and water treatment and energy sectors that have been developed to address isolated issues in food, water and wastewater processing. The challenge comes with combining multiple technologies together, investing in unconventional approaches and access to capital in an often-capital constrained industry with tight margins and cyclical returns.

For each of the components of a dairy plant (e.g. liquid, solid and energy streams) a review of available technologies will be presented, with the culmination being an integrated process which brings together the inputs and outputs to demonstrate that a Zero Environmental Footprint Plant for dairy industry is in fact a possibility.

1.2 NEW ZEALAND DAIRY INDUSTRY

New Zealand is fortunate to have access to plenty of freshwater and land suitable for dairy production. However, there are increasing environmental and consumer pressures on the dairy industry, including but not limited to some key examples:

- Contamination of drinking water with nitrates
- Over abstraction of groundwater and surface water for processing of dairy products
- Increasing levels of nutrients in waterways
- High energy consumption and carbon emissions for wastewater processing
- High carbon emissions for milk processing and carbon emissions from transporting goods to market
- Low levels of resource recovery and water recycling

Another key issue is the biogenic methane emissions produced from the farming sector, which includes New Zealand's large dairy cattle population. This is of key concern to the Country but is outside the scope of this paper.

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The dairy industry contributes up to one third of New Zealand's export goods, valued at approximately NZ$16.7 billion (US$11.87billion) in 2018 (Dairy Companies Association of NZ, 2018). As a significant industry in New Zealand there is an opportunity to invest in long term sustainable outcomes to both benefit New Zealand economically, whilst ensuring the environmental externalities from dairy production are managed.

The supply chain associated with dairy production has numerous components, including farmgate, transport, processing and export. The supply chain has significant issues with carbon emissions and dependence on imported diesel fuels. However, the focus of this paper is on the production and processing that occur at a dairy processing plant which typically produce commodity products such as milk powder, cheese and cream.

1.3 EMISSIONS TARGETS AND FRESHWATER POLICY

The New Zealand government has established a number of important pieces of legislation and policy statements to guide future decision making and spending for emissions reduction and environmental protection.

New Zealand is serious about climate change, with the introduction of the Climate Change Response (Zero Carbon) Amendment Bill, currently before the Environment Select Committee (as of July 2019). This amendment bill provides a framework by which New Zealand can develop and implement clear and stable climate change policies (MFE 2019). The amendment bill has a major goal of reducing all greenhouse gases (except biogenic methane) to net zero by 2050, with biogenic methane reduced within the range of 24-47% below 2017 levels by 2050 (MFE 2019).

The Freshwater National Policy Statement (NPS) (2014) directs regional councils, in consultation with their communities, to set objectives for the state of fresh water bodies in their regions and to set limits on resource use to meet these objectives. An important component of the NPS for industrial manufacturing and wastewater treatment, is the requirement for limit setting on resource use (e.g. how much water can be taken or how much of a contaminant can be discharged) to meet limits over time and ensure they continue to be met (MFE 2018).

1.4 CIRCULAR ECONOMY

A paradigm shift in industrial manufacturing is required to enable businesses to continue to operate in a world with finite resources and limited access to natural resources and remain economically viable. There are many arguments for a shift from a linear to a circular economy to maximise the use of these finite resources and to encourage greater intergenerational equity in the sustainable management of natural assets.

The circular economy requires a different approach to production methods. This means moving from a linear economy that sees the increasing use of raw materials and the generation of waste that is discharged to the receiving environment to a circular economy that is based on regeneration, and the transformation of waste products into a resource, and use of renewable energy (Fernando et al, 2018). The circular economy is based on three principles (MFE 2018):

- Design out waste and pollution
- Keep products and materials in use
- Regenerate natural systems

The comparison between linear and circular economy is shown in Figure 1 (MFE 2018).

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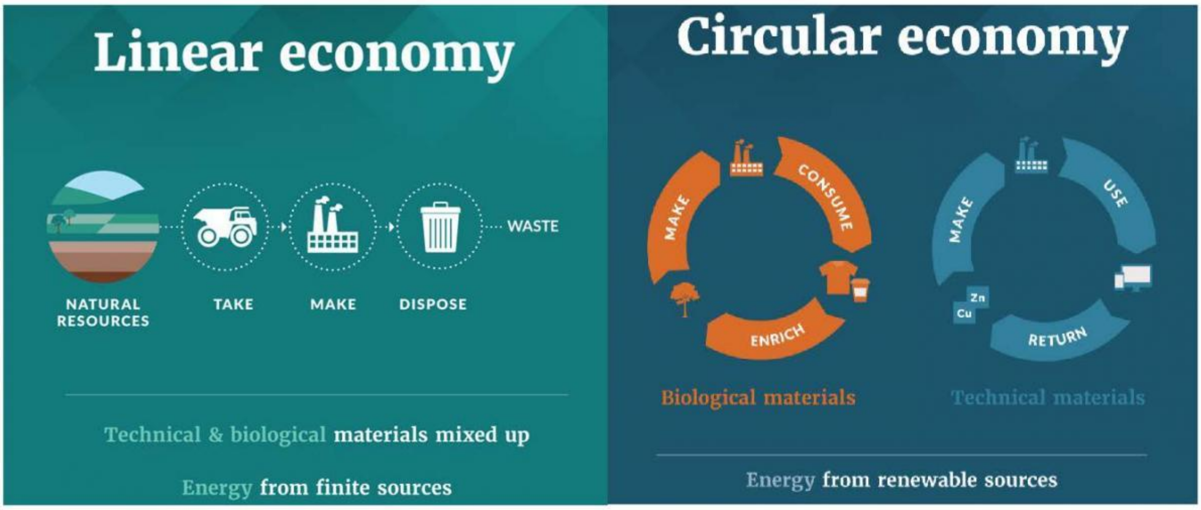

Figure 1: Linear Economy versus Circular Economy (MFE 2018)

The circular economy concept builds further on similar principles of:

- Sustainable development
- Minimisation of public and environmental externalities
- Integrated water management
- Food-energy-water nexus

The food-energy-water nexus is an important concept to evaluate in this circumstance, given the production of dairy food products and the use of energy and water in their production. Figure 2, illustrates some examples of the interconnection between food, energy and water, demonstrating that they cannot be considered in isolation.

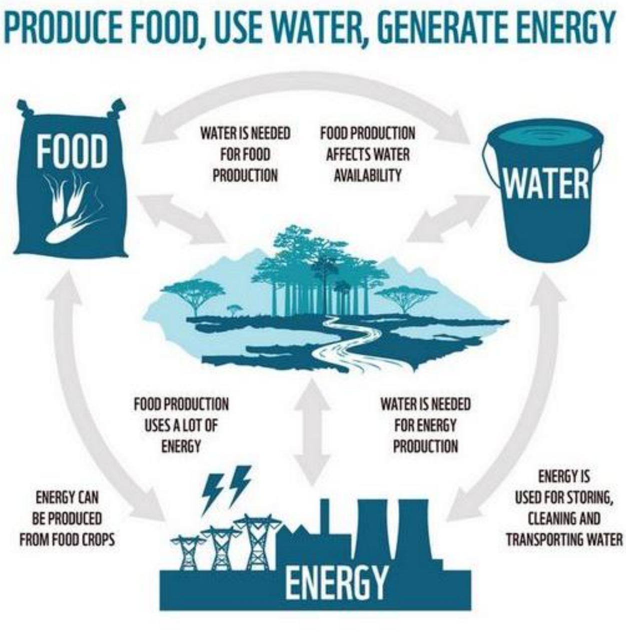

Figure 2: Infographic – Food-Water-Energy Nexus, (Water Footprint 2011)

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2 CURRENT DAIRY PLANT

2.1 MILK PROCESSING

A milk processing and powder production plant typically consists of the following:

1. Inputs of imported energy and water

2. Milk treatment, separation and standardisation

3. Powder evaporation and dryer, and usually accompanied with additional production of cream, anhydrous milk fat (AMF), casein, cheese products, protein concentrates and other commodity products

4. Process heat and electricity consumption and generation

5. Wastewater treatment plant

6. Environmental discharge of carbon, biosolids and wastewater emissions.

Each of these components of the plant, have an inter-relationship with energy, water and liquids that are brought into and processed within the plant, and result in a series of products for sale, or by-products from the process.

Based on current best practice dairy plant design, a typical input and output diagram has been prepared, shown in Figure 3.

2.2 LIQUID STREAMS

A typical dairy plant has several liquid streams (refer to Table 1), with certain characteristics that impact how the stream is treated or potentially reused elsewhere within the process.

Table 1: Liquid Streams for a Dairy Processing Plant

Stream	Characteristics
Groundwater (and surface water)	Clean, potential turbidity and nitrates
Roof water and stormwater	Clean water with some potential contamination
Clean in Place (CIP) Water	Variable Chemical Oxygen Demand (COD), high salt (first flush CIP very high COD, last rinse very low) *(Slavov, 2017)*
Cow water	Minimal COD, salts, but has light "odour" *(Slavov, 2017)*

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Diary plant wastewater is predominately made up from condensate (cow water), Clean in Place (CIP) water, tanker wash water, and other sources of wastewater such as spills and washdowns. It is important to note this stream does not include human (treated through municipal or on-site sewerage systems) or animal wastewater (treated at farmgate).

Dairy plant wastewater has a number of characteristics that require careful management, including influent pH swings of 2-13, high fat loads and variable incoming organic and nutrient loads (Daly and Beuger 2016). These variations in pH are largely due to cycles of CIP water, cycling between acidic and basic solutions to clean production equipment. Variations occur both on a seasonal and daily basis.

Conventional wastewater treatment in a dairy process, is typically by a biological activated sludge system (Daly and Berger, 2016), whereby dissolved air floatation (DAF) is used for fats, oils and grease (FOG) removal and aerated lagoons for organic carbon and nutrient treatment (Daly and Beuger 2016). Lagoons are aerated via electrically powered surface aerators with activated sludge recirculation. The resulting clean effluent stream is applied to land or discharged to the environment. Dairy plant wastewater has high levels of phosphorous via calcium phosphate present in milk and sodium present in large quantities due to caustic cleaners. Nitrogen in wastewater comes mainly in amino groups from milk proteins, urea and uric acids, (Slavov 2017) but also if nitric acid is used in CIP.

Current dairy wastewater effluent disposal to land is hampered by a few factors, including carrying capacity of the soil and vegetation to take up water (especially an issue in high rainfall seasons) and nutrients. This nutrient carrying capacity results in runoff of nitrogen and phosphorus into groundwater and surface water (Brown 2018).

In the current system, the recovery of the condensate stream (Cow water) offers a significant source of water for reuse within the plant. However, a large portion of water (up to 85%) within the milk processing site consists of high-organic strength CIP water, and retentate from the Reverse Osmosis (RO) treatment systems. This supply is not recovered and is simply treated in a conventional dairy wastewater treatment plant. This requires large amounts of aeration air and electrical power to sustain the biological systems and reduce the organic loads before later being discharged to land for farm irrigation. In these circumstances most of the recoverable energy, carbon, nutrients and salt are lost to the environment in the form of water, biosolids and carbon emissions.

Over time dairy factories have employed various technologies to improve water and energy efficiency and reduce their overall environmental footprint. Some of these include:

- Recycling of condensate (Cow water)
- Application of wastewater biosolids to land
- Recovery of waste heat for energy
- Physical and biological treatment of wastewater prior to disposal to waterways or land

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2.3 SOLID STREAMS

In a typical dairy plant, biosolids in the form of waste activated sludge are typically disposed of to land as an output of the wastewater treatment process. Careful control of the cycling is required to achieve optimal nitrogen removal and to prevent performance issues such as odour and poor settling sludge (Daly and Beuger 2016). The dairy industry typically markets this stream as a beneficial by-product which can be used by farms as a fertiliser product.

2.4 ENERGY

Dairy plants require a significant amount of heat generated from boilers to power the evaporation and drying processes. For example, at Edendale, one of the larger dairy factories in New Zealand there is 127 MW of installed heat generation equipment supplied by four (4) boilers ranging from 32-38MW capacity (Bioenergy 2011). The boilers generate steam for processing to turn fresh milk, into milk powder, and other products, largely for the export market. These boilers are fuelled by lignite (brown coal), which has a low heat content and high greenhouse gas production (MFE 2010).

A typical milk drying plant uses energy for the following activities:

- Process heat, in form of steam fired turbines and hot water for milk processing
- Refrigeration/chilling
- Electrical load for operations
- Wastewater treatment plant aeration and pumping

CURRENT DAIRY PLANT

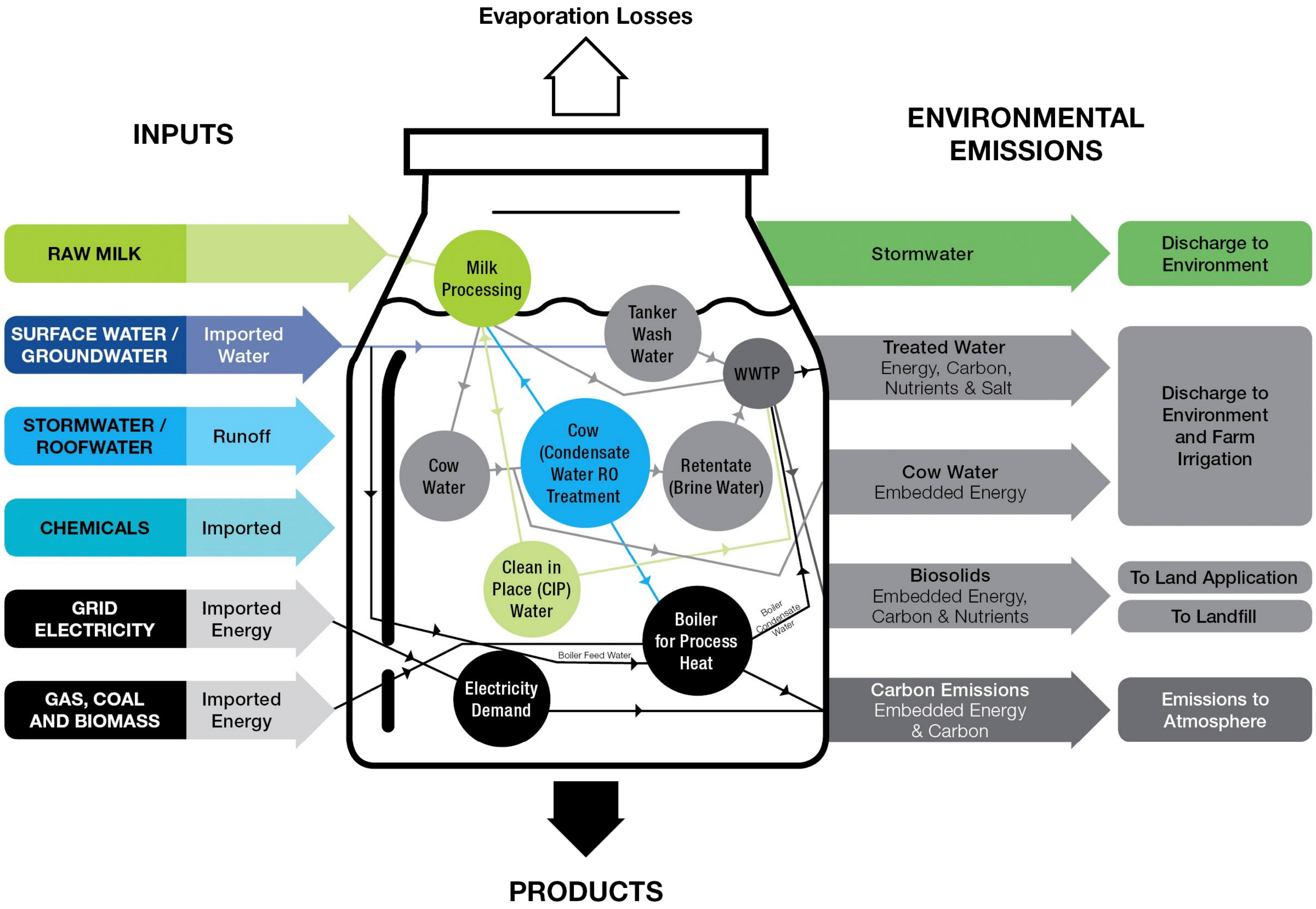

Figure 3: Current Milk Processing Plant, Input-Output Flow Diagram

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3 AVAILABLE TECHNOLOGIES

This section of the paper outlines the liquid, solid and energy streams of the plant, and provides case studies or reference technologies for incorporation into the Zero Environmental Footprint Plant.

3.1 LIQUID STREAMS

As outlined in Section 2, there are multiple liquid streams and uses, with their own unique properties within a dairy plant. Two technology groupings are proposed for incorporating into a ZEFP, these include:

- Zero Liquid Discharge (ZLD) technology to treat and recover all water streams
- Membrane Aerated Bioreactors to treat wastewater and reduce nutrient levels in resulting wastewater streams processed in the ZLD.

3.1.1 ZERO LIQUID DISCHARGE

Employing Zero Liquid Discharge (ZLD) technology within the dairy plant will provide a way to dramatically reduce water consumption. ZLD is the collective term for a wastewater treatment management system that ensures there will be no discharge of industrial wastewater to the environment (Mutha 2017). Creating zero discharge solutions can be accomplished by concentrating the effluent using various techniques and recovery and recycling of water (Rande, & Bhandari 2014). Different methods can be employed including thermal process (evaporation), reverse osmosis (membrane technology), electrodialysis, forward osmosis and membrane distillation (Mutha 2017). A ZLD treatment process train is made up of the following components (Mutha 2017):

- Pre-treatment (physicochemical and biological)
- Reverse Osmosis and/or ultrafiltration (membrane processes)
- Evaporator and crystalliser (thermal processes)

Recycling condensate from cow water using a reverse osmosis plant for reuse for non-product contact operations, such as cleaning and boiler feedwater is now becoming commonplace. The next step is to use a wider range of water streams, and to utilise recycled water in product contact operations to enable a full cycle system to minimise the use of ground or surface waters as a constant feed into the process (GEA 2016).

"The technology to reprocess water, not just for reuse in the plant but for use in product-contact operations, is here. Dairy plants that use no water at all are fast becoming the norm" (GEA 2016).

To enable product-contact requires further treatment processes to be applied, including (GEA 2016):

- Odour removal through carbon treatment
- Disinfection by ultraviolet light and chlorination.
- Mineral dosing to soften water and meet pH requirements

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Zero Liquid Discharge food factories are becoming more common place worldwide, demonstrating that these technologies have been implemented and functioning in the food manufacturing sector. Alfa Laval, Grundfos, Suez and Veolia among other technology suppliers provide solutions for ZLD factories. It is important to note the majority of these are still only using water for non-product contact, largely due to food safety regulations, rather than technology constraints.

The following ZLD examples should be considered:

- Nestle Milk Bottling Factory (California) (Nestle 2015)
- Givaudan Flavours Manufacturing Site (Pune, India) (Givaudan 2018)
- Nestle Milk Factory (Mexico) (Dairy Reporter 2017)
- Arla Food Products - Rødkærsbro Dairy (Denmark) (Global Water Awards 2018)

3.1.2 MEMBRANE AERATED BIOREACTOR

A membrane aerated bioreactor (MABR) process applies a gas permeable membrane to deliver oxygen to a biofilm that is attached to the surface of the membrane media. Experience has shown that high diffusivity of ammonia into a biofilm and availability of dissolved oxygen (DO) results in preferential growth of nitrifiers versus heterotrophs in a counter-diffusional biofilm on the surface of the media, even in high BOD loads (Houweling, et al. 2017).

One of the advantages of this technology is that biofilm is formed on the membrane itself, and the oxygen goes straight into the biomass. Therefore, the usual mass transfer limitation which limits the standard oxygen transfer efficiency to 10% to 40% in conventional fine bubble diffuser aeration, no longer occurs (Houweling et al. 2017).

Membrane aerated bioreactors can also be fed with pure oxygen, a by-product of hydrogen production (refer to Section 3.3.3), which could be used to enhance the efficiency of the aerobic treatment systems within wastewater treatment plants, a process which currently only uses air. This increased efficiency would reduce capital and operating costs of tanks, pumps, and aerators while decreasing the energy required to operate. Any unused oxygen could be used in ozone generation required in advanced water treatment within the Zero Liquid Discharge Plant (Jacobs 2019).

In industrial applications MABR has advantages of strengthening the simultaneous removal of organic nitrogen in wastewater due to unique biofilm structure and mass transfer, leading to its extensive applications in wastewater treatment (Jinpen, Hailon, Baoan 2019).

3.2 SOLID STREAMS

The solid streams of a dairy plant include salts from the brine stream associated with cow water condensate, biosolids from wastewater and the product stream (milk products).

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3.2.1 BRINE SALTS

Brine solution comes from two streams, (i) retentate, a reverse osmosis by-product from processing of cow water condensate and (ii) CIP water due to use of chemicals including nitric acid, sulphuric and sodium hydroxide.

One of the key components of the zero liquid discharge system is the concentration of brine, normally achieved with membrane brine concentrators of electrodialysis, producing a concentrated stream. The next step being evaporation/crystallisation, using thermal processes or evaporation removing impurities until a solid is produced (Lenntech, nd). Brine electrolysis can be used to process brine for use in softening by returning a side-stream back into the brine tank during resin regeneration to support improved efficiency of softening within the reverse osmosis process (WPC 2015). Precipitative softening increases the recovery rate for the RO process by precipitation and removal of sparingly soluble inorganic slats (Cotruvo 2018).

The ability to use brine recovery technology (WPC 2015) to improve the operational efficiency of the Reverse Osmosis (RO) systems and to recover greater volumes of low-salt water for boiler feed, Clean-in-Place (CIP) processes and potable water uses. Salt would also be recovered for third party use with residual solids discharge to landfill as a final option. Brine streams can also be discharge to land, if they have relatively low total dissolved solids and free of heavy metals.

Salts typically difficult to recycle or reuse at this stage and these would be disposed of to landfill, unless another more beneficial use can be found.

3.2.2 CO-GENERATION OF SLUDGE / BIOSOLIDS

Biosolids produced from the wastewater plant could be used to supply a waste-to-energy plant, reducing the imported energy required from the grid, whilst returning energy back into the plant through hydrogen production or gas-fired boiler operation. A waste-to-energy plant involves composting and co-digestion of organic material (such as food waste) with wastewater. This is typically practiced in the municipal setting (e.g. Yarra Valley Water, Waste-To-Energy plant, built in May 2017) and is becoming a more common occurrence (Jacobs 2019).

Furthermore, work is currently being carried out in co-digestion of dairy biosolids with municipal biosolids in municipal wastewater treatment plants. The co-digestion of these biosolids improves anaerobic digestion by producing more biogas for electricity generation, produces a better biosolids end-product for reuse as fertiliser products and assists with overall carbon reduction (Parry, 2019). The remaining biosolids can be used to produce a fertiliser or soil improver product.

Onsite anaerobic digestion to produce methane gas at a dairy wastewater treatment plant is a little more challenging, as it does require a combination of certain high strength wastes. Although there is theoretically energy available in dairy wastewater, accessing it with supplemental forms of biomass may be required to produce methane economically and to convert energy, either as process heat or to generate electricity.

Combining dairy and municipal waste in co-digestion would involve more co-operation between dairy and municipal operators in New Zealand and could result in benefits both in increased revenue (electrical) and reduced carbon emissions for both sides.

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3.3 ENERGY STREAMS

The manufacturing of dairy products, particularly milk powder is highly energy intensive (MBIE 2019). Fonterra, the largest dairy company in New Zealand, operate over 30 dairy factories across the country. According to the 2018 Fonterra Sustainability Report, manufacturing contributes only 10% of value chain greenhouse gas. Fonterra's 2018 Financial Year report set out total energy used by manufacturing was 29.4 PJ, or 7.41 GJ/tonne, with only 13% sourced from renewable energy sources, the remainder sourced largely from natural gas, coal and lesser sources of liquid fossil fuels, and purchased steam (Fonterra 2019a). This points out three opportunities:

(i) The entire supply chain must be considered when evaluating the greenhouse gas emissions intensity of dairy production

(ii) Reduction in energy consumption through energy efficiency programmes is important to reduce the energy demands at these sites

(iii) Increased renewable energy sources either through accessing electricity from the grid or onsite electricity generation offer opportunities to reduce greenhouse emissions

MBIE (2019) identified there are several barriers to investment in emissions reduction technology, these include:

- Risk and return objectives, skewing decision making (positive or negatively)
- Opportunity costs of capital expenditure, resulting in preference for those with the greatest return on investment
- Secondary considerations of environmental and sustainability aspects in business cases and trade-off calculations
- Access to capital, and risks associated with high levels of debt and gearing exposure
- Aversion to production disruption in order to retrofit new equipment is a significant opportunity cost
- Lack of information or aversion to new technologies

The following outline options for improving the energy mix available to power a dairy plant and move away from reliance on imported energy/fuels, particularly coal and gas.

3.3.1 ELECTRIFICATION

New Zealand has an electricity grid with high levels of renewable energy with a goal to move towards 100 per cent renewable electricity by 2035 (MBIE 2019). This means electrification of sites power and process heat load offers a way to reduce emissions in a large-scale manner. Fonterra have investigated switching to electricity at their sites, in many cases they have identified the requirement for distribution or transmission grid and grid capacity upgrades (Fonterra 2019b).

By far the biggest opportunity to reduce consumption of coal and gas, is by way of electrifying the process heat generation, by using electrode boilers rather than coal or gas fired boilers. Electrode boilers can be supplied directly from the electricity grid or via wind or solar PV (Anderson and Duke 2007). Fonterra are currently trialling an electrode boiler at their Stirling site to offset up to 9,700 tonnes of coal annually (MBIE 2019).

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According to MBIE (2019) some of the barriers to electrification of process heat include:

- High cost of electrical energy
- The complexity and cost of electricity supply
- Historical bias whereby electricity has been the last choice fuel for industrial processes

3.3.2 PROCESS HEAT

According to *Process Heat in New Zealand: Opportunities and barriers to lowering emissions* (MBIE 2019), the biggest opportunities for further reduction of energy related emissions lie in two areas in New Zealand: transport and process heat. Process heat refers to thermal energy (heat used to manufacture products in industry, whereby more than half is met by burning natural gas or coal. Fuel switching to renewable sources is the only way to reduce emissions associated with process heat.

Most processes in food manufacturing use hot water and relatively low temperature steam. The highest temperature required for food processing is 150-200°C for drying milk powder (MBIE 2017) (considered to be medium temperature compared to other industries). Opportunities for reducing emissions from low to medium temperature process heat, include process efficiencies (using high temperature heat pumps) and switching to low emission fuels or renewable energy in boiler systems (MBIE 2019).

One of the main challenges is the integration of electrical heating technologies into the various production processes. High-temperature heat pumps in combination with electric boilers are increasingly being used for steam generation. The use of high temperature heat pumps reduces also primary energy consumption by a factor of 2 to 4 compared with a simple electric steam generator. Then sustainable primary energy savings could be reached rather than simply using electrode boilers (Schumer and Schneider 2018).

Electrification is an important option for achieving high carbon dioxide savings in the heating sector. However, industrial application show electrification itself is neither a guarantee for reducing greenhouse gas emissions unless the grid is powered by renewable sources. According to Schumer and Schneider (2018) the picture changes, if more energy efficient heat pumps are considered.

3.3.3 ONSITE GENERATION AND HYDROGEN ELECTROLYSIS

Several onsite generation options exist to supplement the energy needs of a dairy plant. Given the large energy demands of a dairy plant, it would be challenging to provide the entire source of electricity from site generated power. The following technologies would provide supplemental power which could support site power requirements (e.g. for lighting, air conditioning/heating, wastewater treatment plant aeration and refrigeration/chilling). Wastewater treatment plant aeration can be powered by a combination of biogas from co-digestion processes as outlined in Section 3.2 combined with solar photovoltaic (PV).

Solar PV arrays, hydroelectricity or wind turbines can be used to supply renewable electricity to hydrogen electrolysis combined with recycled water from the reverse osmosis plant (Hydrogen Economy 2019), to create a side stream of hydrogen which can be used as a transport fuel and supplement for boiler fuel. The oxygen created as a by-product of the hydrogen production process, can be used for wastewater treatment aeration purposes (as outlined in Section 3.1). This would be considered as an added benefit for using unused recycled water and renewable energy, rather than an electricity source for the dairy plant.

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4 ZERO ENVIRONMENTAL FOOTPRINT PLANT

The concept for a *Zero Environmental Footprint Plant* for milk processing is shown in Figure 4. A ZEFP incorporates a Resource Recovery Facility (RRF) used to provide:

- Membrane aerated biological reactor (MABR) or similar treatment of wastewater
- Zero liquid discharge treatment of water and salts recovery
- Biosolids and nutrient recovery to produce a fertiliser or soil improver product

To complete the *Zero Environmental Footprint Plant, s*upporting infrastructure are included, in the form of:

- Biogas and co-generation of electricity
- Onsite and grid based renewable energy
- Generation of sustainable hydrogen and oxygen by hydrolysis of water using renewable energy

The associated benefits from the ZEFP are many and varied and include:

- Environmental emissions to land, air and water kept to a minimum or zero.
- Reduce the importation of surface water and groundwater.
- Renewable energy production using biogas and electricity co-generation would capture the embedded carbon and energy in the high-strength organic wastewaters and be used to reduce the importation of electricity and use of non-renewable fuels.
- On-site renewable energy generation could be used to supplement power supplies, especially if the overall energy balance has been minimised by other means.
- Wastewater treatment systems would employ an optimised combination of aerobic and anaerobic treatment systems integrated with biogas and electricity co-generation to recover embedded carbon and energy in the wastewater stream. This may be a membrane bioreactor with a digester supplemented by a primary waste stream.
- The ability to have additional treatment for biosolids to produce a useful soil conditioner and recover nutrients such as nitrogen and phosphorus. Reducing disposal of under treated biosolids or disposal to landfill.
- Meet increasing customer demands for more sustainable foods that are low carbon emissions and impact on the environment.
- Meet regulatory targets for zero carbon emissions by 2050.

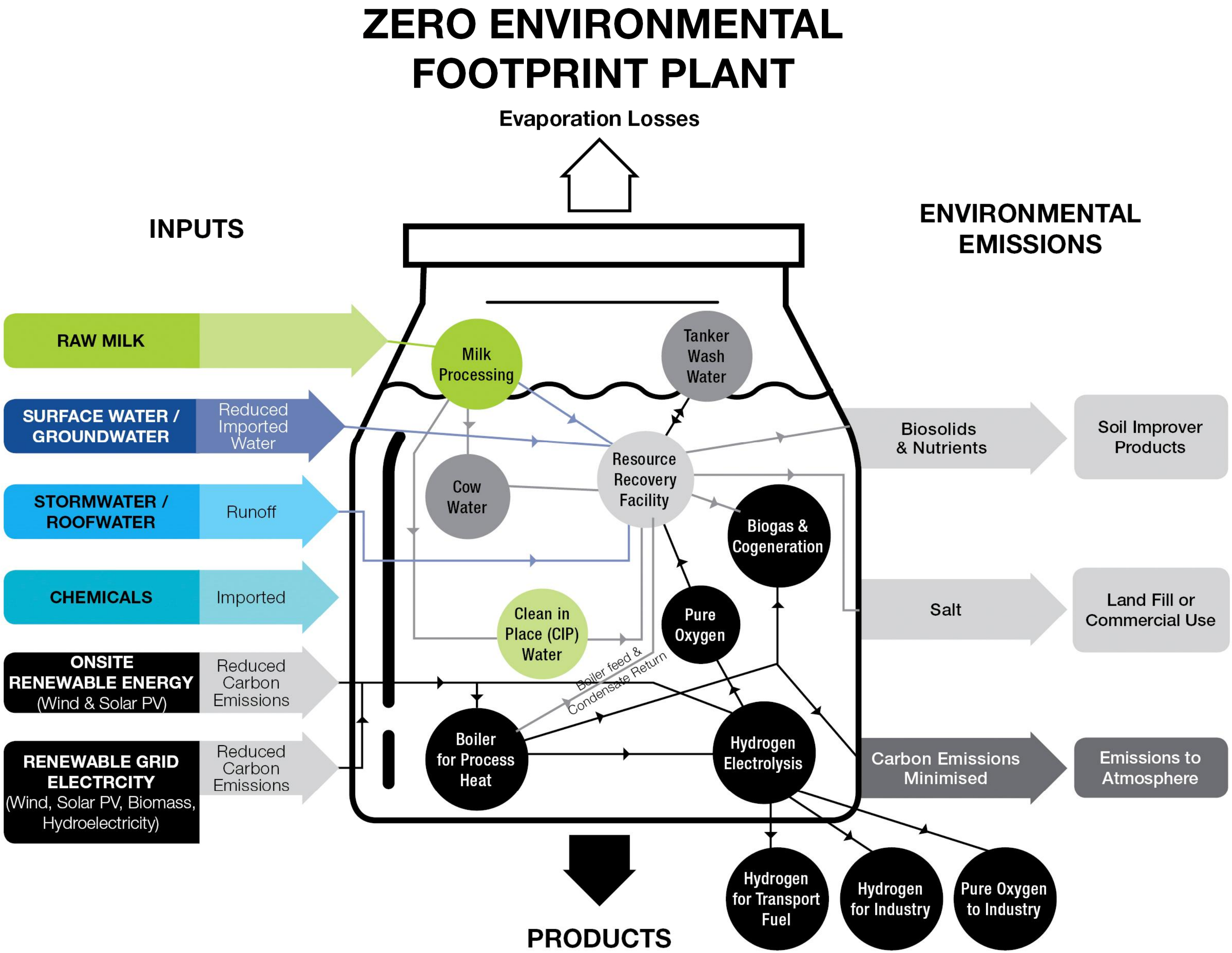

Figure 4: Zero Environmental Footprint Plant, Input-Output Flow Diagram

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5 CONCLUSIONS AND RECOMMENDATIONS

Dairy processing is energy/fuel intensive, highly dependent on imported energy/fuels, extracts large volumes of water from the environment and has significant emissions of carbon to air, water to lands and waterways and biosolids/residuals. Dairy processing is a linear and open economy.

Carbon emissions of the supply chain aspects of the dairy industry has been ignored but opportunities to address this using sustainable hydrogen is mentioned.

A *Zero Environmental Footprint Plant* is a paradigm shift for the dairy industry in how resources are viewed and used within the industrial food manufacturing setting. By applying available, proven technologies with a systems approach to optimise resource recovery, it eliminates or significantly minimises discharges and emissions to the environment and reduces the importation of energy and water.

The solutions are available and can be implemented at the milk processing site scale. Their application allows the dairy industry to further enhance its already strong credentials and brand recognition associated with environmental performance and green credentials, and as to demonstrate socially and commercially responsible practices for community, employees and shareholders by adoption of a circular economy approach.

6 ACKNOWLEDGEMENTS

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