Food waste valorization in Singapore

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Resource and water recovery solutions for Singapore's water, waste, energy, and food nexus.

Part II: Food waste valorization

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Summary

In the last years, Singapore has set clear targets to transition towards a circular economy. To advance on those targets, the country has introduced policies and strategies to encourage businesses and society to adopt sustainable practices. In 2019, Singapore launched a Zero Waste Master Plan, which lays out strategies for waste and resource management within the context of the circular economy. With this plan, Singapore aims to reduce the amount of waste sent to landfills by 30% by 2030. And it targets food, electronics, and packaging, including plastics, as priority waste streams.

This report provides an overview of Singapore's food waste management with special emphasis on food waste valorization strategies. Through an exploratory study and conducting interviews with different stakeholders, i.e., individuals, government, businesses, research institutes, key drivers and constraints to increasing food waste valorization were identified. The report also includes the view of food waste experts on valorization strategies that can be applied in the Singaporean context.

1 Background

The agri-food sector in Singapore mainly produces eggs, fish, and vegetables [1]. In 2019, the production of these food items was 26%, 10%, and 14%, respectively, of the country's total consumption [2]. This implies that the country relies heavily on imports to meet its food demand. However, nearly 7% of the imported food is lost to waste due to inadequate habits of purchasing excess food, as well as to high appearance quality standards.

When referring to the amount of food that does not reach its purpose of feeding people, two terms are commonly used: food loss and food waste. Food loss refers to the decrease in quantity or quality of food before it reaches the consumer, e.g., during production, harvesting, transportation. On the other hand, food waste refers to the decrease of food quantity at the retail and consumer level [3].

1.1 Food waste management in Singapore

1.1.1 How much food waste is generated?

The National Environmental Agency (NEA) oversees monitoring and reporting of food waste in Singapore. Every year, NEA reports the total amount of food waste generated, the amount of food waste that is recycled, and food waste sent to incineration. According to NEA, in 2020, 665 thousand tonnes of food waste was generated. About half of the total food waste came from households, and the rest came from industry and commercial facilities. In the number that NEA reports, however, there is no breakdown of food waste generated along the food supply chain (FSC), i.e., from production, including imported food, transportation, processing, and distribution (upstream and midstream) to consumers (downstream).

A study conducted in 2019 by the Singapore Environment Council (SEC) and Deloitte [4] showed that about 342 thousand tonnes of food losses occur upstream and midstream, with more than 40% of the losses originated from imports (Figure 1).

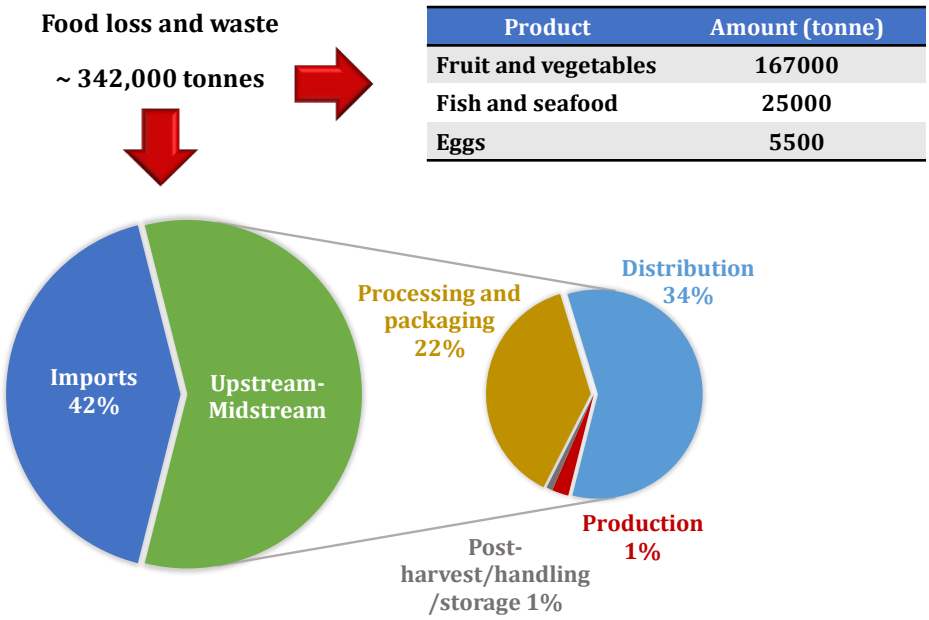

Figure 1 Estimated food waste and loss generated upstream and midstream of the food supply chain. Data includes 13 key food items imported and produced in Singapore, i.e., meat (pork, beef, chicken, mutton, duck), eggs, fruits, leafy vegetables, fish and other seafood, rice, and wheat [4].

1.1.2 Food waste treatment: Current state and plans

In the last decade, Singapore has increased the amount of food that is recycled (Figure 2). However, this amount only represents less than 20% of the total food waste generated. Most recycled food waste is homogenous (one food type), such as okara and spent grains, which is mainly converted into animal feed. Heterogenous food waste, the one that is generated downstream, at the consumer level, is not fully valorized. Only about 12 tonnes per day of mixed food waste segregated at the source from 25 establishments, including universities, schools, army camps, and hawker centers, is sent to a demonstration facility at Ulu Pandan Water Reclamation Plant to be co-digested to generate biogas. The food waste that is not recycled is disposed of together with general waste and transported by licensed waste collectors to the Waste-to-Energy (WtE) plants for incineration [5].

A decrease in the amount of food sent to incineration is expected from 2024 when under the Resource Sustainability Act (RSA), commercial and industrial establishments will be required to dispose of any food waste separately from other types of waste. For new establishments, segregated food must be treated on-site to convert it into compost and water for non-potable use. composting. Old establishments, on the other hand, will have the option of installing an on-site food waste treatment system or using off-site food waste treatment facilities [5]. One of the options for off-site treatment will be co-digestion at the Tuas Nexus facility, which is expected to treat 400 tonnes of used water sludge and food waste per day.

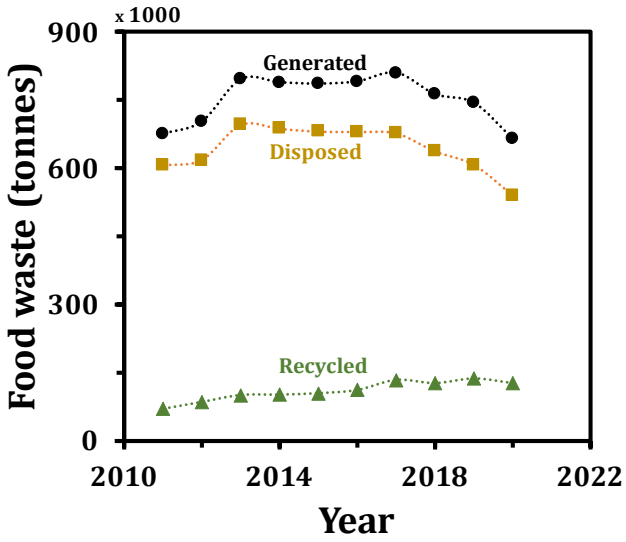

Figure 2 Total food waste generated, disposed of, and recycled in Singapore from 2010 to 2020 [5].

1.2 PIB ReCirc partnership framework

This study is part of one of the activities conducted within the Partners for International Business ReCirc program. Partners for International Business (PIB) is a program in which Dutch companies can realize their international ambitions in a public-private partnership. The ReCirc Singapore partnership aims to explore and exchange collaboration on circular solutions for waste processing, sludge, and resource recovery in Singapore and the Netherlands. The following organizations are part of the ReCirc Singapore partnership: Witteveen+Bos (cluster coordinator), Waternet, Amsterdam Institute for Advanced Metropolitan Solutions, Nijhuis Industries, Paques, CirTec, World of Walas, Asia Pacific Breweries, Organic Village, KWR Watercycle Research Institute, Delft University of Technology, Wageningen University and Research and Upp! UpCycling Plastic. The target topics addressed by the partnership are:

- Incinerated bottom ash and fly ash treatment and application as a building material
- Sorting, separating, segregating, and recycling urban waste
- Integrated recovery of renewable energy and resources from waste, used water, UWTP sludge
- Packaging and plastic waste management and treatment
- Food waste management, treatment, and resource recovery
- E-waste handling and recovery of valuable materials

Part of the activities promoted by the ReCirc partnership includes three Knowledge to Knowledge (K2K) projects. The present report is one of the outcomes of the third K2K project, which aims to identify the factors that are needed to accelerate i) the extraction of valuable components from wastewater and sludge and ii) the valorization of food waste. Previous K2K projects were focused on identifying opportunities for enhancing the circular economy in Singapore and the Netherlands through city blueprint frameworks (CBF) and a material flow analysis (MFA).

2 Food waste valorization pathways

In general, the framework to manage food waste should be based on the food recovery hierarchy (Figure 3). Based on this hierarchy, food waste valorization strategies fall into seven levels, in which the most sustainable strategy is to prevent wastage, and the least favorable is disposal [3]. In between these two options, we find all the strategies for recovery and valorization. Those levels are:

2.1 Food waste into feed

Redirecting food waste to food products for human consumption or animal feed are options higher in the hierarchy. In Singapore, as well as in European countries, end products for human consumption need to comply with strict regulations. To put a product in the market requires the approval of the Singapore Food Agency (SFA), which will verify among other things traceability of all ingredients, compliance with Halal certification, and ISO standards. Besides the legal aspects, technical and economical requirements often influence the application and feasibility of this option to convert food waste into food products again.

Regulations to valorize food waste into animal feed are less stringent, and hence more initiatives are following that direction. One approach to introduce food waste back into the food chain is to use insects in the processing. In Singapore, several start-up companies, such as ***Insectta*** and ***Inseact***, use the black soldier fly (BSF) to convert and recover nutrients from food waste or by-products of the food industry. Due to regulations, these companies are allowed to use mainly homogenous food waste streams. However, in 2021, the company ***Blue Aqua*** got approval to use mixed food waste from an airline company. ***Blue Aqua*** will convert this stream into insect protein for aquaculture using crickets and mealworms.

2.2 Food waste into chemicals

The conversion of food waste into several chemical building blocks, essential basic chemical compounds used for further processing, is often considered more profitable than the conversion to biogas [6]. High-value products, used in the food, chemical, cosmetic, and pharmaceutical industries, are for example produced through fermentation processes of food waste [7]. In Singapore, this strategy remains unexplored. However, the Netherlands has built solid knowledge and know-how on converting organic residues into sustainable products such as fatty acids [8].

2.3 Food waste into soil

Food waste treatment at the source, by converting food waste into compost and liquid fertilizer, is expected to be implemented as of 2024 by the owners of new establishments that generate food waste. Owners of old establishments are not obliged to treat their food waste on-site. The compost produced will be used mainly for landscaping purposes.

2.4 Food waste into energy

Currently, about 80% of the food waste in Singapore is incinerated to produce electricity. This practice is adding little value and is the least preferred in the food waste recovery hierarchy. However, Singapore is exploring another route to treat food waste to energy through the production of biogas in biodigesters. The food waste treatment facility at Tuas Nexus is expected to be operational in 2024 and will serve as an off-site treatment option producing biogas from segregated food.

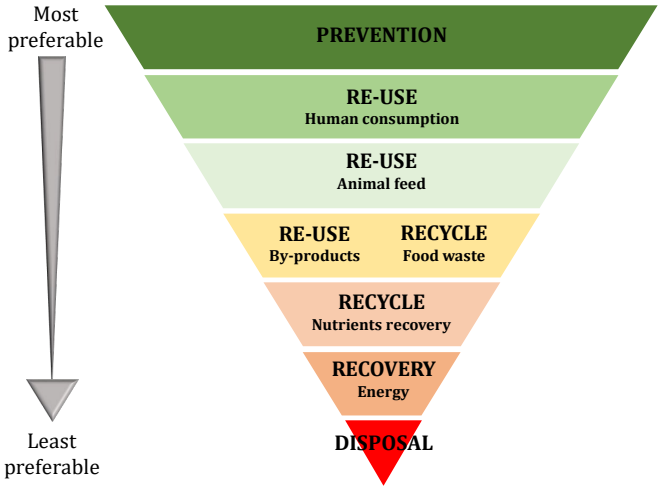

Figure 3 Schematic of the food waste hierarchy [9]

3 Analysis for potential increase of food waste valorization in Singapore

3.1 Opportunities for food waste valorization

Through discussion sessions with experts in monitoring, prevention, and valorization of food waste flows, potential opportunities for establishing new businesses and increasing the amount of food waste recycled in Singapore have been identified.

3.1.1 Valorizing fruits and vegetable losses from the imports

About half of the food loss generated upstream and midstream consists of fruits and vegetables (Figure 1). The main contributor to this food loss stream is the imports, rejections at the ports. NEA, through one of its representatives (personal communication), has mentioned that it welcomes potential solutions to valorize fruit and vegetable waste. Important aspects to consider are the taxes and legislation related to food loss streams generated at the ports and the way they are handled. For instance, do companies need to pay import rights to take over containers with rejected food?

Certainly, there are viable opportunities for valorization routes of fruit and vegetables. And the Netherlands is making some steps in these regards. From the valorization of rejected fruits into products for human consumption, such as banana bread and cookies, to experimenting with BSF or producing biobased chemicals. In this regard, two Dutch start-ups companies are leading the way, technically, operationally, and commercially. The first company is ***Protix***, which uses BSF cultivated on fruit and vegetable residues to produce protein meals and oils used as feed to chicken, fish, and pets. The other company is ***Chaincraft,*** which uses biological processes to transform food waste into chemical intermediates that can be used as a replacement for industry-produced chemicals.

3.1.2 Engaging in the production of sustainable animal feed

Singapore is committed to boosting food security by increasing local food production to 30% by 2030. The clear strategy of Singapore's government is to support the expansion of food industries such as aquaculture and poultry. This expansion opens opportunities to transform side food waste streams into animal feed.

Aquaculture is a central focus in building Singapore's food security, and thus valorizing food waste into feed for this industry is an economically viable strategy. For the poultry industry, the opportunities are more reduced. Currently, there are five chicken and quail farms [2], and most of the effort to support this industry is put into the adoption of large-scale automation.

Opportunities to produce animal feed for other livestock industries, such as pigs, are currently inexistent. However, a shift in the way Singapore addresses food production might offer possibilities for the development of more businesses for animal feed production. For instance, Singapore can take the lead in the region in sustainable pig production by providing sustainable animal feed to the country's biggest suppliers of this livestock, Indonesia and Malaysia. This approach could have benefits that are not available in the current market and supply chain because it involves on one hand managing food waste more sustainably, and on the other hand, creating self-sufficient access to domestically produced animal feed.

In this context, companies such as ***Nijsen*** can have a more solid floor to enter Singapore not only because the robustness of the food waste streams supply is guaranteed, but also an adequate market for economically viable operations. ***Nijsen*** is a Dutch company and a frontrunner in the production of animal feed, mainly to pigs and chickens. This company has a lot to offer, not only because it can treat a big variety of food by-products (about 2300 different side streams), but also because its processes have a high level of automatization that can be replicated, which opens possibilities for other companies to also do business in Singapore.

3.1.3 Establishing partnerships with licensed recycling companies

Many companies are interested in extending their businesses to Singapore. However, it requires large capital initial investments to start operations in that country. Therefore, a more accessible and viable strategy is to establish partnerships or collaborations with companies already operating there. A strategic collaboration can be to engage with licensed recycling companies. These companies are an important part of food waste management in Singapore because they handle a wide variety of food waste streams and food industry by-products. Table 1 lists the food waste recycling companies approved by NEA [10].

Table 1 Food waste recycling facilities operating in Singapore [10]

Company	Food waste
Tiong Lam Supplies Pte Ltd	The company manages 30-40 tonnes of food waste per week. The main food waste stream comes from bread, sugar, chocolate, and noodles producers. Approximately, 95% of the food waste is valorized mainly into animal feed and fertilizers.
Lam Tak Pte Ltd	Dried food waste, milk powder, and other food industry by-products
800 Super Waste Management Ptd Ltd	Spent grain, soy beans waste (okara)
A1 Environment Pte Ltd	Used coffee grounds
Bee Joo Insdustries Pte Ltd	Spent grain, soy bean waste, rejected milk powder, and bread waste
Chuan Huat Poultry Farm Pte Ltd	Bread waste
Eng Cheong Leong Agri Chem Pte Ltd	Bread waste

3.2 Drivers and constraints to increasing food waste valorization

To address food waste valorization, NEA has set up different strategies that can contribute to strengthening the resilience and sustainability of the food system. One such strategy is the creation of an Industry Steering Committee – Circular Economy (Food) with representatives from government agencies, industry associations, and research institutes to investigate the conversion of food waste into high-value products. The valorization efforts are focused on homogenous food waste. It is important to note that businesses that generate food waste are in charge of taking the initiative to apply valorization routes to treat their food waste and food by-products. Businesses can also partner with licensed food waste recycling companies that collect the food waste for processing into mainly animal feed. Currently, most licensed food waste recyclers are only allowed to accept homogenous food waste.

Through interviews with different stakeholders and a SWOT analysis (Table 2), key drivers and constraints for increasing food waste valorization in Singapore were identified. The lack of awareness on potential valorization solutions, investment costs, limited end-users for some valorized products (e.g., compost), are some of the reasons why businesses do not adopt valorization strategies. NEA has taken some actions to overcome some of these challenges. For instance, organizing industry awareness briefings to bring together companies and solution providers to share technological solutions and valorization options. There are also funds and awards programs available for organizations that implement food waste valorization strategies. However, these funds and awards are mostly available to Singaporean businesses.

Table 2 SWOT analysis for food waste valorization in Singapore

Strengths	• In 2024, an Integrated Water and Solid Waste Treatment Facility will treat ~ 400 tonnes/day of source-segregated food waste by co-digestion. • Stablished insect farms that upcycle food waste using black soldier fly larvae.
Weaknesses	• Monitoring of food waste flows at each stage of the FSC is lacking • Only 19% of food waste is recycled. The rest is disposed of together with general waste and sent for incineration. • 50% of food waste can only be valorized to biogas, compost, fertilizers, and liquid nutrient. • Lack of awareness on potential valorization practices. • Government grants and subsidies are mainly aimed at Singaporean companies.
Opportunities	• New strategies to valorize fruit, vegetables, and liquid streams, e.g., dairy products. • Collaborations/partnerships with licensed food waste recycling companies. • As of 2024, new establishments will have to segregate and treat the food waste on-site. • Government funds to help companies to adopt food waste segregation and treatment technologies.

Threats	• Valorization strategies limited by high:
	  ◦ Land acquisition costs
	  ◦ Labor costs
	• Limited market for some end products (e.g., compost)
	• Sustainable solutions will compete with the biodigestion process for biogas production.

3.3 What is needed to increase food waste valorization?

3.3.1 Cooperation

The consensus among the interviewees is that having cooperation with the government is key, especially when kick-starting some new valorization technologies. Some companies are open to exploring new strategies to valorize food waste. However, they require subsidies to set up plants or pilot plants, and subsidies in case the company requires to venture to a new real state.

3.3.2 Financial incentives

More incentives for companies to engage in valorization strategies. Innovative business models in which food waste is valorized into animal feed or chemicals, for instance, are usually more expensive than traditional models that produce similar end-products. Often the added value of waste management solutions and the application of sustainable production practices are not considered when innovative businesses compete with traditional ones.

In addition, with the operation of the new biodigester at Tuas Nexus, there will be less urgency to valorize food waste into other products than biogas. Therefore, different valorization solutions will directly compete with the biodigester. The preferable strategy is that the government continues to encourage and support businesses to look for valorization routes higher in the food waste recovery hierarchy.

3.3.3 Technological advancements

Technological advancements related not only to valorization strategies but also to machinery to automize and increase the efficiency of the processes. For instance, in some recycling companies, removing the packaging of food waste products is mainly done manually. For businesses, it is important to upgrade the manpower to do more things and more efficiently. The economics of doing valorization requires considering that Singapore is becoming scarce not only in land space but also in human resources.

3.3.4 Monitoring

In Singapore, commercial establishments should report their waste, including food waste, every year together with a reduction plan for the coming year. NEA processes that information and reports the outcome. However, the data reported lacks the detailed level to make a breakdown of the food waste generated by volume and type along the food supply chain. The question is whether the information provided by the companies allows making such a type of analysis. Monitoring is key to:

- Identifying the sources of food waste.
- Introducing measures to reduce food waste at each stage of the FSC.
- Assessing the implementation of adequate valorization strategies.

Monitoring efficiently food losses and waste requires different actions, for instance: structural organization at the ports and better survey systems. But monitoring will not be of significant practical use if the information that is obtained from it is not publicly available. Overall, most companies valorizing food waste are not aware of all food waste streams (volume, composition) that are available.

4 What is the Netherlands doing to valorize food waste?

In the Netherlands, several companies have built solid experience and in-house technology for valorizing food waste and by-products of the food industry. Some of these companies are identified in the table below (Table 3).

Table 3 Dutch companies that valorize food waste and by-products of the food industry

Company	Description	Website link
Chaincraft	Chaincraft produces high-value biobased chemicals from organic wastes using biological processes.	https://www.chaincraft.nl/
Fruitleather Rotterdam	Fruitleather Rotterdam converts unused fruit into faux leather. About 45% of produce is thrown away, and the organization hopes to use this material for fashion accessories and furnishing items.	https://fruitleather.nl/
Instock	Instock produces beer from potato peels (Pieper Beer) and saved bread (Bammetjes Beer). The company also makes granola from brewers' grains.	https://www.instock.nl/en/
Jumbo	Jumbo Supermarkets introduces the concept 'Bread of Bread'. With this concept, the company uses returnable bread, white and whole-grain bread, under its house brand to bake new, daily fresh bread.	https://www.jumbo.com/inspiratie/brood/broodvanbrood
Nijsen company	Nijsen is a frontrunner company in producing animal feed from by-products from the food industry. Its strongest point is the variety of food waste streams, i.e., about 2300 different formal food wastes that can be used to produce their products. The company processes about 100,000 tonnes of food waste a year, which is received from different European countries. All the products that are produced are sold in the Netherlands. Nijsen has a showcase with Kipster, a sustainable chicken farm.	https://nijsen.co/en/
Protifarm	Protifarm is a company operating a high-tech vertical farm, which produces sustainable ingredients for the food industry made from insects. Its functional ingredients contain digestible proteins along with nutritional building blocks, such as vitamins, minerals, fiber and healthy fats.	https://www.protifarm.com/
Protix	Protix transforms food waste into high-quality animal protein meals, lipids, and organic fertilizer.	https://protix.eu/#
Rotterzwam	Rotterzwam produces oyster mushrooms that are grown on coffee grounds. The company collects food waste from catering establishments and sells the mushrooms to the same companies.	https://www.rotterzwam.nl/
Wholy Greens	Wholy Greens produces pasta that contains 50% vegetables from surplus and imperfect vegetables.	https://www.wholygreens.com/

5 Concluding remarks

Increasing the valorization of food loss and waste in Singapore is not only a matter of devising alternative uses of these streams or having the technological advancements to convert them into high-value products. It is a matter of putting together a framework that enables more businesses to engage in valorization strategies. This framework should start by providing a complete overview of the side streams available for valorization. This overview is only possible if an efficient quantification system of food loss and waste along the food supply chain is put in place.

Currently, several valorization strategies can be applied in Singapore. The Netherlands is a frontrunner in some of these strategies, with companies leading the production of animal feed using a variety of food industry by-products (Nijsen) and fruit and vegetables waste streams (Protix) or the production of valuable chemicals (ChainCraift), among others. However, for international companies that want to expand their food waste valorization businesses to Singapore, there is not enough support from the government, e.g., funding. There is a way forward to start businesses in that country through partnerships with already established Singaporean companies.

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