

# UNLOCKING VALUE WITH VALORISATION

Technologies to tackle  
food waste



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IPI is an innovation catalyst that creates opportunities for enterprises to grow beyond boundaries. As a subsidiary of Enterprise Singapore, IPI accelerates the innovation process of enterprises through access to its global innovation ecosystem and advisory services.

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## EXECUTIVE SUMMARY

For the few decades leading up to the millennium, the world reaped record harvests, incomes rose and food prices fell across the board. In recent times, however, the economic slowdown brought about by the pandemic and the increasing incidence of extreme weather events have resulted in an increasingly volatile food supply.

In the next three decades, the earth's population will likely swell towards 10 billion. With large swathes of the developing world rapidly undergoing urbanisation, the issue of food insecurity will be brought to a head. Key to this challenge is the problem of food waste and loss, which is growing across both developed and developing regions.

Recognising the severity of food waste and loss, governments across the globe have launched legislation mandating businesses and individuals alike to recycle their waste. In this report, we briefly examine these laws and other important factors driving research in food waste valorisation technologies. We also detail some of the latest waste treatment methods and how they address the limitations inherent in first-generation technologies such as incineration and anaerobic digestion.

From cutting-edge extraction processes to novel microorganisms used in fermentation, not only are these new technologies able to handle waste more efficiently, they also allow for the recovery of valuable resources—such as bioactive compounds—with a range of applications in functional foods, nutraceuticals and more.

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## Key highlights

### 01

#### Key market drivers

Globally, rising food loss and waste, increasing environmental consciousness and more stringent legislation mandating waste recycling are fuelling demand for valorisation technologies. Improved treatment methods resulting in lucrative end products are also spurring firms to invest in technologies to gain additional sources of revenue.

### 02

#### Ideal for industries

Unlike post-consumer waste, industrial food waste tends to be homogeneous, resulting in a better yield and consistency in valorised products. Currently, an array of mature treatment methods exists in the market, and firms can customise these technologies to meet their waste processing requirements.

### 03

#### A bioactive bounty

Not only are perishable fruits and vegetables more frequently wasted compared with other food groups, they also carry high volumes of inedible waste such as seeds and rind. With the market for edible health products growing, fruit and vegetable by-products present an opportunity for businesses to recover valuable resources such as fibres, therapeutic and nutraceutical compounds.

### 04

#### Going greener

Novel extraction processes have been trending towards greener and more sustainable technologies. Unlike conventional methods, these processes aim to achieve zero waste while using milder or natural chemicals and/or water as the primary solvent. They are both economically viable and environmentally-friendly methods for businesses to close the waste loop.

### 05

#### Start with the source

Mapping out the material flows and waste streams in a processing facility is the first step in the journey to valorisation. Different waste streams will vary in their amount, characteristics and timing of food waste generation. The best valorisation technology in any case therefore hinges on the source of the waste.

# COUNTING THE COST OF WASTED FOOD

Each year, more than 1.6 billion tonnes of food are lost or wasted across the global food supply chain. Put into context, that is a third of all food produced, and the number is steadily growing. With developing regions becoming wealthier and demand for more food and diversity rising, annual food loss and waste is expected to reach 2.1 billion tonnes by 2030<sup>1</sup>.

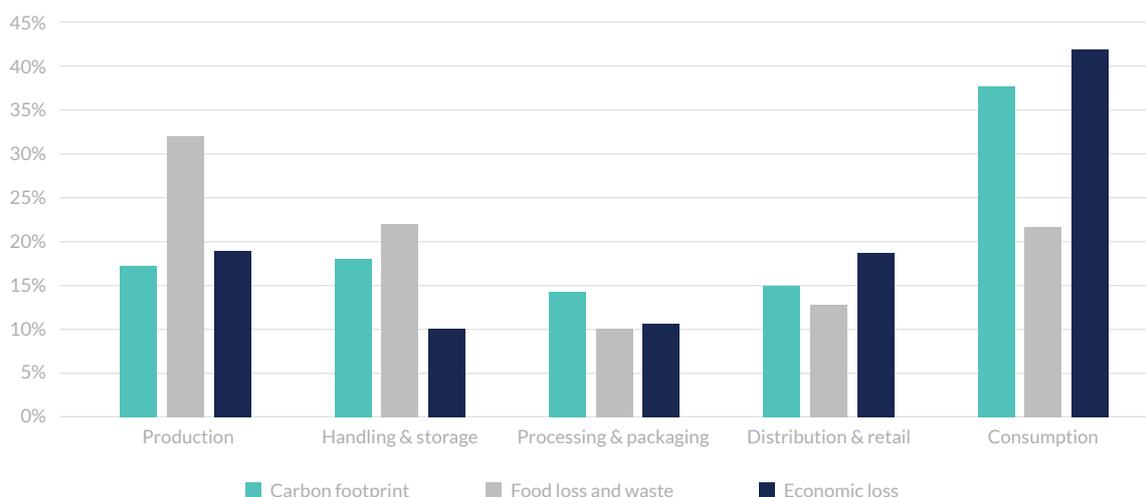
As the global food loss and waste problem has intensified, so has its ramifications. Accounting for about eight percent of human-induced greenhouse gas emissions, food loss and waste is an important contributor to climate change<sup>2</sup>. Additionally, it costs the world upwards of US\$1.2 trillion a year in economic losses<sup>3</sup>, squanders valuable agricultural

land and exacerbates food insecurity at a time where global hunger is rising.

## Food waste from farm to fork

For the consumer at the end of the food supply chain, food waste is synonymous with throwing away expired bread or forgotten leftovers long gone mouldy. While such consumer-driven food waste is indeed responsible for most of the carbon footprint and economic losses of food loss and waste (see Figure 1 below), it may come as a surprise that most of the waste occurs right at the beginning of the supply chain, with producers accounting for 32 percent of food loss and waste.

### Contribution of each stage of the food supply chain to total food loss and waste, carbon footprint and economic loss



**Figure 1** Contribution of each stage of the food supply chain to total food loss and waste, carbon footprint and economic loss globally. Source: 2011 FAO data, 2015 BCG data.

<sup>1</sup> Tackling the 1.6-Billion-Ton Food Loss and Waste Crisis. (2018) Boston Consulting Group. Retrieved on February 2021 from <https://www.bcg.com/en-sea/publications/2018/tackling-1.6-billion-ton-food-loss-and-waste-crisis>

<sup>2</sup> Save Food for A Better Climate. (2017) Food and Agriculture Organization of the United Nations. Retrieved on February 2021 from <http://www.fao.org/3/i8000e/i8000e.pdf>

<sup>3</sup> Tackling the 1.6-Billion-Ton Food Loss and Waste Crisis. (2018) Boston Consulting Group. Retrieved on February 2021 from <https://www.bcg.com/en-sea/publications/2018/tackling-1.6-billion-ton-food-loss-and-waste-crisis>

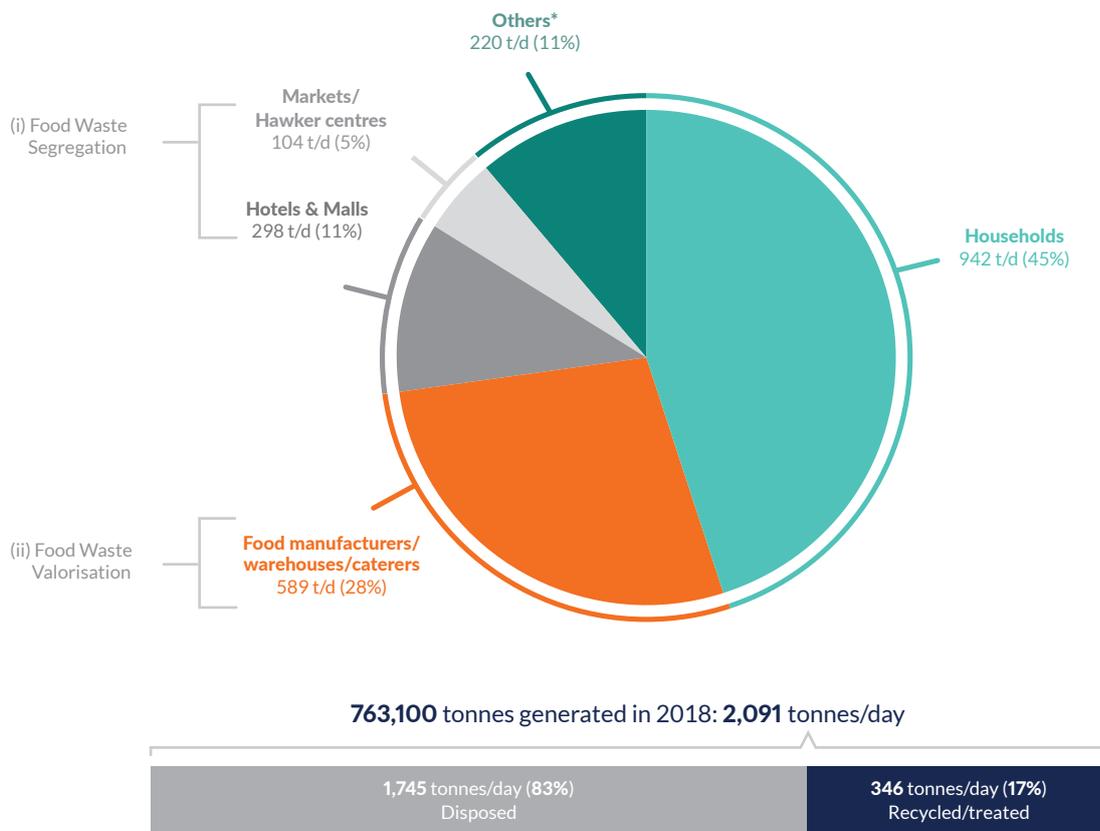
Food waste refers to food that is fit for human consumption but is thrown away, often at the supermarket or individual consumer level due to surplus or spoilage. Food loss on the other hand refers to food lost in earlier stages of production, such as during harvest, storage or transportation. Collectively, they make up food loss and waste, which is the total amount of food lost to the supply chain from production to consumption, and which includes inedible parts such as fruit peels, bones, skin and shells.

In highly urbanised Singapore, which does not have a large agricultural sector, upstream food producers contributed to nearly a third of the 763,100 tonnes of food loss and waste generated in 2018 (see Figure 2 below). However, there is a silver lining: such industrial food waste is a prime resource

for recycling, since it is largely homogenous and produced in large volumes at a single site. In contrast, post-consumer food waste needs to be collected across many different households and tends to be difficult to process due to its sheer variety and high contamination levels.

Recognising this opportunity, industry players involved in pre-consumer food processing and manufacturing are increasingly interested in valorisation technologies that allow them to convert their waste into high-value end products, effectively closing the loop. Apart from edible waste that can be converted to human or animal food products, inedible parts such as bones, feathers and scales can also be valorised to harvest everything from textiles to high-value nutraceuticals.

## Food waste generated by sector in Singapore (tonnes/day)



**Figure 2** Contribution of each sector to food waste generated in Singapore. While households contribute the most to food waste among all sectors, this post-consumer food waste is often mixed and less suitable for effective valorisation, unlike homogeneous industrial food waste. Estimates based on NEA figures from site surveys/interviews and waste characteristic studies.

\*Others: Restaurants, coffee shops, military camps, prisons, hospitals, schools, institutions of higher learning, etc.

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# UNDERSTANDING THE FOOD WASTE MARKET

Globally, the market for food waste valorisation technologies is growing, driven by diverse factors including a rising amount of global food loss and waste, new legislation on recycling food waste, and better valorisation methods that make it economically viable for businesses to recover valuable resources from waste.

## Growing environmental awareness

Rapid population growth in the developing world, coupled with increased climate-induced volatility in the food supply, is contributing to global hunger and intensifying the spotlight on the social and environmental costs of food waste. Responsible production and consumption is one of the 17 United Nations Sustainable Development Goals, and this growing awareness of food waste among consumers and governments has also shifted attitudes in the food industry.



With the rise of Environmental, Social and Governance frameworks, food industry leaders and investors are increasingly viewing valorisation technologies as more than costly investments. When implemented effectively, they are opportunities to mitigate risk, respond to increasing regulatory pressure, obtain additional streams of revenue, and demonstrate a commitment to sustainability.

In 2020, 14 of the world's largest retailers and manufacturers came together to launch a CEO-led Coalition of Action on Food Waste, including US-based Kellogg's and Swiss multinational Nestlé. Such concerted industry efforts could create the critical mass for the development of sustainable and cost-effective valorisation technologies.

## Legislation for industries

Governments across the world are increasingly enacting legislation to curb food loss and waste and mandate food waste recycling. Such laws vary in binding power and enforcement efficacy depending on the country, but developed regions such as Europe and industrialised Asia have shown a strong commitment to food waste reduction.

For instance, the European Union has waste legislation that calls on member countries to reduce food waste at each stage of the food supply chain and report back on progress; in France, recycling is mandatory for all businesses that produce at least ten tonnes of organic waste per year, including the food and hospitality industries. Likewise, Singapore's government is targeting a Zero Waste Nation, with a 30 percent overall domestic recycling rate by 2030, of which food loss and waste plays a significant role.

## Better valorisation processes

Even for businesses operating in countries where food waste valorisation investments are not subsidised, treatment methods have progressed to a stage that makes it commercially viable for them to generate new revenue from waste streams.

Generally, first-generation food waste valorisation technologies include anaerobic digestion for biogas, animal feed production, composting and incineration to generate heat and electricity. These treatment methods have already been scaled-up and commercialised across multiple regions in the past two decades, and are still in use today.

In recent years, spurred by rising disposable incomes and increasing consumer awareness concerning health issues, the market for edible health products has grown. This has correspondingly driven demand for natural bioactive components, such as those extracted

from fruits and vegetables, thereby encouraging further research in the valorisation space.

Currently, novel technologies exist that allow businesses to extract not only bioactive components, but also other lucrative products from their food waste streams. These higher value end products, with applications in the cosmetic, pharmaceutical, food and nutraceutical industries, are raising the profitability of food waste valorisation processes—thereby enabling the production of low-value, high-volume products such as chemicals and biopolymers that would not have been cost-competitive otherwise.

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## SPOTLIGHT ON SINGAPORE

In Singapore, the 2019 Resource Sustainability Act mandates the segregation of food waste for treatment by large food waste generators. From 2021, developers of new large commercial and industrial premises are to set aside space for on-site food waste treatment systems in their design plans. From 2024, large commercial and industrial food waste generators will have to segregate their food waste for treatment, either on-site or off-site. To support businesses amid the then challenging economic conditions, the government had introduced a Food Waste Fund in 2020 to cover the capital cost of food waste treatment solutions, capped at \$100,000 per applicant. This fund will help businesses in segregating and treating food waste ahead of the mandatory requirements and transition towards a Zero Waste economy.





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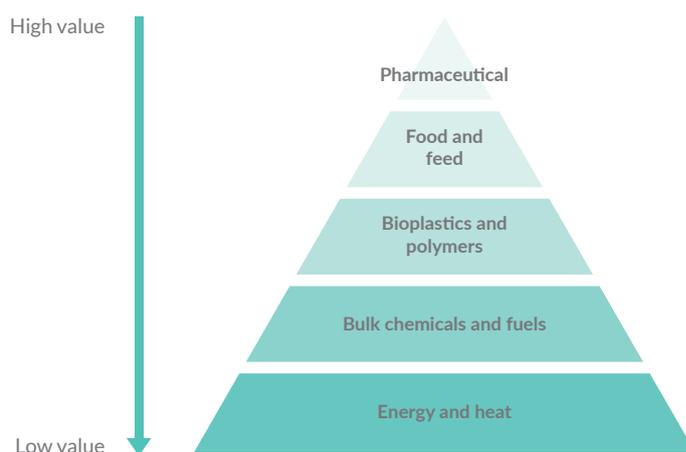
## STATE OF THE ART & EMERGING TECHNOLOGIES

While the average consumer might think of food waste as the mixture of bones, shells and rice grains left on their plate after a meal, processing such heterogeneous waste remains the elusive holy grail of valorisation. Current technologies are limited in their ability to convert food waste of varying compositions into useful materials due to the differences in raw material inputs. Hence, majority of treatment methods today process food waste into lower value commodities such as compost, fertilisers, animal feed and even energy via waste-to-energy or biodiesel production technologies.

However, novel methods that enable businesses to extract lucrative products such as proteins, carotenoids, polyphenols, vitamins, enzymes and other bioactive compounds from waste streams are emerging. These products have applications in the pharmaceutical, nutraceutical and food industries, and represent an upward shift on the valorisation value pyramid (see Figure 3).

These new technologies, which include fermentation, hydrolysis and a variety of extraction methods, have been largely applied in the area of fruit and vegetable by-products. Fruit and vegetables have the highest loss and waste among all types of food, and comprise a relatively higher volume of unavoidable, inedible waste such as seeds, skin, rind and pomace. They also contain exceptionally high amounts of useful therapeutic and nutraceutical compounds, from dietary fibres and oils to vitamins and enzymes, making them suitable for the extraction of bioactive compounds.

In the area of fermentation-based valorisation strategies, the production of specific compounds is largely dependent on the raw material and particular microorganism selected. For example, bacteria can be used to ferment rice bran after enzymatic hydrolysis,



**Figure 3** Moving up the valorisation value pyramid. In recent years, homogeneous food waste valorisation has grown beyond low value fertilisers and animal feed, to higher value pharmaceutical, nutraceutical and even cosmetic products.

to produce high purity lactic acid, while yeast and filamentous fungi can convert cocoa by-products into enzymes and polysaccharides<sup>4</sup>.

Fermentation aside, conventional processes including solvent extraction and novel extraction techniques such as subcritical water extraction, enzyme-assisted, ultrasound-assisted and microwave-assisted extraction can help businesses recover bioactive compounds present in their industrial food waste, to varying degrees of effectiveness.

In traditional solvent extraction, raw material is exposed to different organic solvents, which take up soluble components of interest. Once the solid residue is filtered out, the extract can be used as an additive, food supplement or in the production of functional foods. While solvent extraction is commonly used due to its low cost and ease of operation, its drawbacks, such as possible thermal degradation of compounds during the long extraction process, have spurred the development of new and more effective methods<sup>5</sup>.

Two of these technologies are ultrasound-assisted and microwave-assisted extraction. Compared with conventional methods, these processes are particularly effective in deriving bioactive compounds from natural products. By facilitating the diffusion of solvent into cells through ultrasound and microwave technology respectively, they promote the release of bioactive components, improving extraction yield while reducing time taken.

## Effective and eco-friendly extraction

In recent times, extraction processes have been trending towards greener and more sustainable technologies. Unlike traditional methods which require significant amounts of toxic chemicals and generate a considerable volume of waste, these green processes aim to produce zero waste while using milder or natural chemicals.

For instance, enzyme-assisted extraction, which uses enzymes to catalyse reactions under milder processing conditions, is an attractive alternative to conventional solvent extraction. Relying on cellulase, xylanase, pectinase and a host of other enzymes to degrade cell wall structure and release useful intercellular substances, and using water as a solvent instead of harsher chemicals, the process offers a more environmentally-friendly method of extracting bioactive compounds.

Another green and promising valorisation technique for obtaining compounds from food waste is subcritical water extraction. Subcritical water refers to water at a temperature between 100 and 374°C, and at a pressure high enough to maintain its liquid state. Using subcritical water as a solvent, this method allows for compounds to be extracted from plants and algae efficiently and in an eco-friendly manner, without the use of toxic chemicals.

<sup>4</sup> Sabater, C. et al (2020). Valorization of Vegetable Food Waste and By-products Through Fermentation Processes. *Frontiers in Microbiology*. Retrieved from <https://www.frontiersin.org/articles/10.3389/fmicb.2020.581997/full>

<sup>5</sup> Kumar, K. et al (2017). Food waste: a potential bioresource for extraction of nutraceuticals and bioactive compounds. *Bioresources and Bioprocessing*. Retrieved from <https://bioresourcesbioprocessing.springeropen.com/articles/10.1186/s40643-017-0148-6>

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# THE CASE FOR VALORISATION

## Case study: Extracting phytochemicals from sesame oil cake

Whether it is used in a stir-fry or seasoning sauce, sesame oil is a common ingredient in Asian cuisine. This fragrant vegetable oil is produced by extracting oil from sesame seeds, with each seed typically yielding about half of its dry mass in oil. The remaining half, a by-product known as sesame oil cake, remains high in nutritional value; more than third of the leftover dry mass consists of protein.

With Singapore producing 2,000 tonnes of sesame oil cake in 2014 alone, valorisation of this nutritional by-product is potentially lucrative. Currently, sesame oil cake is most commonly processed into livestock feed, usually in combination with other protein sources. With suitable treatment techniques, sesame oil cake can be transformed into end products of even higher value.

Using suitable valorisation technologies, businesses can obtain valuable phytochemical extracts, such as antioxidants and vitamins, from sesame oil cake. Such extracts can then be sold for additional revenue, used in-house to develop other products such as nutraceuticals, or employed as more natural alternatives to synthetic food additives such as butylated hydroxyanisole and butylated hydroxytoluene.

Treatment methods range from mature extraction technologies, such as conventional mechanical pressing and organic solvent extraction for targeted ingredients, to more novel solutions. These newer techniques, involving pulsed electric fields and high-voltage electrical discharges<sup>6</sup>, have shown promising results in efficiently extracting specific ingredients.



<sup>6</sup> Sarkis, J. et al (2015). Effect of pulsed electric fields and high voltage electrical discharges on polyphenol and protein extraction from sesame cake. *Innovative Food Science & Emerging Technologies*. Retrieved from <https://www.sciencedirect.com/science/article/abs/pii/S1466856415000478>

## Case study: Deriving protein and collagen from fish waste

When fish meat is stripped from the bones and processed into fish balls, fish cakes and other products, offcuts such as the heads, scales, innards and tails often go to waste. Valorisation technologies play a key role in unlocking value in these scraps, in particular hydrolysis methods that can transform them into useful food products such as fish sauce and nutraceutical ingredients.

Using enzymatic hydrolysis, Norwegian biotechnology and nutrition firms Biomega and Hofseth are producing fish meal, calcium bone powder, protein hydrolysates and fish oil from offcuts of salmon. Both their technologies can be further adapted to handle sardine and mackerel waste.

With a technology readiness level of 9, Biomega's and Hofseth's valorisation solutions are mature, with Biomega processing 60,000 tonnes of fish waste a year. The firms' high-quality, peptide-rich protein hydrolysates are used in both human nutrition and premium pet food and can command up to US\$2,500 a tonne.

In Singapore, researchers from Nanyang Technological University have developed a chemical extraction method to obtain collagen from the scales of commonly consumed fishes such as sea bass and tilapia. With a technology readiness level of 6 to 7, the solution is currently under development to increase collagen yields, which can be sold or used as an alternative to bovine-derived collagen. Additionally, the collagen has biomedical applications, particularly in wound-dressing to promote tissue repair and regeneration for non-healing, chronic wounds such as those of diabetic patients.





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## OUR INSIGHTS

### Key market drivers

Demand for valorisation technologies is growing due to various drivers. First, food loss and waste is on the rise globally and projected to continue increasing, spurring demand for solutions that enable businesses to better manage and reduce their waste. Further, growing awareness of the environmental costs of food waste and new legislation for industries that mandate recycling mean valorisation technologies are increasingly viewed as opportunities to mitigate regulatory risk and demonstrate a commitment to sustainability. Lastly, improved treatment methods are making it commercially feasible for firms to profit from food waste processing. For instance, demand for bioactive components that can be extracted from fruit and vegetable by-products is rising, driven by a growing market for edible health products.

### Ideal for industries

Current valorisation methods are not sufficiently advanced to handle post-consumer food waste, but many are particularly effective in processing industrial food waste. Such pre-consumer waste tends to be more predictable in both its composition and quantity, allowing for more targeted treatment strategies and resulting in a better yield and consistency in valorised products. From the extraction of phytochemicals from sesame oil cake to obtaining protein and collagen from fish waste, there currently exist many valorisation technologies that effectively close the waste loop with minimal residues, while providing businesses with an additional stream of revenue. However, depending on the differences in food waste sources, businesses might still need to customise the technology to meet their unique requirements.

## A bioactive bounty

Due to their perishable nature, fruits and vegetables have the highest loss and waste among all types of food. They also comprise a relatively higher volume of inedible waste such as seeds, skin and rind. With the market for edible health products burgeoning, fruit and vegetable waste and by-products present an opportunity for businesses to recover valuable resources in the form of bioactive components. From fermentation to varying methods of extraction, novel technologies exist that generate compounds with high-end pharmaceutical, nutraceutical and food applications. With their higher profit margins, these products further unlock valorisation value for companies by enabling them to produce low-value, high-volume commodities such as chemicals and biopolymers which would not have been cost-competitive otherwise.

## Going greener

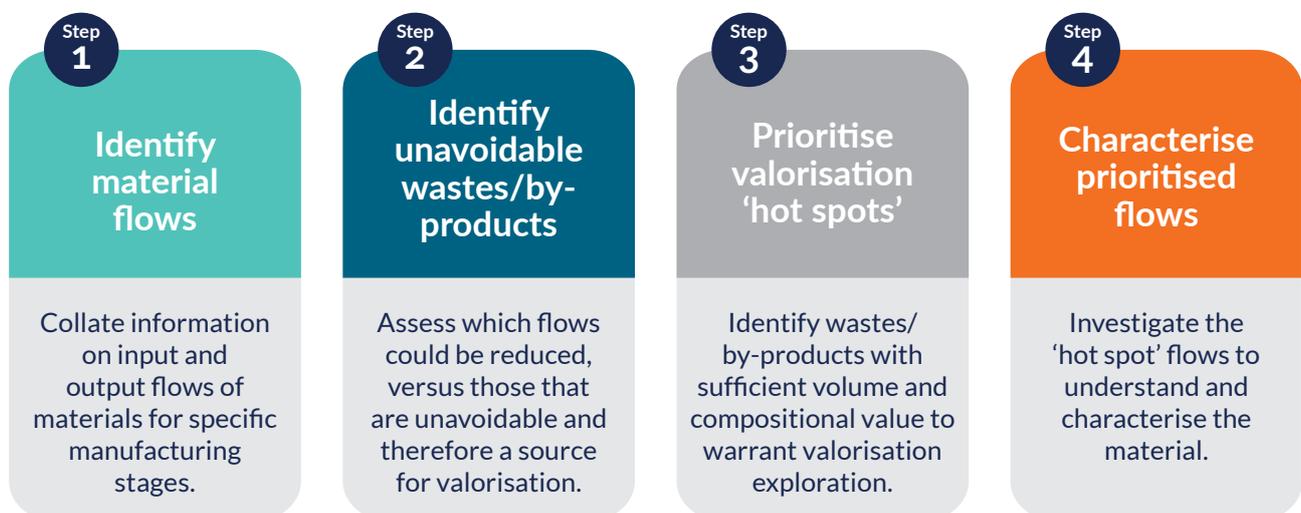
Novel research and technologies in the valorisation space have tended towards greener and more sustainable methods. Unlike conventional technologies which typically make use of toxic chemicals, some new extraction processes are able to effectively break down cell walls in fruit and

vegetable waste to facilitate the release of useful compounds within by mainly using water or other natural compounds as a solvent. By omitting harsh chemicals in the treatment process, these methods of enzyme-assisted extraction and subcritical water extraction reduce toxic waste generated and provide companies with an environmentally-friendly solution to close the waste loop.

## Start with the source

Identifying the material flows and waste sources in a processing facility is the first and most critical step for any business looking to enter the food waste valorisation market. Each food waste stream will have its own unique profile, differing in the amount, characteristics, and timing of food waste generation. The best technology pathway for managing a specific stream will therefore also vary accordingly, and considerations such as the business model and existing operations of the company, environmental policies and subsidies, and the existence of a market for the valorised end product will be key factors in a firm's decision to invest in valorisation technologies. Additionally, mature treatment methods are less risky to invest in, but funding novel technology developments could pay off in more efficient treatment and higher-value end products.

# HOW TO BEGIN VALORISATION?



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## TECH OFFERS

Novel technologies have emerged that enable the recovery of lucrative products from by-products. Harness these innovative valorisation methods and manage your waste streams with our diverse range of Tech Offers.

### Food-safe coating to curb microbes

- When fresh fruits and produce are harvested and washed, they usually experience a decline in shelf-life due to microbial spoilage and damage during handling.
  - To stave off spoilage at the subsequent transportation, distribution and retail stages, food-safe coatings made of natural and synthetic materials have been developed.
  - However, these conventional coatings have their limitations. Some materials are formulated with compounds from non-food sources, while others require harsh heating processes for their application, making them unsuitable for many fruits and vegetables.
  - To address this issue, an Italian company has developed a food-grade spray-on coating that uses functional compounds that are fully derived from fruit and vegetable by-products to extend the shelf-life of produce.
  - The coating is naturally bio-based and edible with anti-fungal and anti-microbial properties to reduce harmful pathogens and avoid cross-contamination. It also acts as an ethylene barrier against spoilage without affecting either the flavour or scent of the produce.
- The technology, which can be customised and formulated according to the application, can be used on fresh produce, dried food products, and even as an anti-microbial coating for non-food surfaces.
  - When applied to climacteric fruits, the coating extended their post-harvest life by 50 to 100 percent, which is comparable to existing synthetic coatings. The company is currently seeking partners keen to develop customised coating solutions for food products.



## An integrated biorefinery for food and textiles

- In recent years, there has been growing demand for biotechnology-based processes for material, chemical and fuel production as more sustainable alternatives to chemical-based solutions.
- To meet this need, a Hong Kong research team has developed an integrated biorefinery strategy to valorise mixed food waste into these desired end products.
- Through the use of microorganisms in processes such as enzymatic hydrolysis and fermentation, and by utilising industrial methods including saccharification, pyrolysis and other green chemical treatments, this technology transforms food waste into value-added products such as bio-surfactants, biopolymers, bio-colorants and chemical precursors.
- The technology has thus far been effective in treating fruit, vegetable and bakery waste, converting these by-products into succinic acid, a food additive and chemical precursor.
- Restaurant food waste has been used to generate sophorolipids, a bio-surfactant, while carbohydrate-rich snacks and beverages are turned into fructose which can then be further processed into a biopolymer precursor.
- This technology can also handle textile waste in the form of cotton and polyester blended fabrics, which have been recycled into rPET and bio-products such as glucose.



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## CONCLUSION

The amount of food loss and waste generated has grown over the decades, and is projected to continue increasing in most regions. As incomes rise in developing nations, demand for more food and a greater diversity of food will inevitably lead to larger amounts of food loss and waste across all sectors of the supply chain.

With food waste set to become a growing problem, stringent laws mandating waste recycling have been enacted worldwide, spurring industrial demand for food waste valorisation technologies. At the same time, novel treatment methods are presenting businesses with more than waste management opportunities; valuable resources can be extracted from by-products that can be sold for additional sources of revenue.

If you would like more details and to learn about opportunities in food waste valorisation, please contact: [techscout@ipi-singapore.org](mailto:techscout@ipi-singapore.org).

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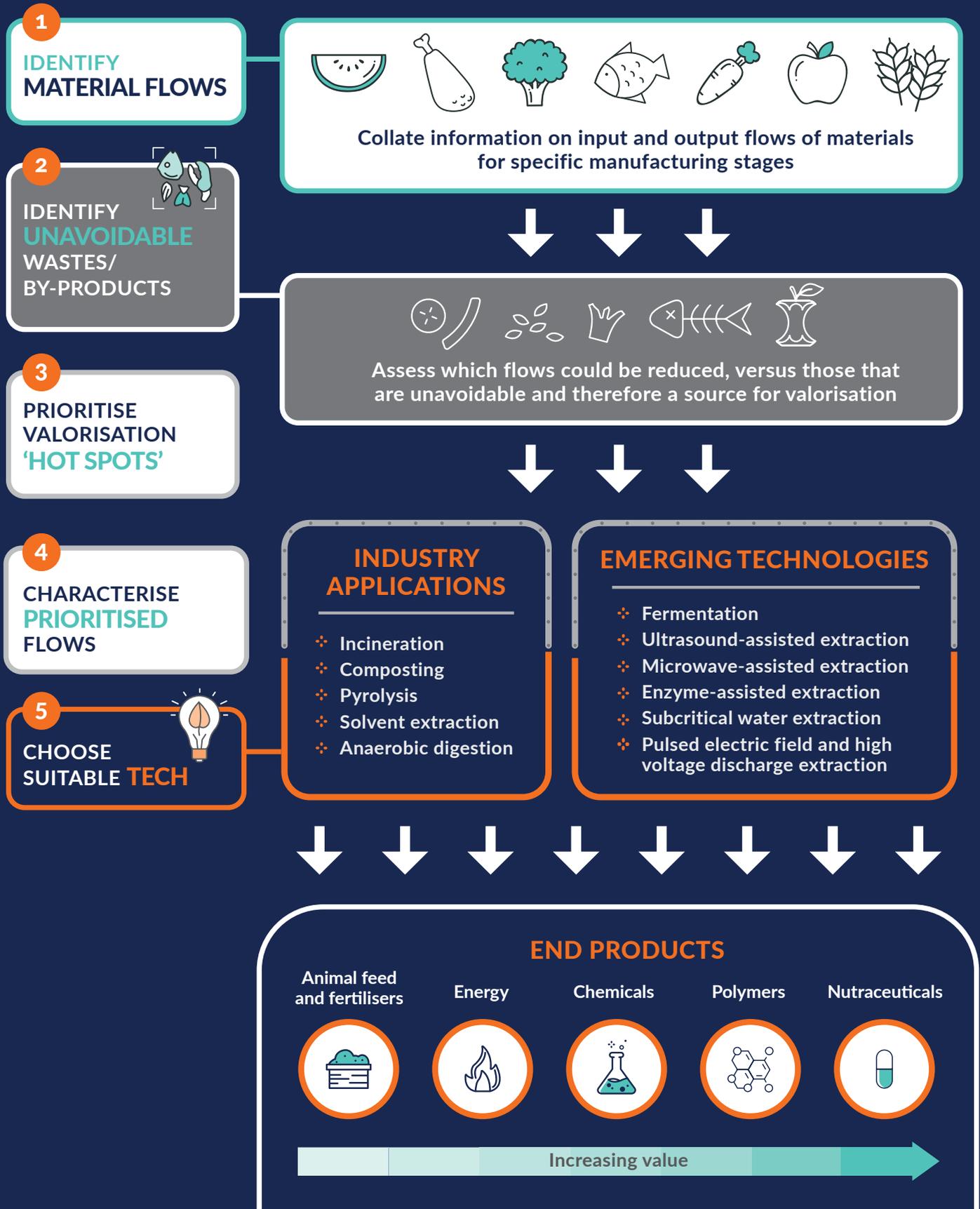


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# VALORISATION ROADMAP





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