Water Management in the Food and Drink Industry

An IChemE Green Paper

The application of core chemical engineering thinking can lead to significant improvements in the efficiency of water use in industry, agriculture and domestic settings. This paper includes case studies that highlight examples where the chemical engineering approach has been applied to improve water management.

We often consider the carbon footprint of our food, but most of us don't consider the water footprint. Water scarcity is increasing; in a climate-changed world, water stress is becoming more widespread. Rainfall and water availability are likely to become more uncertain[1], with significant consequences for food production.

With the world's population predicted to pass nine billion by 2050, the additional food required to feed future generations will put enormous pressure on freshwater resources. Food production is reliant on water, with an estimated 70% of all extracted freshwater used for agriculture alone. A further 20% is used in the production and processing industries[2], leaving just 10% for domestic use (eg drinking water).

Studies have shown that these pressures on freshwater will continue to increase due to a combination of climate change, increasing population and socio-economic demands[3].

At present 7% of the world's population live in water scarce areas. With population expansion, it is anticipated that 67% will live in water scarce areas by 2050[4]. Future increases in food production will be required to feed the population and increased production will need larger water supplies.

It is estimated that global water withdrawal will grow from 4,500 billion m^3/year to 6,900 billion m^3/year by 2030[5]; a 53% increase in water extraction.

The world is facing a complex challenge. Population growth, urbanisation and rapidly developing economies are driving consumer demand for food[3]. An expanding middle class leads to more people choosing western-style diets. These diets are high in protein, sugar and fat, all of which are expensive in terms of water for food production.

At the same time there are more than two billion people living on less than US$2 per day. It is important to alleviate food poverty whilst working to reduce the demands this places on our planet. UK food and drink manufacturers have been working towards the Federation House Commitment[6] of reducing water usage by 20% for 2020. Since 2007, a 16% reduction in water use has been achieved, equivalent to 6.1 million m^3.

Without more effective management of water usage in food and drink production worldwide, there may be major repercussions; rising food prices, food shortages, pollution, famine, social unrest, and geopolitical instability. It has even been suggested that this could lead to a 'world water war'[7].

The systems thinking approach and scenario-based analysis that are central to the chemical engineering skill set must be brought to the forefront in order to tackle this problem.

Chemical engineers are involved in implementing three strategies developed to manage water in the food industry:

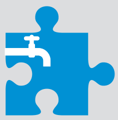
1. Reducing water use
2. Recycling and reusing waste water
3. Using alternative water sources

Chemical engineering matters

The mission of the Institution of Chemical Engineers (IChemE) is to advance chemical engineering worldwide. We are doing this because chemical engineering matters and it makes a positive impact on quality of life for all. IChemE's technical strategy – *Chemical Engineering Matters* – highlights the need for us to confront water scarcity head on.

The topics discussed in this green paper refer to the following lines on the vistas of IChemE's technical strategy document *Chemical Engineering Matters*:

Food and Nutrition
Lines 1-2, 18-19



Water
Lines 5-6, 16, 21-24

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Water resources

In some areas in the world, water has been considered as readily available at negligible cost, but in a world with an uncertain climate future a new approach is required.

An estimated 97% of water is stored in our oceans as saltwater; just 3% of all water on earth is fresh water and the majority of it is found in glaciers and ice caps[8]. Reliance on freshwater for the maintenance of life places strains on this limited resource.

Population growth will require 60% more food by 2050 and thus a 19% increase in agricultural water use[2]. The water consumed in the production of an agricultural or industrial product is termed 'virtual water' [9]. Every day a person drinks 2-4 L of water, but they will also consume 2,000-5,000 L of virtual water embedded in their daily food. There is a hidden cost of water in the food we eat.

Dietary choice has a significant impact on water consumption. Calculations of the water consumed in meat production in the US indicate that beef requires 11 times more irrigated water than pork or poultry rearing[10].

Types of water

IChemE defines the different types of water as follows:

Freshwater – water often found in ice caps, rivers and rainfall, with a low salinity (<0.05%)

Blue water – freshwater from lakes, rivers, icecaps, ground reserves and mains sources

Green water – freshwater from rain and surface water (eg puddles, water in the upper levels of soil)

Grey water – freshwater used to dilute discharge from domestic (eg laundry) or industrial (eg fertiliser leaching, cleaning products) use

Black water – water containing faecal matter, urine or sewage

Saltwater – water from the sea or ocean, brackish water, saline and brine, with a high salinity (>0.05%)

Alternative definitions are available

Water footprint and virtual water

When a country imports a water-intensive product, it imports virtual water. Real water trading between water-rich and water-poor countries is limited, but trading water through virtual water products is significant[11].

The development of the water footprint concept has been an important step in understanding the importance of freshwater. Existing methodologies mainly assess the quantity of water used in food production and processing rather than the related impacts.

Case study 1

CSIRO, Mango production in Australia[30]

The Australian mango industry produces an average annual crop of c 45,000 tonnes. This crop production uses c 2,300 L/kg of virtual water (green, blue and grey water combined). However, the processing of mangos means that the actual virtual water content of 1kg of mango exceeds 5,200 L. Consumer waste of Australian mangoes represents an annual waste of 27 GL of green water and 17 GL of blue water. This indicates that interventions to reduce processing and consumer food waste will have as great an impact on freshwater availability as improving agricultural efficiency.

Reducing water use

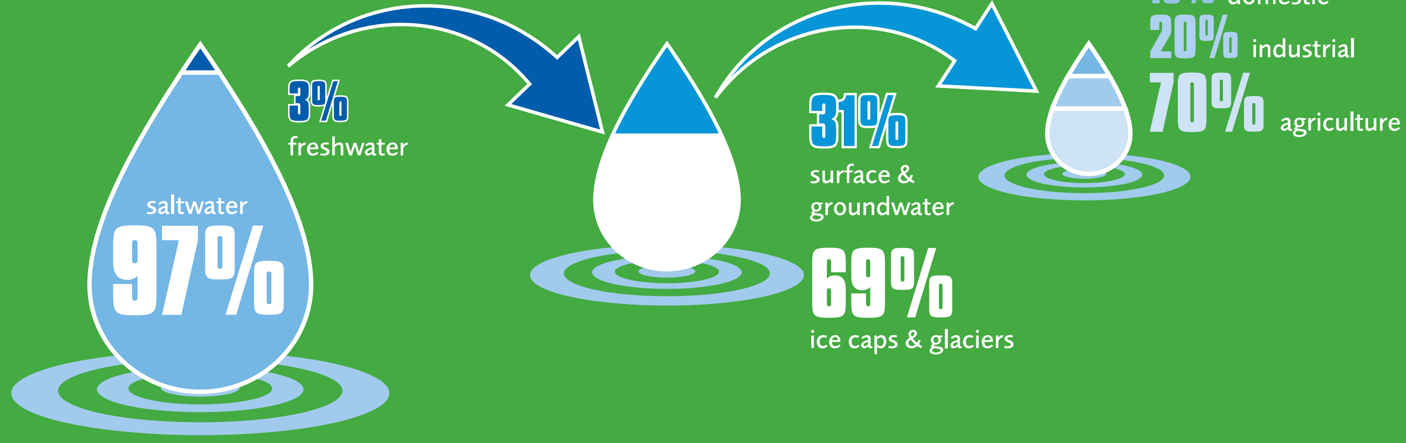
Using less water seems like the obvious strategy to combat water shortages; eg by selecting crops suitable for the available water resources. However, the application of this principle to industrial and agriculture processes can be complex.

Efficient irrigation

Agriculture is the single biggest user of freshwater, accounting for at least 70% of current water use by humans. However, water scarcity is not the only production issue for food; available new arable land is also limited.

Globally, less than 30% of the water used for irrigation is actually taken up by the crop for transpiration and growth[4], and in water-scarce areas this can be as low as 5%. Improving the efficiency of irrigation has huge potential for improving water use, especially in areas where water is scarce.

Where is the water and where is it used?



Case study 2

SABMiller, Reducing water usage in India[29]

SABMiller have been working with farmers in India to help reduce water requirements in water-stressed areas. In the Sonepat District, the average annual rainfall is 550 mm, thus groundwater is often exploited and is currently being depleted at an unsustainable rate.

SABMiller have introduced a variety of methods that reduced water usage by 18% including close pipe irrigation, sprinkler irrigation, drip irrigation, land levelling and flood irrigation. This has led to productivity increases of 17% in grain and 21% in vegetable crops; and also increased local income by 22%. In addition, the reduced water usage has resulted in energy savings.

The cost of agrochemicals

Grey water accounts for the largest proportion of agricultural water use[12]. Using fertilisers can reduce water consumption because crop yields will increase whilst water usage can remain more or less the same. However, there is a threshold level for the use of fertilisers, above which nutrient leaching and run-off into the fresh water system causes pollution and increases grey water outputs. Strict regulation of fertiliser usage can reduce grey water production; however, development of fertiliser usage strategies using chemical engineering principles can further reduce this risk.

Food and drink processing

Systems engineering is a key aspect of chemical engineering that allows for process optimisation. Best practice in any production method should aim to use the minimal amount of raw materials (eg water, energy, ingredients) possible to achieve the highest production rate. In the UK, some food and drink companies are already making significant improvements in water consumption, showing that reductions of 20–50% can be achieved through good management and adoption of best practice[13].

In the UK, the top five approaches[14] to water use reduction in food manufacture processes have been identified as:

1. Reuse of cooling water (25%)
2. Fixing water flow and leaks (12%)
3. Automatic shut-off (6%)
4. Control of overflows (6%)
5. Optimising supply pressure (5%)

Food and factory cleaning

Beyond agriculture, the biggest water use in the food industry is the cleaning of processing equipment/plants and food products. This can account for up to 70% of a factory's water usage[15]. Methods such as dry cleaning, cleaning in place and pigging of piping can help to limit this. However, optimisation of cleaning routines and controlling effluent concentration (to minimise grey wastewater production) can easily help to cut this level without investing in new and complex strategies.

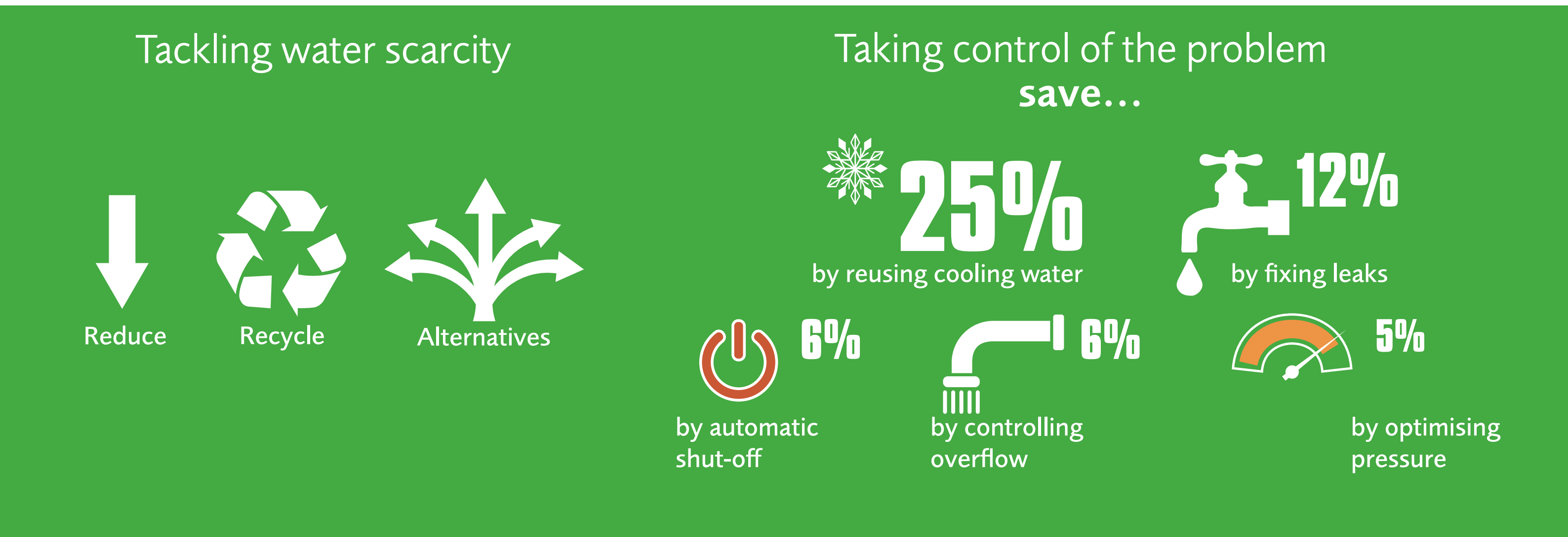
Recycling and reusing water

This is an area where chemical engineers are currently working to ensure more efficient use of the available water eg grey water. Technologies such as membrane bioreactors and reverse osmosis are already being used to treat wastewater[15].

Improved public perception is often a powerful driver for change. Moves towards recycled water usage have been impeded by reports that the use of recycled water in the processing of products intended for human consumption is unacceptable[16].

A recent study examining the use of recycled water in Australia[16] indicates that this is changing. This research indicates that recycling water during food production is acceptable to the public if the water has been collected, treated and processed to drinking water quality. It was felt that as long as this water treatment was credible and trustworthy, the public were happy to consume products processed using recycled water.

Building public confidence in recycled water in the food industry will take time. It is critical that there is investment in effective implementation and monitoring of the process safety and food hygiene standards for the use of recycled water.



Case study 3

Germany, Treating water in the food industry[31]

A variety of methods can be used for the effective treatment of process water. Nanofiltration techniques have been developed to produce water of potable quality from the spent process water side streams in small and medium-sized food and beverage factories. Treated water met the limits of the German Drinking Water Act (DWA) and was approved for use. The treated water was then reused for various purposes, eg boiler make-up water, cooling water.

Hygiene and safety

A significant obstacle to the wider reuse of recycled water is the associated risk of microbiological contamination of food and the production environment[17]. Chemical engineers specialise in process safety and the use of Hazard Analysis and Critical Control Point (HACCP). This is necessary for implementation and evaluation of systems for the reuse of water in the food industry. Information on food- and water-borne pathogens and their sensitivity towards various water treatment methods requires evaluation.

Chemical engineers can contribute to the development of in-factory water quality monitors for chemical and microbiological contaminants. Further discussion by decision-makers and regulators is needed to set internationally acceptable quality levels for water used in food production.

In Brazil there has been considerable focus on water conservation and water reuse in the food industry. Brazil is a water-rich country with an estimated 44,000 m^3 per capita and over 80% of its electricity is generated from hydroelectric power. The country has a large agricultural capacity and 35% of all exports are food products.

There are only general regulations in Brazil that deal with non-potable water reuse. Poultry production in Brazil has been studied and this highlighted the need for industry standards to be applied when using recycled water in order to allay public fears of contamination[18]. A reduction in water consumption of almost 31% was achieved by focusing on water reuse in areas which required least effort at lowest cost. It can therefore be concluded that water conservation and reuse strategies are important tools for improving the sustainability of the food industry by preserving fresh water resources.

The dairy industry in the UK now uses new anaerobic membrane bioreactor technology followed by reverse osmosis to treat wastewater, eg Arla Foods processes 500 m^3 water per day at its Aylesbury site[19]. The process not only provides treated water of better than potable quality but also produces biogas which is used to fuel the on-site power plant, reducing both water and carbon footprints.

Alternative water sources

Most of the water on earth is present as salt water. The use of saltwater in food production offers a potential solution to the blue water availability problem. Although the use of saltwater is not currently feasible on a large scale, other freshwater sources do exist, eg rainwater.

Desalination

The use of desalinated water on a large scale is energy intensive and not economically viable for most countries. Over-use of limited groundwater supplies in arid climates (eg the Middle East) has created a reliance on salt water desalination to produce potable water for human consumption[20].

Water desalination is achieved through either thermal energy (using phase-change processes) or electricity (driving membrane processes), and the use of these methods as water sources are best matched to the specific requirements[21].

New developments using renewable solar and wind energy to power the desalination process may improve the viability of desalinated water use in the food industry. Water treatment via solar thermal desalination can be achieved through different chemical engineering approaches (eg distillation, separation and solar still methods)[21]. However, these technologies are currently expensive and at an early stage of development. Nonetheless, significant potential exists.

Case study 4

PepsiCo, Extracting water from potatoes[28]

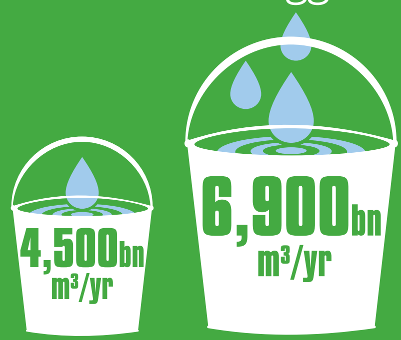
PepsiCo have improved process water efficiency by more than 20%. Chemical engineers have developed a method to capture water from potatoes, which are fried for crisps. Using thermodynamic technology (stack heat), the company is able to extract water and reuse it throughout their plants. PepsiCo have pledged to take their UK factories off the water grid by 2018 and are aiming to reduce the water impact of crops grown in water-stressed areas by 50%.

Hidden water in our food

Drinking 2 L

Eating 2,000 - 5,000 L

The world needs a bigger bucket



today

2030

Extracting water from food

European sugar beet processing is one of the most water-efficient methods of food production[22]. The industry has made considerable progress to reduce water usage. Sugar beet can withstand drier conditions than many other crops without significantly impacting yields eg 95% of sugar beet crops in Europe are rain fed.

Typically 75% of a sugar beet is water and this water content is used in sugar production[23]. In the UK over 60% of all the water used in production processes comes from the sugar beet itself[22]. Water used in sugar production from sugar beet is then treated on site and either reused for agriculture or discharged into local water sources. Anaerobic digestion of grey water also produces biogas, which can then be used as a fuel for thermal processes[23]. This is a good example of an integrated process developed and implemented through the application of chemical engineering principles.

Rainwater capture

The use of green water (rain water) is commonplace in agriculture. Efficient management of rain water is now becoming more common in food production[1].

Zero water factories

Major companies are investing in research into more effective water conservation[24]. In common with most industrial practice, there is a concerted drive to produce more with less or even with 'zero water'.

The 'zero water' concept does not mean that no water is used. Rather, water 'neutral' process operations are achieved through the return of water, post process, to the local ecosystem. Water consumed is taken from sources other than blue water before being recycled and/or reused then returned to the environment. This is achieved by applying chemical engineering principles to optimise and intensify processes thereby minimising water use.

The water-energy-food nexus

Optimal chemical engineering solutions for water use reduction in food processing must also give full consideration to a third component, energy. The water challenge cannot be solved in isolation. An understanding of the water-energy-food nexus[25] is essential if we are to address food and water security effectively. Energy is required for food production and also to produce the process water upon which food production depends. Some routes to food grade water are particularly energy intensive, eg desalination. Water is also consumed in all forms of power generation.

Recommendations and conclusions

IChemE asserts that improved water management across the food and drink manufacturing landscape is essential to achieving more sustainable process operations. The following options are put forward for consideration and debate by chemical engineers and all those with an interest in food processing, including operating companies, equipment suppliers, regulators, shareholders and decision-makers:

1. **All governments should set targets for reducing the amount of water used in food production worldwide by 20% by 2020[14].**
2. **Industry should improve the monitoring of water usage in food production worldwide by using water footprinting[26].**
3. **Governments should ensure that the use of recycled water in food production becomes more widely accepted through creating, enforcing and promoting rigorous international quality standards[16].**
4. **Manufacturers should be incentivised to use alternative, sustainable sources of water (eg water in food, rainfall, saltwater)[11].**
5. **An investment of US$800 billion per year in the construction of new capacity, infrastructure and appropriate technologies to improve efficiency of water management globally[27].**

Water is a finite resource, which is essential to food production. Recognition that water will not always be readily available and is likely to increase in price is essential to the development of more sustainable food process industries.

Chemical engineers are working to ensure that the food industry achieves a step change in the reduction of water use with the end goal of water neutrality. This involves the optimisation of existing processes, improved understanding and the research and development of novel process solutions.

Chemical engineers are already making and will continue to make a central contribution towards ensuring that all processes are efficient, cost-effective and sustainable. State-of-the-art-water management in the food and beverage industries provides a compelling illustration of the role played by the discipline in creating, sustaining and improving quality of life in the 21st century.

References

1 WWF, "Water Stewardship: Perspectives on business and responses to water challenges,"2013.

2 UNFAO, "Coping with water scarcity - An action framework for agriculture and food security," Rome, 2012.

3 SABMiller and WWF, "The water-food-energy nexus: Insights into resilient development," 2014.

4 J. S. Wallace, "Increasing agricultural water use efficiency to meet future food production," *Agriculture, Ecosystems and Environment*, vol.82, pp. 105-119, 2000.

5 McKinsey, "Charting Our Water Future," 2009.

6 WRAP UK, "The Federation House Commitment Progress Report 2014," 2014.

7 S. Goldenburg, "Why global water shortages pose threat of terror and war," *The Guardian*, 9 February 2014.

8 UNFAO, "Coping with water scarcity - An action framework for agriculture and food security," Rome, 2012.

9 D. Renault, "Value of Virtual Water in Food: Prinicples and Virtues," UNFAO, Rome, 2002.

10 G. Eshel, A. Shepon, T. Makov and R. Milo, "Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 111, no. 33, pp. 11996-12001, 2014.

11 D. Vanham, M. M. Mekonnen and A. Y. Hoekstra, "The water footprint of the EU for different diets," *Ecological Indicators*, vol. 32, pp. 1-8, 2013.

12 M. M. Mekonnen and A. Y. Hoekstra, "Water footprint benchmarks for crop production: A first global assessment," *Ecological Indicators*, vol. 46, pp. 214-223, 2014.

13 DEFRA UK Government, "Food Industry Sustainability Strategy," 2006.

14 WRAP UK, "Water use in the UK food and drink industry," 2013.

15 WRAP UK, "Water Minimisation in the Food and Drink Industry," 2013.

16 H. J. Lease, D. Hatton MacDonald and D. N. Cox, "Consumers' acceptance of recycled water in meat products: The influence of tasting, attitudes and values on hedonic and emotional reflections," *Food Quality and Preference*, pp. 35-44, 2014.

17 S. Casani and S. Knochel, "Application of HACCP to water reuse in the food industry," *Food Control* vol. 13, pp. 315 327, 2002.

18 E. M. Matsumura and J. C. Mierzwa, "Water conservation and reuse in poultry processing plant - A case study," *Resources, Conservation and Recycling*, vol. 52, pp. 835 842, 2008.

19 Food & Drink Business Europe, "Veolia Memthane - Veolia Provides Green Wastewater Solution For Arla's New Dairy," *Food & Drink Business Europe*, p.33, August 2014.

20 M. J. Haddadin, "Water issues in the Middle East challenges and opportunities," *Water Policy*, vol. 4, pp. 205-222, 2002.

21 A. Al-Karaghouli, D. Renne and L. L. Kazmerski, "Solar and wind opportunities for water desalination in the Arab regions," *Renewable and Sustainable Energy Review*, vol. 13, pp. 2397 2407, 2009.

22 NFU Sugar and British Sugar UK, "UK Beet Sugar Industry: Sustainability Report 2011," 2011.

23 CIBE (International Confederation of European Beet Growers) and CEFS (Center for Environmental Farming Systems), "Environmental Report: Beet growing and sugar production in Europe," 2003.

24 P. Clark, "A world without water," *The Financial Times*, 14 July 2014.

25 R. Martin-Nagel, E. Howard, A. Wiltse and D. Duncan, "The Water, Energy and Food Security Nexus - Solutions for the Green Economy," Conference Synopsis, 2012.

26 A. Y. Hoekstra, A. K. Chapagain, M. M.Aldaya and M. M. Mekonnen, "The Water Footprint Assessment Manual: Setting the Global Standard," *Earthscan*, 2011.

27 C. J. Vorosmarty, P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. R. Liermann and P. M. Davies, "Global threats to human water security and river biodiversity," *Nature*, vol. 467, pp. 555-561, 2010.

28 PepsiCo, "Water," PepsiCo UK, 22 September 2014. [Online]. Available: http://www.pepsico.co.uk/purpose environmental-sustainability/water.

29 SABMiller, "Ground Water Management Initiative at Sonepat, Haryana," SABMiller, 2014.

30 B. G. Ridoutt, P. Juliano, P. Sanguansri and J. Sellahewa, "The water footprint of food waste: case study of fresh mango in Australia," *Journal of Cleaner Production*, vol. 18, pp. 1714 1721, 2010.

31 C. Blocher, M. Noronha, L. Funfrocken, J. Dorda, V. Mavrov, H. D. Janke and H. Chmiel, "Recycling of spent process water in the food industry by an integrated process of biological treatment and membrane separation," *Desalination*, vol. 144, pp. 143-150, 2002.

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To continue the conversation you can engage with us in different ways:

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