WASTE-TO-VALUE: A WHITE PAPER ON THE FUTURE OF FOOD UPCYCLING IN ASIA

A Future Food Asia initiative

In partnership with

Dole

Agency for Science, Technology and Research
SINGAPORE

BÜHLER

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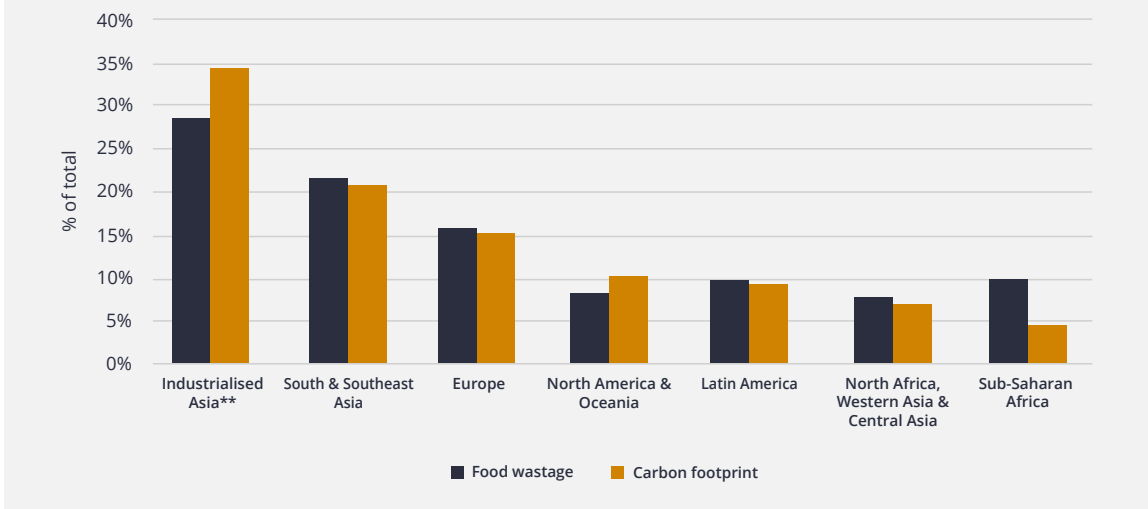
Waste-to-Value: Extracting New Worth From Asia's Agrifood Waste Streams

- Asia's food waste is both excessive and undervalued. Expect that to change rapidly in the years to come thanks to a mix of new tech and policy resolve. Investors, policy makers, and corporations eying 'circular solutions' for agri-industrial food valorisation stand to make major gains.

Let's start with the bottom line: today's agri-food waste levels in Asia are untenable and undervalued. Untenable because farmers here are already straining to supply this vast continent of over 4.6 billion people – a task only getting tougher as populations here grow in size and wealth. Finding fresh ways to meet this unprecedented demand is also running into challenges like climate change, biodiversity loss, and soil depletion. Geopolitical strife in global food powerhouses like Myanmar or Ukraine is only adding to the burden, ratcheting up prices for fertilisers, food, and feed. Supply chains, meanwhile, are still chastened by the Covid-19 pandemic, and could take months if not years to recalibrate.

So while more agri yield hikes are of course an essential aim, the days of more than one third of Asia's food getting lost and wasted on its way from farm to fork have to be consigned to the history books — and fast. It is not just a humanitarian duty; it is also good business practice, as much of this waste holds huge stores of underutilised value just waiting to be unlocked.

Contribution of each region to food wastage and carbon footprint*



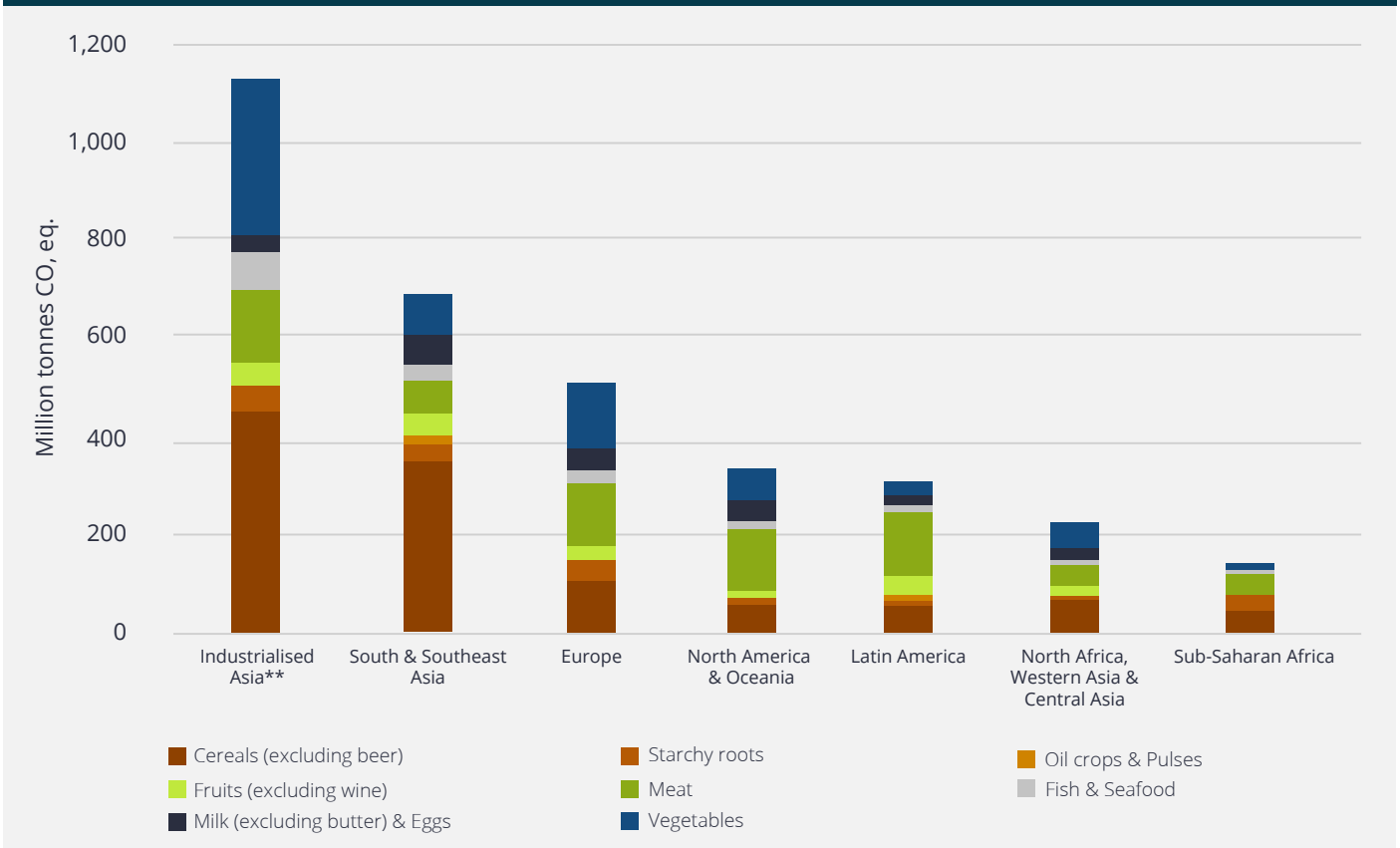
*Source: FAO, Food Wastage Footprint, Summary report

** Republic of Korea, China and Japan

Financial and Carbon Incentives

The financial incentives for unlocking the value of foodwaste are stacking up, not just in Asia but globally. According to the UN, the global toll of food waste comes to a shocking US$2.6 trillion per year.[1] The costs are hammering Asian economies at all levels of development. Even an economic dynamo like Japan has massive scope for improved practices on food waste. In 2018, 6 billion kgs of food was reportedly lost and wasted there, roughly the same sum of food that 13 million people in Tokyo eat each year.[2] The carbon incentives are mounting too. Food wastage is intricately tied in with carbon footprints; and this is where, as these graphs show, there are massive spaces for better practices in both 'Industrialised Asia' and 'South and Southeast Asia.'

Carbon footprint of food wastage, by region and by commodity*



*Source: FAO, Food Wastage Footprint, Summary report
** Republic of Korea, China and Japan

Fresh Waves of Tech and SDG Ambition

Reacting to this innovation nexus are fresh waves of emergent agrifood waste management technologies. This White Paper will investigate many of these, ranging from automated insect waste digestion right through to energy efficient drying and storage technologies.

Elsewhere, we take a close look at how government agencies like Singapore's Agency for Science, Technology and Research (A*STAR) are helping to drive mission-oriented research that advances scientific discovery and help companies remain competitive. We feature a spate of other public and private waste upcycling initiatives on the horizon in the Asia-Pacific region, whether that is experimental pilot schemes to turn potatoes into plastic, or scaled-up anaerobic digesters bringing electricity and heat to local communities – all drawn from sugar cane that would have otherwise been burnt in the fields, the smoke left to drift into nearby towns.

These sorts of technology breakthroughs and pilot schemes are coalescing with a growing appetite for policy action from Asia's corporates, investors, governments, and startups. Regulatory frameworks,

Initiative	Region	Summary of key elements and targets
SDG 12 - Responsible Consumption and Production	United States	Target 12.3: by 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains.
Various	EU	Green New Deal, Circular Economy Action Plan, and Waste Legislation address circularity food system to reduce waste and tackle climate change; Farm-to-Fork Strategy (forthcoming) will propose specific target to cut food waste.
SG Green Plan 2030	Singapore	Reduce the amount of waste to landfill per capita per day by 30% and meet 30% of Singapore's nutritional needs through locally produced food
National Food Waste Strategy	Australia	Framework to support collective action towards halving waste by 2030.
Food Loss Act	Japan	Measures to reduce household food waste by half by 2030; previously enacted Food Recycling Act to turn food waste into fertilizer and feed.
Recovery and Distribution of surplus food Regulation	India	Establishing protections for organizations and individuals who donate food in good faith, and a network of agencies to facilitate distribution.

classically relaxed, are tightening in some countries across Asia-Pacific.

Barely a day goes by without another major commitment in the region to bolster Environmental, Social and Governance (ESG), or announcements of bold pledges to meet – or indeed surpass – the UN's Sustainable Development Goals. Indeed, SDG 12.3 calls for halving food waste by 2030.[3]

Nor are UN-led goals like 12.3 the limit of what's possible. Dole Sunshine Company, one of the world's top fresh fruit producers, is an example of how some companies are urgently seeking new ways to get far in front; Dole has set out its own plans to "eliminate its food waste by 2025," all while pledging to be carbon neutral by 2030.[4]

By a cascading effect, reducing food waste will also affect 8 other different goals, listed here below.*

*Source: http://lifefoster.eu/food-waste-reduction-sustainable-development-goals

We should focus on food waste to decrease the CO_2 emissions. But we do not have any type of carbon credit system to incentivize food companies to reduce this waste.

Ninna Granucci, CEO, Green Spot Technology

New Dawn for Upcycling

Interwoven in pledges like Dole's is a wholesale awakening to the inherent value of previously underutilised sidestreams. Whether it is from spent grain or banana stems, or from coconut husks to wonky mangoes, food producers and processors are drawing inspiration from Asia's fledgling upcycling movement and the rising sway of circular economic thinking. Encouraged by non-profits like the Ellen Macarthur Foundation, strategic decisions to move supply chains away from a linear model of production-to-consumption — and toward a 'reduce, reuse, recycle' model — are opening up fresh opportunities, both in value addition as well as for marketing to increasingly environmentally conscious consumers.[5] Indeed, circularity even helped a company like Dole emerge as a behind-the-scenes star of New York fashion week via its collaboration with upcycled banana textiles company Musa Fabric – a boost for both brand and bottom line.[6]

Upcycling banana stems into fabric for sustainable alternative fashion products

Okara: Soy pulp extract.

The Upcycled Food Association defines upcycled foods as ones that "use ingredients that otherwise would not have gone to human consumption, are procured and produced using verifiable supply chains, and have a positive impact on the environment."[7] The upcycling certification movement may be in its nascence in Asia; but the continent has a rich tradition (and world leading capacities) of using techniques like fermentation and other techniques to repurpose waste. So an impending uptick in consumers coming to value upcycled products is not to be ruled out — especially when combined with Asia's notable rising appetite for alternative protein sources. Already there are signs of success with upcycled alternative protein products like okara, the soy pulp left over from tofu or soy milk production. Companies like Korean startup RE: Harvest are pioneering okara meat analogue ingredients via novel fermentation.

Establishing the Hierarchy of Waste

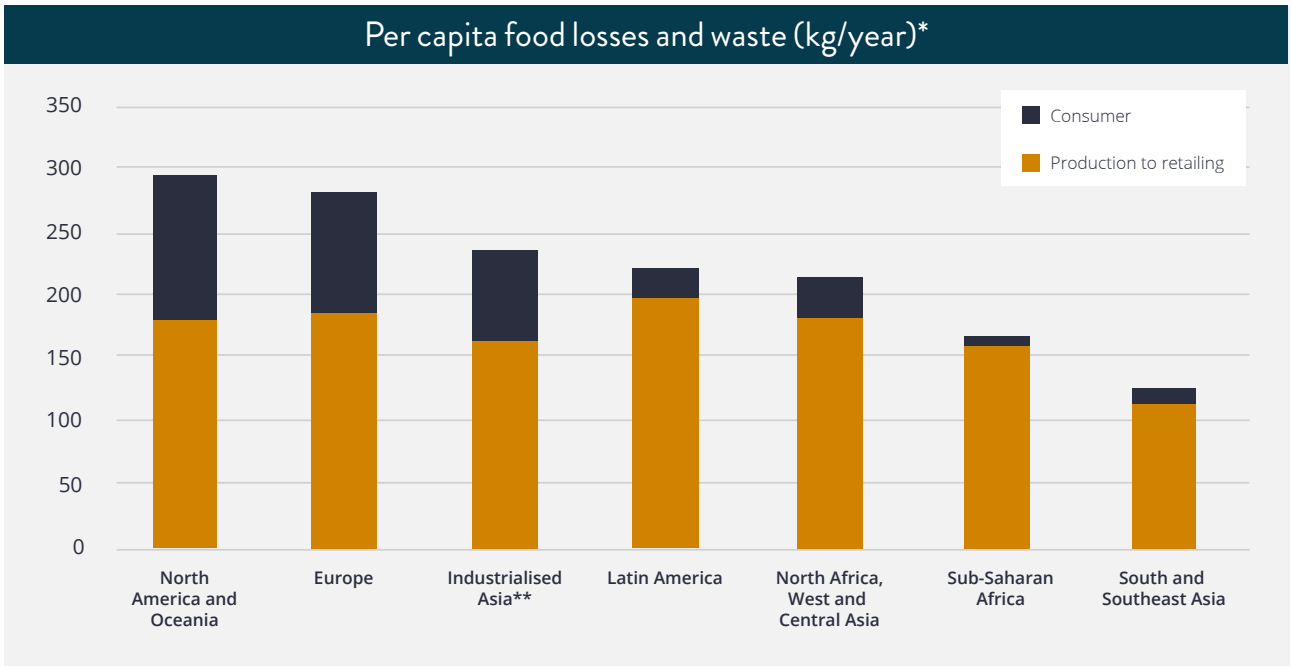
Where and how might such an upcycling movement take off in Asia? this paper asks. And for investors and corporations, where might the major opportunities lie? Where can policy makers support the movement?

There is the self-evident conclusion that more needs to be done to reduce food waste pre-harvest, at the retail level, or in the household. In all of these, we saw major promise in anti-waste social networks like food sharing app Olio, which is planning its Asian expansion. Or upstream, companies like India's Ecozen are designing, financing and supplying distributed networks of energy-efficient and solar powered cold storage to food producers in South Asia.

That said, we see the vast volumes of food wasted at the agri-industrial level in Asia as a focal point with major scope for food valorisation, and hence the driving focus of this report.

Besides volumes, we see other pivotal advantages justifying our point of focus. Unlike at the household level in most of Asia, there are far fewer waste collection bottlenecks at the agri-industrial level; food waste from agri-industrial facilities have more ready possibilities to be rapidly collected, stored, and processed.

Similarly, waste here is often more homogeneous than household or retail waste, reducing some of the engineering



*Source: FAO: Global food losses and food waste – Extent, causes and prevention report
** Republic of Korea, China and Japan

headaches that can come when dealing with multiple or mixed waste stream systems. There is a far lower risk of contamination, making food safety easier to ensure.[8] Incremental technology improvements are well poised to change the game here too. At the agri industrial level, the incremental efficiency improvements of freezing and drying technologies will have a strong chance of reaching scale quickly, as will biotech breakthroughs in enzyme deployments, insect husbandry, fermentation techniques, or textile hybrids with novel food waste materials like pineapple leaves.

Yet to wade into this area is to navigate a complex set of dilemmas over end products. The debate on industrial agri food waste often comes down to competing theories of hierarchy. Namely, what is the most valuable end-product to create as a side stream?

These will vary depending on all sorts of factors, like what might be the raw material in question, and where exactly is it being produced compared to its potential market destination; what sort of capital expenditure or added facilities would be required (or available) to do something imaginative (and sufficiently value additive). How about feedstock supply? Finally, is there a credible market fit once you are done. It is easy and tempting to delight in today's widening array of upcycling possibilities that are theoretically available with new processing techniques. Yet demand potential has to be there too. And even when demand is there, competing with, say, subsidized conventional single use plastics with an upcycled food waste product is going to be a struggle, often requiring a consumer preparedness to pay a "sustainability premium."

On top of that, the question of what is truly more sustainable or more economically valuable is not always clear cut at the outset. There are often several overlapping claimants with their own ideas for how to glean value from side streams. Burning agri-residues in the field, for instance, is considered an undesirable misuse of a potentially valuable by product of sugar cane or palm. Yet technically, even this serves a rudimentary if inadequate purpose of pest control and basic fertilisation. And for business model creation, there's the mixed blessing of getting too close and intertwined to the source; the pricing of feedstocks tends to rise as producers wake up to the sidestream end value potential.

To better navigate this complex hierarchy of value, we have opted to follow the lead of the Swiss food processing technology company Bühler, which has devised the following value pyramid in its operations across Asia. The company is committed to having solutions ready to reduce energy, waste and water by

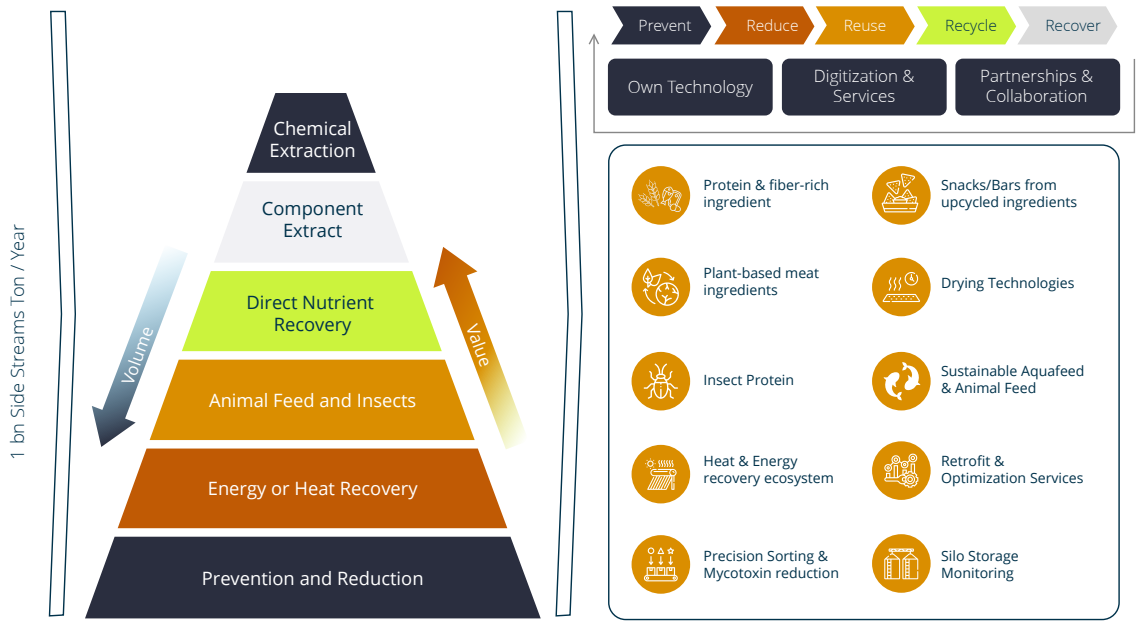
50 percent in its customer's value chains by 2030. As shown, its focus delves into drying technologies, sustainable aquafeed and animal feed solutions, plant-based meat ingredients, silo storage monitoring, precision sorting and mycotoxin reduction, insect proteins, and retrofit services.

The placing of 'Prevention and Reduction' at the base of the pyramid is to show the huge volumes of food that can be recovered from initiatives like better storage or transport. However, this contains limited value add for food producers operating in side stream value addition, according to Bühler's Food Science Officer, Béatrice Conde-Petit.

In a similar vein, the role of biomass for heat and energy is always locked in a tough battle with fossil fuels, she explains, albeit potentially more viable in a global context of high fuel prices or a local context of limited fuel access in remote rural areas of countries like Indonesia or the Philippines. The placing of Animal Feed and Insects higher on the Bühler hierarchy represents the lower volumes available than for heat or energy, but also some of the higher value potential. Insect feed for poultry or aquaculture in particular has been hailed as nutritious and immuno-positive, thus coming with a premium as producers eye reductions in antibiotic use and consumers warm to ideas of 'carbon neutral' or 'omega-3 rich' eggs and fish.[9]

Besides its environmental and health benefits, insect feed for aquaculture can

Today's Side stream Valorization Opportunities*



*Source: Bühler waste to value white paper

make a strong business case on the back of Asia's surging demand for seafood amid dwindling wild fish stocks. Already on a global level, fish farming is dominated by Asia, which has produced 89 percent of the world's total farmed fish by volume in the last 20 years. The FAO predicts that "over the next ten years, Asia will produce asimilar majority of sectoral aquaculture production growth. That will pushup demand for premium feedstocks like insect feed, and facilities will need to be built out rapidly to keep pace."[10]

Sitting at the higher end of the pyramid, even more so than insects for aquaculture feed, are Chemical Extraction, Component Extracts, and Direct Nutrient Recovery (Some insects, like the Black Soldier Fly, are also well placed for the extraction of chitin, which has several medicinal, industrial and biotechnological uses.). The report will focus substantial attention on some of the other value creation opportunities here, like the extraction of functional enzymes like bromelain from fruit pith. But first, it is worth mapping out and highlighting some of the waste streams of note across Asia in greater detail.

Mapping the Geography of Waste

- Industrialised Asian economies like Japan, Singapore or South Korea offer strong testing beds for experimental upcycling pilot schemes with emphasis on high tech automation and widening access to capital.
- Emerging Asian economies with a greater agrarian focus like Indonesia or the Philippines bring opportunities for waste-to-energy biofuel systems, textile manufacturing from agri-residues, and functional ingredients from perishable fruits.
- More agro processing at the farm level could provide chances for farmers to boost their own revenues and incentivise agri-residue collection and storage.

The Asia Pacific region is economically, culturally, politically and climatically diverse. So the way the region wastes its food is similarly various, and is often dependent on the value stream in question. Banana skins get wasted in a very different way to rice husks or empty palm fruit bunches.

On the one hand, in the more industrialised countries of Asia Pacific, like South Korea, Singapore, or Japan, the tendency is more toward greater proportions of food waste getting lost at the household or retail level. Consumers here can afford to be more wasteful and extravagant. Then again, waste collection systems are also easier to roll out here to counter that, and major cities from Taipei to Kyoto are full of initiatives for smart food waste collection. In the Korean capital of Seoul, municipalities have equipped thousands of bins with scales and Radio Frequency Identification (RFID) to weigh and charge residents for their waste using an ID card. The pay-as-you-recycle machines (or reverse vending machines, as they are called in similarly pioneering Nordic countries like Sweden), encourage the drying of the waste they deposit to make it lighter and therefore cheaper to throw out; according to the World Economic Forum, the system has reduced food waste in the city by tens of thousands of tonnes, as well as saving the city budget millions from collection costs.[11]

At the agri-industrial level for South Korea, strong best practices combine an early

High-tech food waste recycling machines in Seoul

adoption of next generation automation with an ease of doing business, making it well placed for pilot schemes of novel waste treatment. That said, higher energy and unit economics costs can be a drawback compared to more affordable if less developed parts of Asia.

Meanwhile, the investment scene in highly developed parts of Asia is also receptive to new ideas, and there is capital ready to be deployed. Increasingly, there are promising signs of regulatory activism in the pipeline, as well as grants, which will push companies to more waste reduction and valorisation.

On the consumer demand side for end products, there is also a nascent appetite for higher grade food ingredients and more sustainable food choices.[12] This can get overstated, but climate awareness is certainly growing among millennials and Gen Z and there is major scope for an Upcycling movement along similar contours to those in Europe and North America.

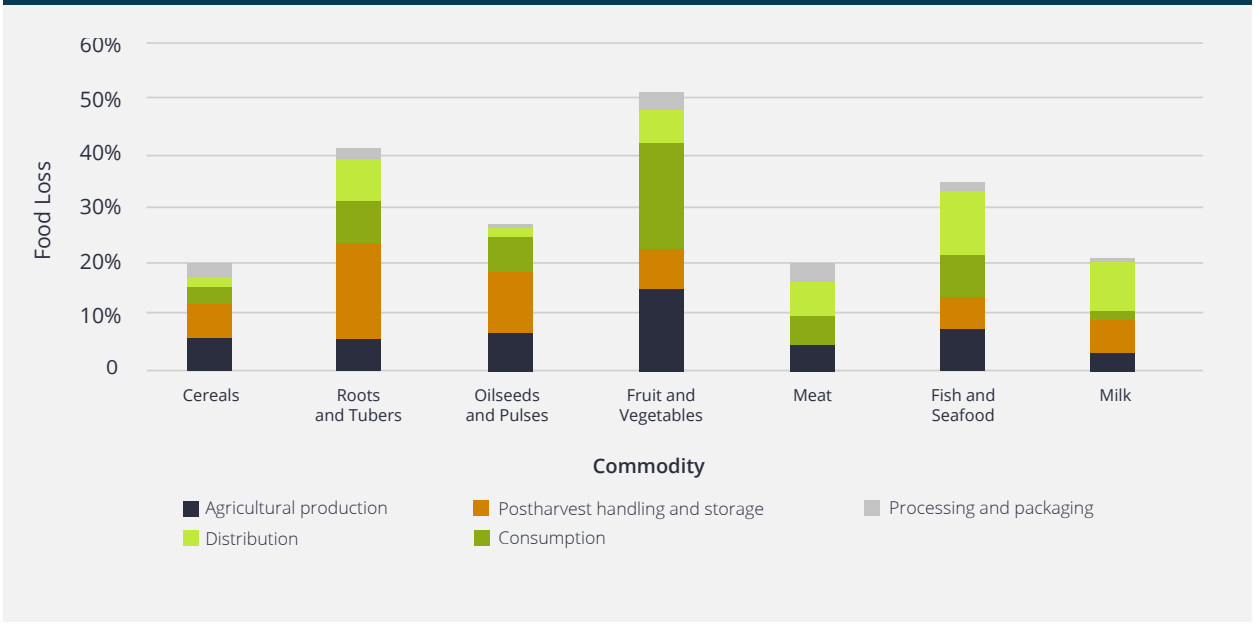
Upstream Waste in Asia-Pac's Emerging Economies

Countries in South and Southeast Asia, meanwhile, are home to more rural and agrarian societies of high proportions of smallholder farmers.

While there is less waste by consumer focused spending power, there's a far greater proportion of waste upstream. Preharvest losses can be reduced by widening access to new, robust and efficient technologies, as well as agrarian practices that provide greater resilience in the context of climate change. Food loss is mostly caused by the inability of smallholder farmers to provide proper postharvest handling. That includes a lack of state-of-the-art storage facilities, infrastructure, cooling chains, packaging and marketing systems. Governments, companies and international investors can do more to provide necessary infrastructure upgrades.

These limitations, along with climatic conditions in the country, are favorable to spoilage and diseases that often lead to large amounts of food losses. The agroprocessing sector also contributes to wasteful practices

Food Losses Within the Food Supply System in South and Southeast Asia, by commodity Group*



*Source: FAO: Global food losses and food waste – Extent, causes and prevention report

Tonnes of avocados dumped due to rising labour and shipping costs during the pandemic.

in the food industry, with specific food shape and appearance requirements.

As for agriresidues, like palm oil or sugar cane, it is often simply not seen as worth the time, money or effort to collect and store huge volumes of it on a farm. The ones that are already in use are usually low-hassle solutions. 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.

But again, these do not take in the sheer volume required, and with food profit margins already razor thin for smallholder farmers, there are questions over the cost, hassle and manpower required to collect, store and distribute it. "Often, you're competing with a tank of gasoline and a match, which is quick and cheap," says Peter Tomich, CEO of the biotech company Sustinent.

Another holdback to bear in mind can be seasonality – ensuring steady supplies of seasonally produced products. Agricultural production databases and numerical estimates show large potential agro- residue availability. However, for most crops, like rice, wheat and sugarcane, their highest volume is available during their annual growing season (planting to harvest). Out of season, their availability depends on their preservation and storage in safe facilities. Agro-residues follow these same trends. To see why seasonality can be a problem for valorisation, take the example of the textile industry's early attempts to use upcycled food waste. Due to textile manufacturing being a year- round industrial process, it has been harder for food waste or agro-residue based materials to get into the textile supply chain. Seasonal variability of agro-residue feedstocks forces manufacturers to consider options like pre-processing, densification and safe storage to ensure consistent supplies that align with demand. Standardising quality across suppliers is also a hard nut to crack.

Some crops are more vulnerable than others to post-harvest storage lost. In Asia's developing economies, from India to Indonesia, there is a major challenge with more perishable goods like fruits. Some

estimates claim that 114 million tons of banana waste is left to rot annually.[13] Here, the rollout of decentralised solar powered cold chain technologies could be a major opportunity to watch. On the processing side, there are many more opportunities to rescue value, like agro residues, or the valorisation of skins, pips, seeds or husks.

Stronger food valorisation options should be a priority at the policy level too. Aside from the wider problems of crop burning, like methane emissions and crop disease, the adverse effects to human health of air pollution has been a major concern. In a country like India, where more than 20 million acres of rice straw gets burned every year, air pollution from agri-residue burnoffs leads to more than 250,000 deaths a year.[14]

With a crop like palm oil, any waste of its residue is problematic and sparks debate among environmentalists wary of deforestation. The burning method of oil palm residues, including post-deforestation trunks of palm oil trees, is under greater scrutiny, with the world's top producers, Indonesia and Malaysia, both straining to adopt and enforce zero open fire burning policies.

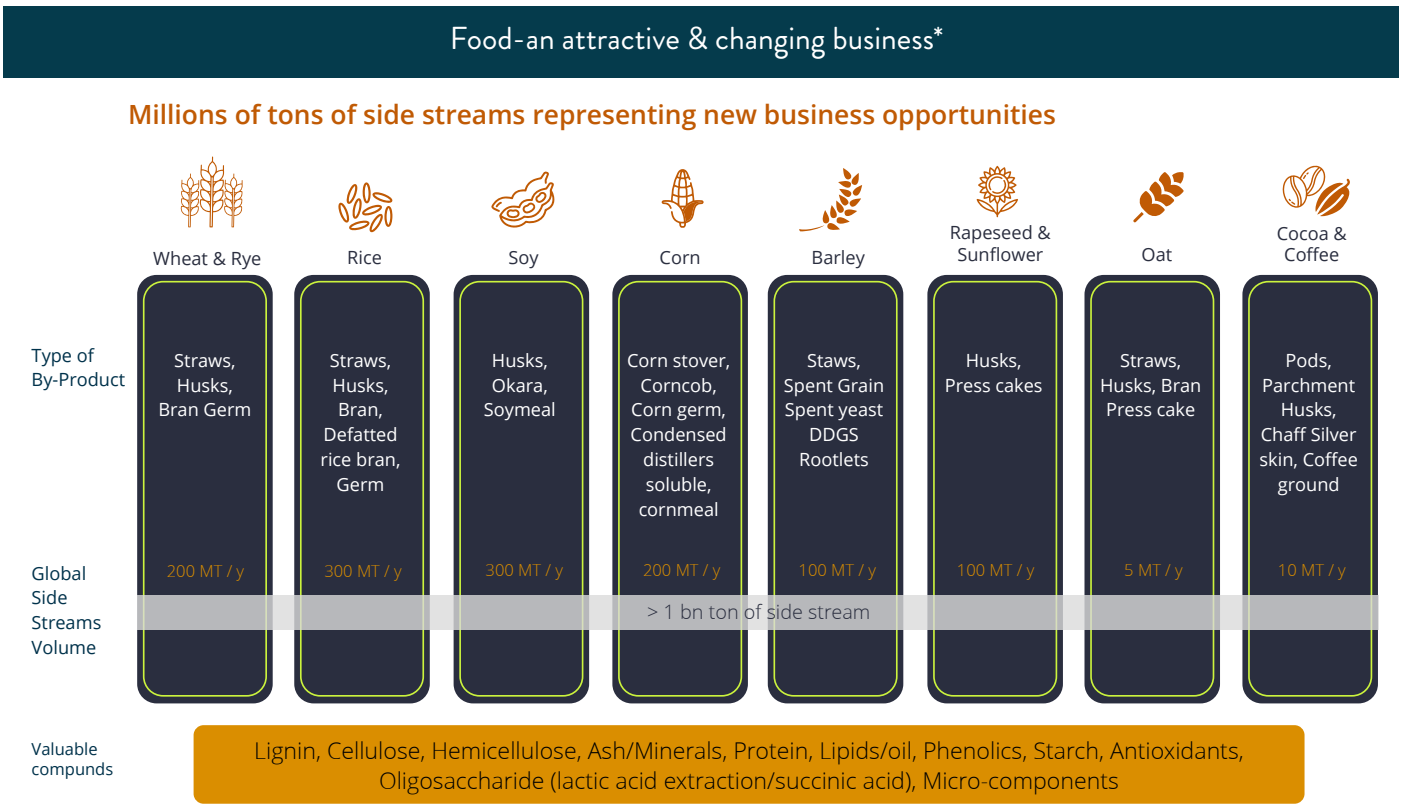
> *The goal of food upcycling for agrifood companies is to minimize food loss, food processing by-products, and side streams that can be captured for valid business cases and markets.*
>
> Melanie Weingarten, Deputy Director Biotransformation, A*STAR's Singapore Institute of Food and Biotechnology Innovation

Light Touch Regulation and Commodity Fluctuations

Some of the drawbacks across much of the emerging Asian context is that regulations tend to be light touch and funding for waste management schemes can be scarce or unresponsive. The risks of not earning back money on extensive capital expenditure are high, especially in areas where there is risk of fluctuating harvest volumes due to climate change or even political instability, as in countries like Myanmar. Patience and high risk tolerance have been regrettable virtues for investors.

Similarly, for innovators creating biogas out of waste streams there is the risk of fluctuating energy prices which could render biogas uncompetitive economically vis-a-vis fossil fuels or renewable energies like solar.

Although there is data scarcity here making it harder to draw firm and current conclusions, the general picture of agri-waste points to major losses from fruits and vegetables. Not only are perishable fruits and vegetables more frequently wasted compared with other food groups, they also



*Source: Bühler waste to value white paper

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. There are major opportunities in particular here to to obtain value-added products such as bioactive peptides, antioxidant-rich polyphenolic compounds, biopolymers, natural pigments, enzymes, dietary fiber, essential minerals, vitamins, and functional food supplements.

Other standouts – certainly from a processing perspective – are oilseeds, pulses, roots and tubers. There is much to be done with potato skins, for instance. In aquaculture, there is clearly more that can be done to utilise the fish bones, head, or skin. Meat production already has major processes for upcycling, whether that is whey protein powder, or gelatine from cow bones. With cereals, there's a huge volume of spent grain at breweries, which producers in Asia are looking for newer applications.

A challenge for companies is to tap into a new market. I feel there is a need for a lot of collaboration across sectors, and huge opportunities when we can work together with other industries and learn so much more.

Noemi Kaufmann, Project Manager
Circular Economy, Bühler

Country Highlight: The Philippines

The Philippines: a potential upcycling powerhouse

The Philippines is the third most populous country in Southeast Asia; 100 million people live across this mountainous volcanic archipelago of over seven thousand islands. According to the country's Food and Nutrition Research Institute, 1, 717 metric tons of food is wasted here each day. Likewise, the International Rice Research Institute claims you could feed a meal to 4.3 million Filipinos with the rice that gets wasted in the country every day.[15]

As with most growers in developing countries, many in the Philippines lack farm to cold storage facilities; thus, perishable produce is often left in the open or kept under ambient temperature conditions, where rot or disease can set in. Bananas are a major export where as much as 30 percent is lost to disease or rotting, as well as high visual standards (an intolerance for misshapen fruit.) Similarly, the Filipino mango trade is blighted by disease or fruit drop cracking and immaturity. Wrapping is

30 percent of banana produce is lost to causes like disease and rotting, as well as high visual standards

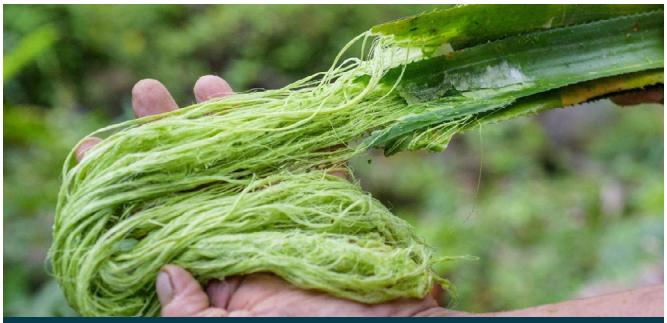
a major way to avoid insect infestation or disease.

Generally, a lack of modern agricultural technologies, resources and skills, infrastructure, support for research, innovation, and agricultural workers contribute to food loss on the archipelago. Despite these developments, data on the patterns and causes of postharvest losses remain highly variable and the level of losses reported is high.

Desirable outcomes: More localised agroprocessing, banana textiles and pineapple sneakers

Incorporating agroprocessing systems at the farm level can help reduce food losses. They can help farmers adjust during peak season to preserve agricultural produce and improve shelf life. And localised post harvest handling should not end at ways to extend shelf lives. Value adding should be considered to offer consumers a new perspective of high value agricultural produce.

For the problem of what to do with agri-residues in the Philippines, companies like Dole have been leading the charge with social entrepreneur partnerships. Dole teams up with a company like Musa Fabric to turn its banana stems into fabric for sustainable alternative fashion products (more than 4.4 million of these stems are currently wasted every year, according to Dole.) These have proved a hit, even to the point of being featured at this year's New York Fashion Week — quite a rare accolade for a fruit producer. Besides the upshot of upcycling, the partnership finds a workable model through its philanthropic affiliation to the Kasilak Development Foundation. The aim is to find marginalized communities in the highlands of Bukidnon and teach them how to extract banana fiber. The yarn will then be distributed to the Davao Penal Colony, where prisoners will make fabrics as part of their rehabilitation into society, which will bring them income.



Pineapple leaves repurposed to form a leather substitute by Ananas Anam

Dole has also partnered with Ananas Anam—the London-based company behind the innovative vegan pineapple leather Piñatex — to put the pineapple leaves from Dole farms in the Philippines to good use. Dole's Philippines farm is one of the largest pineapple plantations in the world, and through this particular partnership, Ananas Anam collects Dole's harvested pineapple plant leaves, which are washed, dried, and processed to create a non-woven mesh to form the base of the sustainable Piñatex material.

Country Highlight: Indonesia

Indonesia: vegetable waste and palm oil overload

According to the results of a study by Indonesia's Ministry of National Development, the country has been disposing of between 23 to 48 million tons of food waste per year in the period of 2000-2019. That equates to 115-184 kilograms per capita per year. The resulting economic loss is Rp 213-551 trillion per year – about 4-5 percent of Indonesia's yearly GDP.[16]

Socially, it causes a loss of energy which is the same as a portion of food for 61-125 million people per year. And the situation could get far worse. Based on the projection of the next 25 years, without any interventions to stem this trend, it is calculated that Indonesia's food waste generation in 2045 may reach 112 million tons/year or 344 kg per capita each year. Emissions from food loss and waste in Indonesia make up more than 7 percent of the average Indonesian Greenhouse Gases, according to government studies.

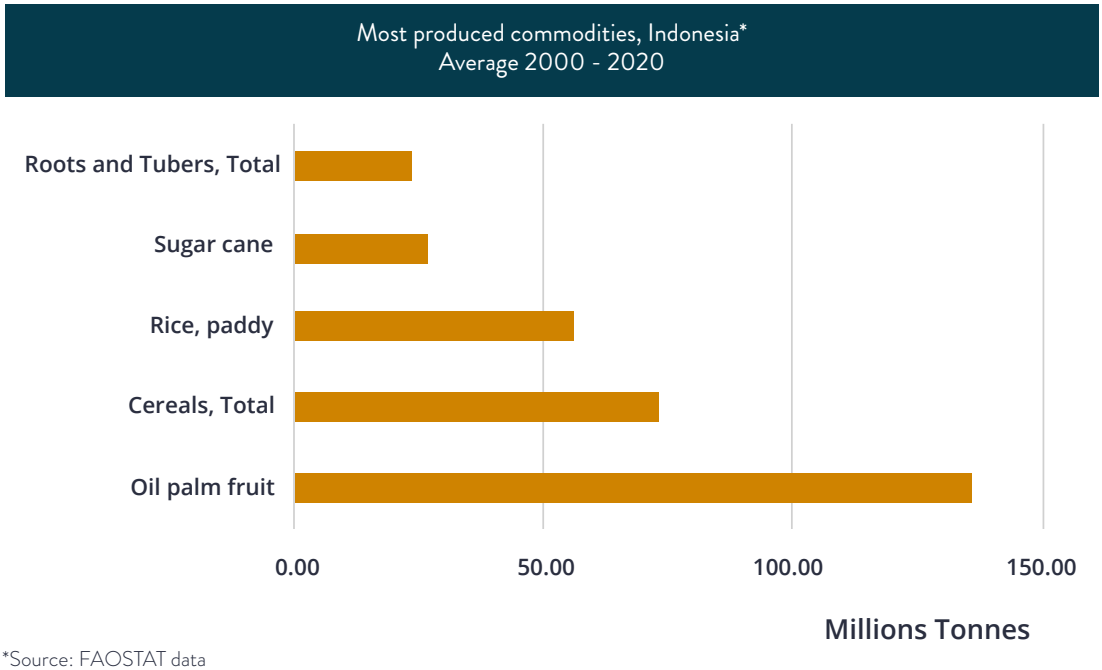
So there is certainly huge potential – and necessity – for systemic improvement. Where to start? Food loss and waste in Indonesia is dominated by grains – rice, corn, wheat and related products; the most inefficiently processed food types are vegetables, where its loss is 62.8 percent of the total domestic supply.

A significant possibility for improvement would be in waste-to-energy systems. While palm oil production is controversial in Indonesia due to its links to deforestation, palm oil's total biomass productivity of tonnes per hectare is about three times higher than the average of other crops. Indonesia is the biggest global producer of palm oil with over 16 million hectares (mostly in Sumatera and Borneo Islands) and 7.8 million workers.[17] While the heating value of palm oil biomass is similar to other biomass, palm oil is the most efficient bioenergy provider compared to other crops. Even the liquid waste of palm oil from factories carries huge potential as biomass feedstock for biogas production. The waste comes from the water used in the process of palm oil production and hence it is called Palm Oil Mill Effluent (POME). Considering its high organic content, POME is a potential source of renewable energy.

The current treatment of POME in Indonesia is in need of reform; it involves using several large lagoons to retain the waste until it is degraded by microbial activity. Many of the lagoons are open and emit greenhouse gases. So converting POME into biogas, which can be tapped for renewable fuel for electricity, is not only solving for an energy distribution system in remote areas; it also contributes to the efforts to reduce the emission of greenhouse gases.

Similarly, in palm oil processing, Indonesia produces huge volumes of what are known as empty fruit bunches, or EFB. These are valuable palm oil mill waste by products that could be used to produce multiple forms of heat, energy, chemicals, feedstocks, and materials. Therefore, efficient utilization of these biomass resources is essential to optimize the profitability of the industry while addressing environmental issues. The holdup often comes down to supply chain issues: getting the initial processing stages for converting the biomass into intermediates and products; building out solid transportation networks that use trucks, train or pipelines, and creating options for a product's direct sales or for further refinements.

Similarly, Indonesia is one of the world's top sugarcane producers. It produces 33, 700 million tons per year.[18] There are market price issues to contend with for bioethanol versus fossil fuels, though sugar cane has additional derivatives that could be used too if the pricing and the extraction prove viable: this is known as stillage or vinasse, the liquid waste from the bottom of the distillation column in bioethanol rectification. An incentive for its utilisation is that without proper treatment, this waste can prove damaging to the surrounding environment.



*Source: FAOSTAT data

An overview of SIFBI's efforts to tackle food waste

A*STAR's Singapore Institute of Food and Biotechnology Innovation (SIFBI) brings together research capabilities in food, nutrition, public health, biotechnology, manufacturing and agri-food technology to address innovation opportunities across the food value chain.

(1) Applying SIFBI's established capabilities in discovery and strain engineering to enable the microbial valorisation of food waste

SIFBI develops and applies synthetic biology and metabolic engineering approaches, as well as natural evolution strategies to improve the ability of microorganisms to valorise sidestreams. SIFBI hosts A*STAR's Natural Product Library (NPL), one of the world's most diverse and extensive collection, with more than 160,000 plant, fungal and bacterial specimens. This provides a rich resource bank for the discovery of novel strains (bacteria, yeast, fungal) and enzymes, which can be optimised for efficient valorisation and breakdown of different agri-food sidestreams. Intermediate products, after bio-based breakdown of the agri-food sidestreams, are valuable sugars that are subsequently used as feedstock for fermentation and downstream processing, to yield alternative proteins or specialty ingredients.

(2) Fostering partnerships to take an ecosystem-approach to solve food waste

These processes are developed in close collaboration with industry partners for the food, feed, nutrition and personal care industries. In 2021, Dole, Economic Development Board (EDB) and A*STAR's SIFBI and the Institute of Sustainability for Chemicals, Energy and Environment (ISCE2) established a partnership with the goal to reduce fruit loss at its source and transform fruit sidestreams into specialty ingredients for pharmaceutical, nutraceutical, food & beverages etc[19].

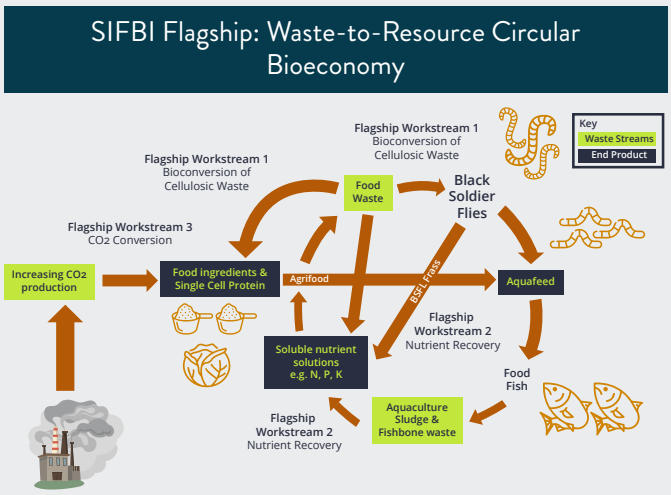
This new partnership rides on earlier success of A*STAR's collaboration with a Singapore start-up company, Westcom: the teams developed an efficient microbial consortium that converts mixed food waste to odourless fertilizer within 24 hours. Unlike other food waste treatment, this system saves up to 50% electricity due to the low operating temperature required[20].

Besides industry, SIFBI worked with A*STAR's Singapore Institute of Manufacturing Technology (SIMTech) and the Singapore Manufacturing Federation Standard Development Organisation (SMF-SDO) alongside other stakeholders

to develop two Singapore Standards on Food Waste Management. A*STAR's SIFBI, SIMTech, and the Institute of Materials Research & Engineering (IMRE), are also engaging local institutions e.g. NUS and NTU to explore further R&D to tackle the food waste problem.

(3) SIFBI's upcoming Flagship: Waste-to-Resource Circular Bioeconomy Programme

Building on the momentum of ongoing efforts, SIFBI is engaging ecosystem partners to develop a comprehensive flagship programme, called "Waste-to-Resource Circular Bioeconomy". It is envisioned to comprise 3 workstreams as shown in the diagram below:



Workstream 1: Develop a platform technology to bioconvert lignocellulosic waste and its derivatives - a major component of common food waste streams in Singapore e.g. spent brewer grain, fruit and vegetable peels into food ingredients, insect feed and yellow biotechnology application. The technology could be applied to paper waste (the largest waste category in Singapore by volume), horticulture waste and empty fruit bunches which are major sidestreams in South East Asia, expanding the technology's application and export potential.

Workstream 2: Develop microbial solutions to tackle nutrient recovery and waste valorisation from Singapore's local agrifood production e.g. aquaculture sludge and fishbone waste. The recovered soluble nutrients can be re-circulated back into the food system e.g. soluble nutrient fertilizers for vertical farming.

Workstream 3: Support Singapore's goal to halve greenhouse gas emissions by 2050[21], via a combined chemical and biological approach of carbon capture and conversion to valuable products. The technology can also aid waste valorisation efforts by using syngas produced from gasification of recalcitrant waste streams as the energy source for producing valuable products.

SIMTech's Life Cycle Assessment and Techno-Economic Analysis will be applied to these workstreams, to evaluate the environmental and economic sustainability of the food waste valorisation processes.

For further enquiries, please contact SIFBI at info@sifbi.a-star.edu.sg.

Valorising Waste Through Innovations

Responding to many of the challenges mapped out above are a growing suite of technologies, a widening cohort of technologists, and deepening pools of capital — all combined with shifting consumer drivers. This chapter looks closely at these converging pathways to industrial agri-food waste valorisation.

Suites of Food Waste Tech

On the technology front, we caution that current valorisation methods are not sufficiently advanced for any one company to significantly valorise — affordably, at scale — enough of Asia's post-consumer food waste. Collecting, sifting, decontaminating is a multi-pronged task, and tech can only get so far without city authorities providing educational initiatives, new collection models, and regulations like Japan's recent Food Recycling Law, which mandates food waste to compost, feed and energy conversion centers.

There may be huge scope for improvement in the collection of packaged household waste (even in the dissemination of

*Source: Adapted from EPA's Food Waste Hierarchy

compositible packaging). Elsewhere at the consumer level, food waste social media companies like Olio are expanding to Asia in a bid to harness mass behavior change. But it is not all about tech startups with consumers; do not underestimate the national educational or policy level. On the education front, Japan for example, has rolled out national programs to retune the next generation's attitude to food waste. On policy, too, Japan now has a national food bank organization called Second Harvest which "rescues" and reallocates edible food from grocery stores and other retailers to people in need. Bonus point schemes for near-expiry date food purchases, and Japan's Food Recycling Law, which aims to divert food waste towards centres that convert it to compost, animal feed and energy.

Yet for industrial agri-food waste solutions, a wide range of technologies are set to be a game changer here. Different Asian countries will apply this tech to different extents and intensity. Leading food and beverage companies, as well as third-party organisations, have a window of opportunity. Applying new techniques and technologies to reduce upstream food waste could earn competitive differentiation. Dovetailing with this is the opportunity to develop new consumer product offerings which valorise waste streams.

> *You've got to be very careful, there are some materials that do not produce a lot of electricity. So, you could be energy neutral or energy short, but your upcycling process can in essence be inefficient and produce an enormous amount of fertilizer as a by-product. So, it does very much depend on exactly what market you are approaching.*
>
> Peter Fusarelli, Founding Director, UAG BioNutritent

Waste to Energy, Construction, Fertilisers

In waste to energy, for instance, there are new and better boilers capable of burning at greater efficiency and also burning a broader mixture of waste. These can be combined to provide energy requirements in food processors looking to use renewable sources of electricity to lower their emissions and improve the circularity of their systems.

Take Cambodian rice production as an example, where most paddy is either exported raw or processed with diesel engines due to intermittent and costly access to electricity. That keeps rice prices inflated in local markets, with all the ensuing social consequences. Too few rice millers have access to the latest drying and processing technology — or can convert their rice husks into energy by using rice husk gasifier technology.[22]

While the price of the capital expenditure is very high, there are possibilities for major processing improvements. Systems like those of the Belgian food processor designer Vyncke are able to incorporate this into its latest milling operations for palm oil or rice. Both involve waste to energy as a vital component. Vyncke rice mills consume large quantities of both thermal and electrical energy. Thermal energy in the form of hot water or steam is needed for paddy drying (seasonal) and for parboiling (throughout the year). Rice husks represent around 20 percent of the resources processed in rice production and using this as fuel can cover the complete energy need of the milling and parboiling process. Vyncke's solutions are especially designed to handle the extreme ash properties of rice husk. The ashes from Vyncke's combustion systems are a very valuable raw material which can be sold to the steel and concrete industries.

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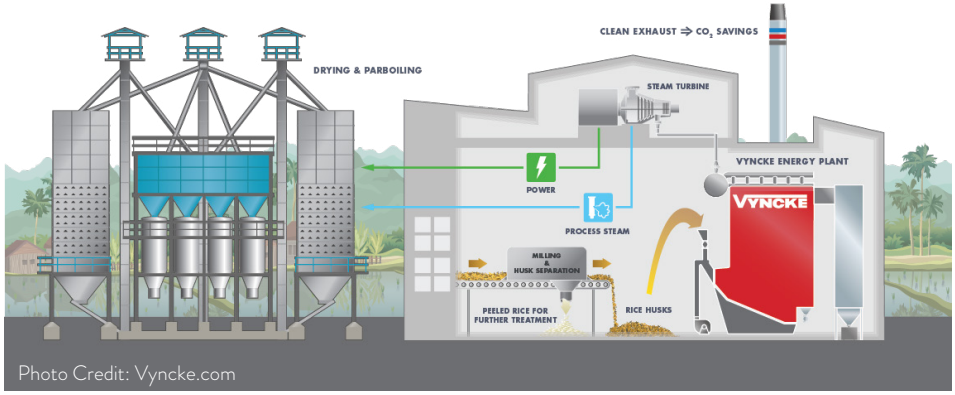
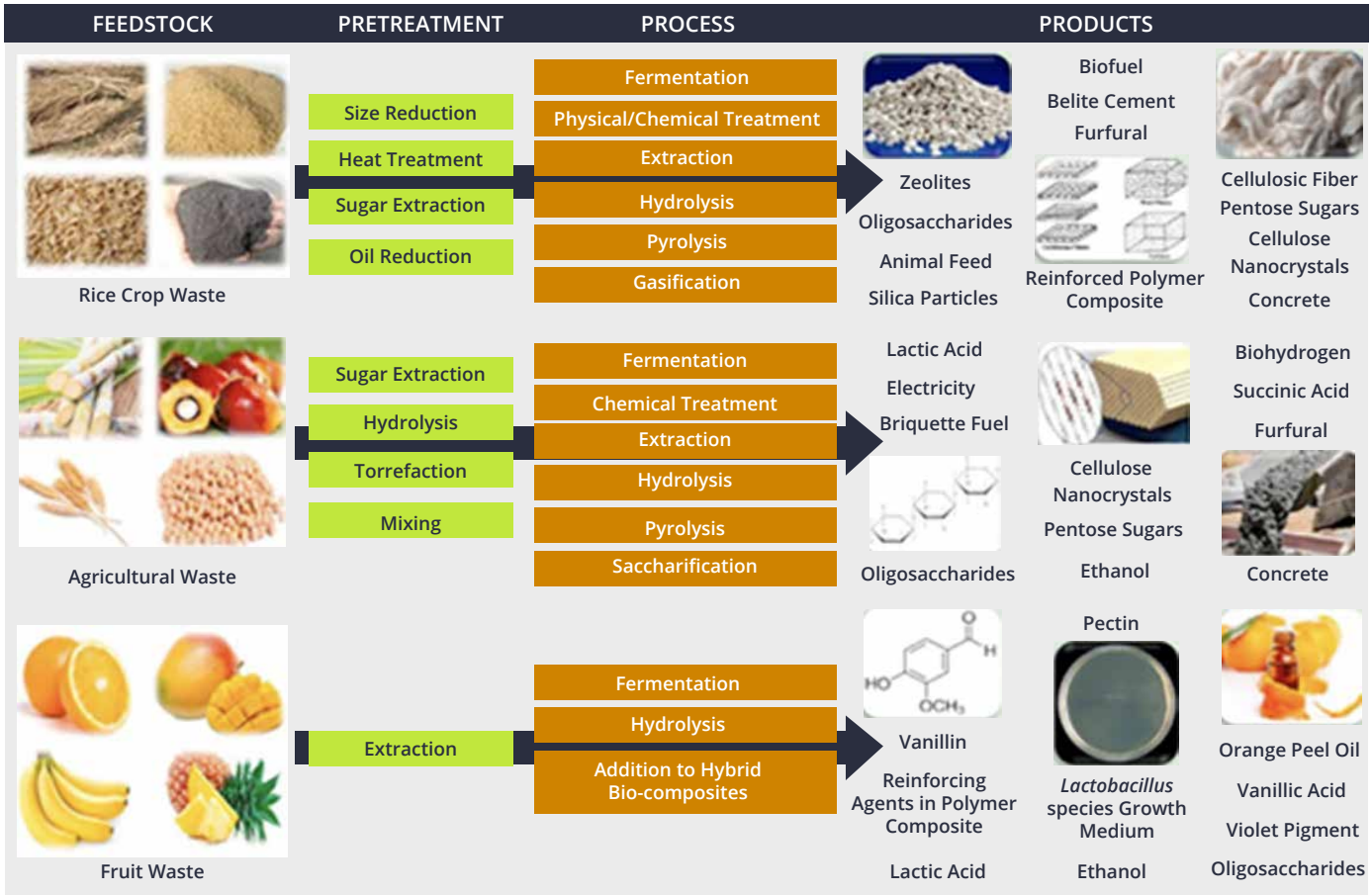


Photo Credit: Vyncke.com

Feedstocks, Fermentation, Enzymes

As this infographic shows, rice crop waste has a wide range of options depending on whether the end product is biofuel, silica particles, nanocrystals, concrete, or zeolites. To extract these, look no further than new fermentation technologies and hydrolysis. Conventional sources of these sorts of bulk chemicals are often from fossil fuels. The market is becoming more open to food waste as a source for these chemicals as companies move to wean themselves off fossil fuels and look more toward renewable sources. Fermentation processes can create similar acids and alcohols, which make for useful bulk chemicals or energy carriers. Though there are bottlenecks here that are worth stressing, like the challenge of keeping a bioreactor continuously running and producing at a consistent quality. It helps too if waste separation is integrated into the fermentation process to increase product recovery rates. (Bear in mind, fermenation always produces its own waste streams that need handling.) Getting to these, new fermentation technologies and hydrolysis



are of particular interest for valorisation. Through fermentation processes, acids and alcohols can be generated, which can be used as bulk chemicals or energy carriers.

RE:harvest, the first food-upcycling company in Korea, is currently upcycling by-products from beer and shikhye (a Korean traditional drink). Harnessing the power of fermentation, RE: Harvest has developed a new kind of flour from by-products to close the loop in the F&B industry. RE:harvest currently manufactures B2C food products in the convenient meal replacement sector like granola bars, granola cereal, puffs. For B2B food products, RE:harvest manufactures pasta, pizza dough, and rice cakes.

With hydrolysis, the incorporation of enzymes is of note — a rapid and softer alternative to chemical or mechanical treatments, like that promoted by the Singaporean company Allozymes. Enzymes are capable of hydrolyzing proteins, thereby allowing the production of free amino acids, short peptides, and fatty acids. These are useful for biotechnology, nutrition, and the cosmetics industry. It is also useful for what cannot be hydrolyzed. Meats can be broken down, yet the collagen cannot be, making it easily recoverable for biomedical applications. A company like Australia's Sustinent, meanwhile, engages industries to recycle their 'green waste' at scale, producing high-quality livestock feed from sugarcane trash via biotechnology – cellulose digesting enzymes. Great Wrap in Australia, by contrast, is creating compostable plastic wrap from potato skins and peels. The founder, Jordy Kay, mentioned how similar possibilities for upcycled bioplastics were available from the dairy industry, which he described as wasteful, but he did not feel that products like these would have the same consumer resonance as working with potato chips.

For fruit and vegetable waste, a crucial element for any company seeking to valorise waste streams lies in better storage facilities or new forms of preservation technology. Waste itself needs better taking care of if it is going to retain value and not gather toxins. Once it gets to the processing itself, there are more ways to cope with these toxins where they creep in. New forms of fermentation and enzyme hydrolysis can also break down previously indigestible forms of food waste into ingredients with high functionality.

Elsewhere Wei Tze Ooi, a managing director at Dole Specialty Ingredients, sees major opportunities for enzyme extraction from banana powder, pineapple fiber powder, and papaya: "We are utilizing all kinds of rejected fruits to produce something valuable," he says, underscoring his team's work to improve the efficiency of the extraction

of bromelain, a group of enzymes found in the fruit and stem of the pineapple plant. Bromelain can help alleviate a wide range of illnesses, like digestive disorders. Dole will roll out ideas like this via its partnership with the Singapore Economic Development Board (EDB), A*STAR's SIFBI and a new corporate venture, Dole Specialty Ingredients (DSI). "We will transform all fruit losses and underutilized fruit side-streams into high-value, natural products for highly profitable, less volatile product categories through innovation," said Pier Luigi Sigismondi, President of Dole's Food and Beverages division, when commenting on the move. "This way," he added, "fruit losses are upcycled instead of being left behind or sent to landfills."

Consumers are helping to drive functional food adoption here, spurred by rising disposable incomes and increasing consumer awareness concerning health issues. 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. The same drivers are impacting the rollout of sustainable textiles.

> *When we decided to move towards zero fruit loss, we realized that there is a whole set of new capabilities we would need to acquire. And that in some instances it would make more sense to partner with the best-in-class in their domain.*
>
> Barbara Guerpillon, Global Head of Dole Ventures

Consumer Drivers: Mushrooming Popularity of Sustainable Fashion

The transition to sustainable fashion — led by artists, fashion designers, and influencers — is cultivating feedback loops between consumers and companies. The more demand is there, the more companies will react. Several prominent global fashion brands are joining hands with innovators to bring products from alternative materials to mainstream consumers. Waste and residues from sources like apples, pineapples, citrus fruits, cactus, mushrooms, or algae are steadily entering the apparel and textile market through products like bags, shoes, clothes and leather goods.

South Asian countries too are joining this vanguard. Start-ups in this region are producing fibre and leather from alternative bio-based materials at a small scale, in collaboration with local artisans and weavers. Some have found success in using a diverse mix of residues from banana, pineapple, sugarcane, eucalyptus, corn, lotus stems, and other crops as the raw material base for textile products.

Factories across textile hubs in Tirupur, India and Dhaka, Bangladesh have quietly been stepping up manufacturing capacities for integrating the use of bio-based materials.[23] However, in spite of the early promises and successful pilots for vegetable and plant-based approaches, the arena for use of residues across rice, wheat, maize, sorghum, bagasse, palm oil and other sources is still wide open and remains relatively unexplored.

A company like Nextevo is innovating in this space, harnessing hybrid textiles well. Extracted from pineapple leaves, pineapple leaf fibre (PALF) textiles are a unique

Coconut husks are processed into cocopeat and coir fiber and used for various products

natural option ideal for use in four key textile categories — footwear, apparel and accessories, home textiles, and upholstery and interior furnishings. Nextevo also works with cocopeat — a spongy material, found in the pith of coconut husks. It provides a sustainable soil amendment and conditioning option for horticultural, floricultural, landscaping and greenhouse purposes. Nextevo founder Harold Koh reasons that his product, coir fiber, is a sustainable alternative to synthetic soil conditioning. "The world is going to be faced with a shortage of good quality peat for greenhouses," he said. "Coconut husk is a perfect substitute." And back to the world of fashion, he adds, "it's natural, breathable and allergy- resistant." It could even add value to cushions, mattresses, and bedding.

Drying Technologies and Automated Insect Husbandry

- Another breakthrough has been how the use of breeding, AI and computer vision is assisting in the development of a new type of livestock husbandry: that of insects. With selective breeding, these insects are capable of not only breaking down huge amounts of food waste while growing with great resource efficiency but themselves becoming useful in pharmaceutical applications, fertiliser, and even bioplastics.
- Distributed solar powered waste separation and drying systems are set to make food waste management simpler, cheaper and less carbon instensive.

One game changer for reducing waste weight is as simple as the notion of drying. Except drying is notoriously energy intensive. Same goes with freezing. Fortunately, drying technologies have also been improving at a steady rate in terms of speed and efficiency.

Designs of dryers vary widely, and for the sake of emissions reduction, emphasis is often placed on energy drawn from renewable sources. Open air drying, as with some parts of Asia, risks spoilage from intermittent rain. On an experimental front, there is the recent pilot of the Dralod Pilot plant in Spain, which is being tested for the drying of different types of by-products from the food and beverages industry. The plant is being tested for the drying of different types of by-products from the food and beverages industry, including Brewer´s Spent Grain (BSG). The drying process runs on renewable energies — solar as the main source, along with biomass heating. Technologies further down the line on provability and scale are machines like the Swiss food company Bühler's EcoDry or Ceres Plus, which can reduce cleaning time in a coated cereal drying process by as much as 75%. It brings improved productivity, performance, and energy efficiency — all of which open up options for not only driving down food waste, but also finding uses for byproducts like Brewers Spent Grain.

Another waste-to-value stream coming into the open is insect farming. Among

Eco Dry – A continuous flow drying systems for corn, grain, oilseeds and rice.

*Source: Bühler Eco Dry Brochure.

ento-preneurs, one species has paramount popularity in the food waste management space: the Black Soldier Fly (BSF.) This particular species of insect is generating a buzz among scientists and investors because they are capable of rapidly growing in biomass while breaking down food waste; once grown, these tiny livestock offer a highly nutritious protein source for larger livestock like poultry or fish. (Pet dogs or cats of the future might enjoy a serving of this too, though humans could find this particular protein source a little icky; they are apparently less palatable than grasshoppers or crickets.)

As many other insect startups have done, Protenga – which is headquartered in Singapore with a production facility in Malaysia — has identified the BSF as its insect of choice. Breeding this species, the team believe, can be a way to provide sustainable protein sources to livestock, aquaculture stock, and pets. Protenga's production line also generates organic material for fertilizer through a process similar to composting. This "zero-waste" approach helps to solve the issue of insect frass — that is, the waste produced by the farmed insects themselves — by transforming excreta into bio-fertilizer.

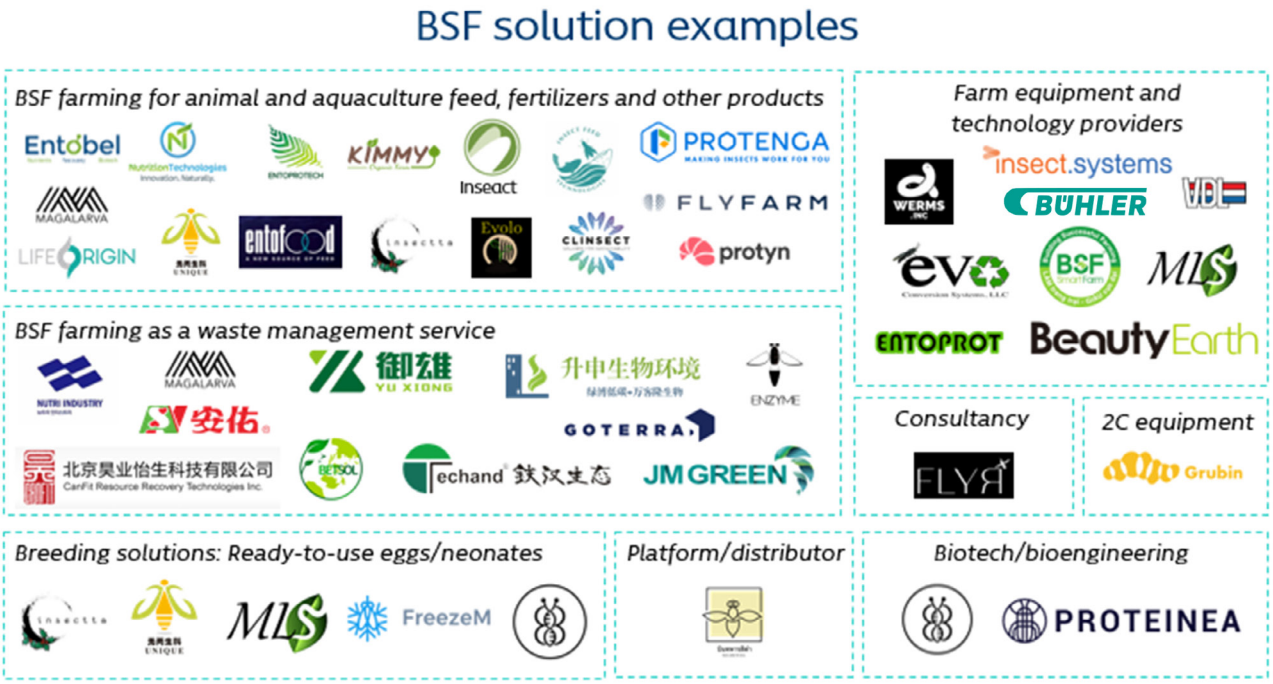
The startup is carrying out further research and development around genetics. It also has its 'Smart Insect Farm' offering — a

*Source: Mana Impact

decentralized model that turns agricultural and food waste into useful products — across Asia Pacific.

The distributed model of Protenga's mini-farms contrasts with some of the centralizing ideas of other ento-preneurs, like those designing central mega facilities on behalf of mature global startups like Ynsect, Enterra, AgriProtein, and Entocycle.

Nestled between the two models is India's Loopworm, a Bangalore-based biotech startup, is setting up its indoor insect vertical farms adjacent to micro-breweries and bread manufacturers. Its larvae convert food waste into premium feed products for aquaculture, poultry, pigs, and pets, like its Defatted Dried BSF Larvae Protein Powder, Whole Dried BSF Larvae, or insect oil.



*Source: Mana Impact

Other startups are considering leaving the production and breeding to others, to instead focus on the extraction of valuable chemicals from insects. Singaporean entrepreneur Chua Kai-Ning co-founded a startup back in 2017 called Insectta, which set out as a farm for animal feeds but recently pivoted to the extraction of Black Soldier Fly biomaterial. Chitin, for instance, is a major product derived from BSF — and also produced by the team at Loopworm. It can be converted to chitosan for what the Loopworm team call "disruptive applications in healthcare sectors like drug-delivery, bone-cartilage repair, making dirt-free clothing in textile industry, along with other numerous applications in pharmaceutics, biomedicine, cosmetics, food industry, and heavy metal extraction. Chitosan has global demand of three times its supply." Coming to the support of insect rearing companies like these has been the Swiss food processor, Bühler, which works alongside rearing units containing stacked crates that are automatically filled, harvested and cleaned. This makes optimal use of the available space and minimizes manual labor and operator errors. The feedstock is dosed accurately and in a consistent pattern to maximize the availability and delivery of nutrients. A patented air distribution system ensures uniform climate conditions in each crate even at high rearing densities. Finally, the overall solution is designed to withstand the harsh conditions experienced in mass rearing environments and can be easily cleaned.

Who are the enabling investors?

Imaginative applied research is a starting point for innovation and early stage investment. Researchers from the Singapore University of Technology and Design (SUTD), to give a niche example, developed a method to perform direct ink writing (DIW) 3D printing of okara—a soybean byproduct generated from the production of soy milk and bean curd — without using food thickeners.[24]

As the public sector is responsible for maintaining food safety and security as well as coordinating a country's response to environmental damage and the affordability of food, it is likely that greater support for food waste management will be coming down the pipe from the public sector. These will likely take the form of grants, large-scale procurement, regulatory frameworks, tax incentives, and innovation parks. These could come from international organisations like the UN or ASEAN, from national governments, or from city municipalities.

DIW 3D-printed models of okara. Freeze-dried 3D-printed okara snacks with various infill levels and sizes.
Photo Credit: SUTD

International organisations and lenders: Well suited to larger projects and collaborations..

The moves from the UN include an ambition to implement the "Target-Measure-Act" approach to food loss and waste reduction. At the UN meeting last year of Champions 12.3 – the UN Sustainable Development Goal focused on food waste – participants all reckoned there is a need for a dedicated global investment mechanism. A Global Food Loss and Waste Finance Facility is consequently in the pipeline; it will offer a deal-making platform for actors across the value chain and provide financing instruments that can be blended with existing investments.[25] It aims to increase investment, especially from the private sector, to support country-level actions.

Another top level example: Multinational lenders like the World Bank (International Bank for Reconstruction and Development, IBRD, Aaa/AAA) will also be playing their part. The World Bank has in fact recently issued a 2-year Sustainable Development Bond raising CNH 500 million (approximately US$ 77 million equivalent) while engaging with investors to raise awareness for the importance of combating food loss and waste. The bond was placed with investors committed to highlighting the importance of this theme, with Gavekal Capital Limited as the lead investor.

Venture Capital and Food Waste Innovation in Asia-Pacific

Asia-Pacific private equity investors have been active throughout the pandemic and have become more receptive to sustainable alternative investments. The region's economies grew solidly in 2021. That set the stage for robust dealmaking and spurred Asia-Pacific investment value to a record $296 billion, according to Bain, a management consultancy.

Startups looking to venture into the circular innovation space, however, still often lack the necessary capital and funding. They often find investors are less willing to fund innovative technology in these non-conventional areas of business. This is where corporate venture capital can come into play, providing strategic investments across the value chain. In a sign of things to come, fresh fruit group Dole Asia Holdings, headquartered in Singapore, has launched a US$2m fund centred on nutrition solutions and sustainability. The Sunshine for All Fund "will support global strategic partnerships and innovation in the crucial areas of sustainability, food access and waste," Dole said in a statement. "By partnering with talented innovators, promising start-ups and progressive partners, the fund will address these gaps of affordability and waste, as well accessibility and acceptability."

Similarly, there are initiatives like the 3R fund launched by the National Environment Agency (NEA) and the Water-Waste-Food Virtual Market Entry Program hosted by the Nordic Innovation House in Singapore.

The Asian Development Bank – for larger, later stage projects — also has its part to play, even in remote areas where venture capitalists are often wary of the risks. The ADB's Ulaanbaatar Community Food Waste Recycling Project, for instance, will help the Municipality of Ulaanbaatar (MUB) conduct food waste recycling with

community participation, to improve living environment, reduce health risk, reduce greenhouse gas (GHG) emission, and provide opportunities for new business and jobs, particularly for the poor, through pilot projects.[26]

Food Waste Credits

Jurisdictions that regulate carbon emissions, or have carbon emission caps or reduction targets, should consider providing tradable credits for the rescue of food or other beneficial reuse. This will be complicated, particularly in the absence of economy-wide regulation of carbon emissions. Nonetheless, an administrable system would create a new avenue to enable would-be producers of food waste to monetize their good deeds through tradable carbon-avoidance credits. As a first step to any of this, we should agree on a transparent and understandable standard for measuring the carbon impact from food rescue. The Food Loss and Waste Accounting and Reporting Standard is one potential example. Once a methodology is accepted, the carbon benefits of food waste reduction can be quantified and then rewarded.

Even in the absence of tradable credits, requiring carbon offsets in the form of food waste reduction could form part of a jurisdiction's larger carbon reduction plan. For example, regulatory authorities with mandates to minimize environmental impacts could require development projects (particularly those involving the food industry) to offset incremental greenhouse gas emissions through food waste reduction. Similarly, environmental regulators who retain the ability to consider supplemental environmental projects could consider food waste reduction as part of resolution of environmental enforcement actions.

Country Highlight: Singapore

Singapore is leading the way on food waste investments, innovations and regulation

Singapore is proving an Asian trailblazer and an Asia pacific hub on food waste innovation. With strong government funding, regulations, and other incentives, the Lion State is positioning itself as a research and development testing bed for the region, a springboard for piloting and then exporting new industrial agrifood waste upcycling technologies and business models.

The regulatory tailwinds are clearly a positive signal for innovators. The Resource Sustainability Act, introduced by the Ministry of Sustainability and the Environment (MSE) 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 2021, data from the National Environment Agency (NEA) showed that food waste was ranked 5th in Singapore's total waste generation and 3rd in total waste incinerated. But food waste was only in the 9th position in terms of recycling rates. Just 19% of the food waste in Singapore gets recycled; 81% still gets incinerated. With the current waste management strategy, Semakau landfill is expected to be completely filled by 2035.[27]

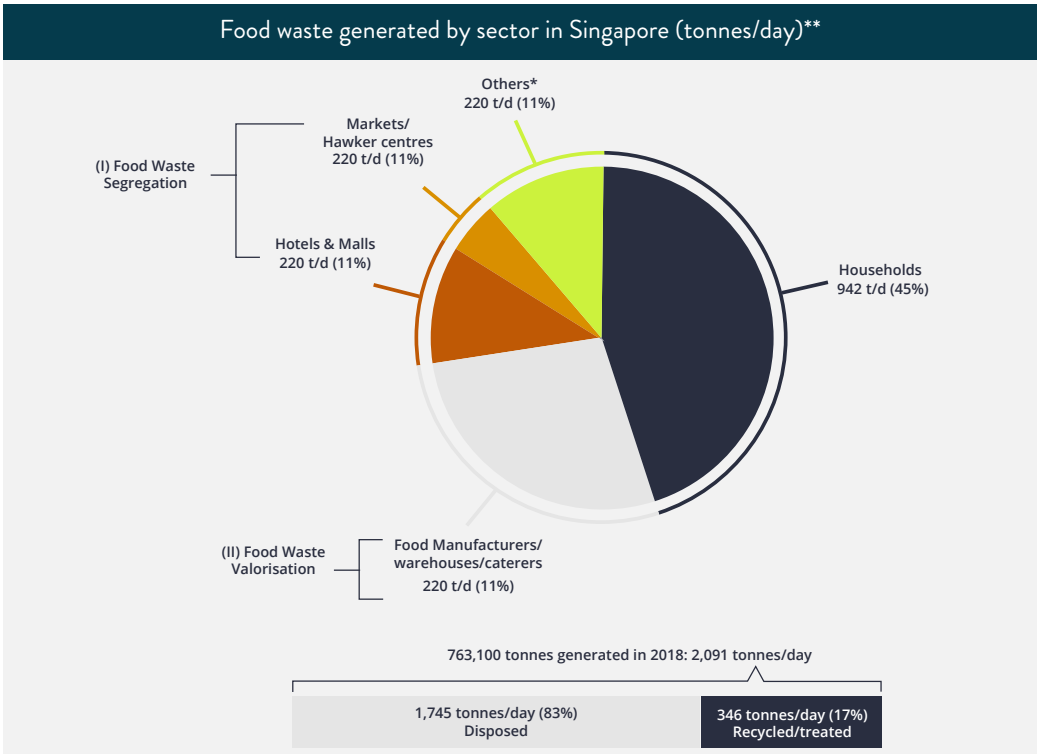
To solve this food waste problem, Singapore has developed a very strong national agenda on sustainable development, namely "The Singapore Green Plan 2030" where the goal is set to reduce waste sent to landfill by 30% by 2030.[28] From 2024, large commercial and industrial food waste generators will have to segregate their food waste for treatment, either onsite or off-site. To complement the food waste segregation for treatment requirements, industrial and commercial buildings that generate large amounts of food waste will be required to measure and report the amount of food waste they have segregated for treatment. The reporting requirements will take effect in tandem with the food waste segregation requirements.

Stronger regulatory pathways and rising consumer awareness, combined with capital availability, make Singapore a country to watch when it comes to innovative ways to drive down food waste.

To tackle this food waste problem effectively, there is a need to develop solutions aiming towards closing the waste-to-resource loop. An Industry Steering Committee (ISC) comprising government agencies (e.g. NEA, SFA), research and learning institutions (e.g. Science and Technology Organisation like A*STAR's Singapore Institute of Food and Biotechnology Innovation (SIFBI) and Singapore Institute of Manufacturing Technology (SIMTech) and institutes of higher learning) and industry associations was set up to look into raising awareness and promoting adoption of food waste valorisation solution. Local solutions for recycling okara waste, soybean waste, recycling spent barley grains and coffee grounds were also introduced at the series of Industry Awareness Briefing (IAB) webinars organised under ISC.[29]

Broadly, five possible pathways for food waste recycling were highlighted:

1. Food to Food: This category consists of upcycling food waste to products that can go back into the food chain. For example, vegetarian snacks and meat floss made from Okara.
2. Food to Feed: This is currently the most common path to convert food waste to animal feed for chicken or fish.
3. Food to Fertilisers: Another common path in producing high grade bio fertilisers and composts from food waste.
4. Food to Fuel: Here food waste is converted to Biogas, Syngas, Bio-butanol/ethanol and Bio-crude oil.



*Others: Restaurants, coffee shops, military camps, prisons, hospitals, schools, institutions of higher learning, etc.
**Source: Unlocking value with valorisation: Technologies to tackle food waste, IPI, Singapore

5. Food to other products: Finally, this category consists of mixed bag of products that can be extracted from food waste such as essential oil, cosmetic products, packaging materials and clothing materials.

Such partnerships and strategies is necessary to shift the needle and create a greater effort and impact in tackling food waste.

Case Study: Tuas Nexus

A possible food waste treatment technology is anaerobic digestion which converts post-consumer food waste into biogas, electricity & fertiliser as demonstrated by Prof Tong from NUS who is looking to valorise up to 400kg/day with his anaerobic digesters.

PUB, the National Water Agency, and NEA are building an integrated development comprising of Tuas Water Reclamation Plant (Tuas WRP) and the Integrated Waste Management Facility (IWMF), collectively known as the "Tuas Nexus". Tuas Nexus is Singapore's first integrated water and solid waste treatment facility. The co-location of the two mega facilities will optimise land use, improve energy and resource recovery from waste and used water, and result in carbon savings. For example, the co-digestion of food waste slurry (extracted from up to 400 tons of food waste per day) and used water sludge will increase biogas production at Tuas WRP. The biogas produced will be combusted at the Waste-to-Energy (WtE) facility in IWMF to

An artist's impression of Tuas Nexus Integrated Waste Management Facility (IWMF)
Photo credit: National Environment Agency (NEA)

improve the overall plant thermal efficiency and boost electricity production.[30]

The first phase of construction of Tuas Nexus has begun, and it is set to be completed in phases from 2025 onwards. IWMF will be funded via 'Green Bonds'.[31]

Bühler: pressing ahead in innovative upcycling solutions

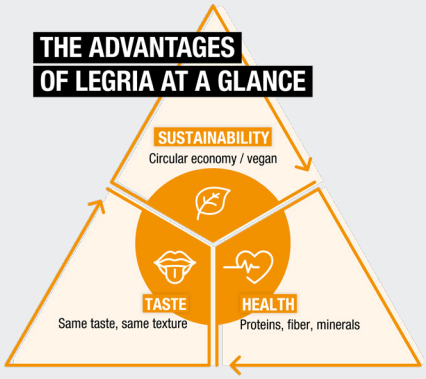
Legria - Planet Based Meat Alternatives through Upcycling

BREWERS' SPENT GRAIN is a real powerhouse. It's rich in fiber, trace elements, and protein, and it could play an important role in the food industry.

However, the majority of the estimated 30 to 40 million tons of brewers' spent grain produced annually as a by-product in beer production worldwide has thus far only been used as animal feed or it ends up as waste. Circular Food Solutions wants to change this.

The important thing in the upcycling of brewers' spent grain is to preserve valuable ingredients while ensuring food safety and accomplish this in an efficient and environmentally friendly way. "Thanks to the close cooperation with Bühler, we have been able to develop an innovative technology to upcycle Spent Grain and to use it in a wide variety of food products.

We are especially proud that we are now also able to produce plant-based meat substitutes that differ from known products through taste, nutrition and origin of the raw materials." says Carsten Petry, CEO at Circular Food Solutions AG. "Legria is an excellent example of upcycling by-products to create more value. As such, it reflects our focus on creating value from every kilo of material that leaves the field. We cannot afford to utilize valuable agricultural land to generate waste. With the current transition to more sustainable protein sources it provides a more sustainable option for product formulation," says Ian Roberts, CTO at Bühler and Chairman of CFS.



Carsten Petry and Friedrich Witschi are currently working on building the first Legria plant in Europe

Photo Credit: Thomas Eugster
For more information please contact: carsten@legria.ch

Insects to feed the world

Bühler Insect Technology provides industrial-scale solutions for the transformation of organic residues into quality ingredients for animal and plant nutrition. We cover the entire supply chain from feedstock handling to rearing, separation and extraction. Insects offer a unique opportunity to address two of the major global challenges: protein supply and organic waste disposal. They recycle nutrients from organic waste and bring them back into the local food value chain. Work with us to design and construct your industrial insect plants. Our automated solutions are designed to meet the safety and quality standards required by the feed and agricultural industry.

As inputs for insect rearing and processing plants, access to suitable side streams are needed as well as a steady supply of seed larvae, either through an integrated breed unit or through seedstock supply services. Bühler's technology scope ranges from the feedstock preparation line, where the feedmix for the larvae is prepared, over an automated rearing system till the processing of both the larvae and the frass into the end products.

High-quality end products.

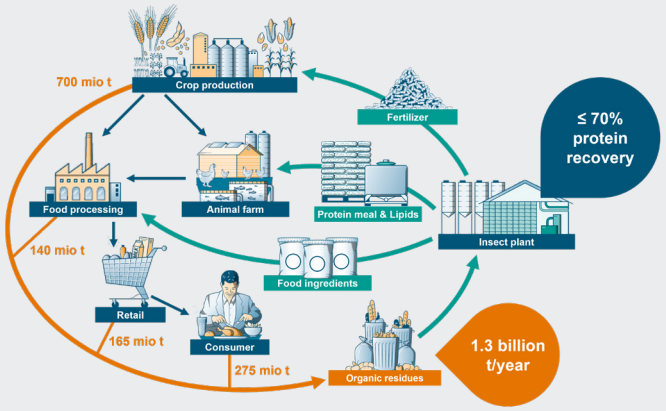
Protein meal.

Benefits	Sample applications
– Balanced amino acid profile. – Very good digestibility > 85%. – Highly palatable. – Adequate techno-functional properties.	– In pet food products, given its nutritional profile and hypoallergenic properties. – In fish feed for high growth performance, a good feed conversion rate, and a better gut health. – In shrimp feed as an attractant for better feed intake. – In broiler and pig feed for better nutrient digestion and satisfactory productive performances.

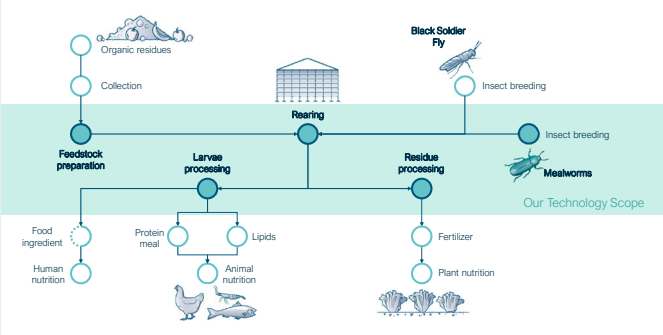
Lipids.

Benefits	Sample applications
– High in lauric acid that has antibacterial and antiviral properties. – Easily digestible source of energy. – Naturally palatable. – Simple integration into products.	– In piglet feed for improved feed intake and better gut health. – In broiler feed with satisfactory productive performances and overall meat quality. – In cosmetics and detergents as an alternative to animal or vegetable fats.

Bühler Insect-based Circular Economy

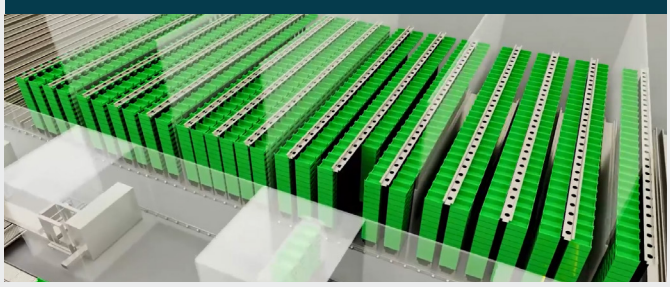


Bühler's Technology Scope in producing insects for food and feed



Visualization of Bühler's solutions in insect processing

Visualisation of Bühler's solutions



For more information please contact: Nicolas.braun@buhlergroup.com
Bühler AG

Circular Bioeconomic Opportunities

- The circular bioeconomy represents an economic opportunity and an environmental imperative. But that does not make for many quick and easy wins by default. Patient capital and innovative business models are also needed for a circular bioeconomy to succeed.

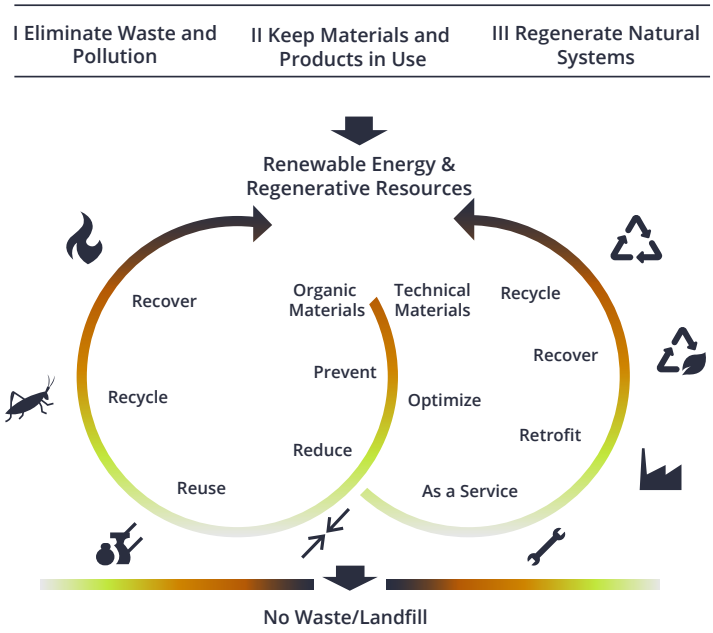
The circular economy requires a radical reimagination of how to do business in the 2020s and beyond. It provides an ideal of zero waste systems that will allow humanity to tread more gently on the planet — a new understanding of how we should be treating (and re-treating) our waste. As earlier parts of this White Paper have shown, there are huge prospects for upcycling initiatives to bring added economic and environmental value while moving us along to a more circular economy. But there are still inherent difficulties in the pursuit and definition of those goals.[32] Even from a practical level, since waste is very difficult to eliminate entirely from a value chain, and there are still complex decisions and tradeoffs to make about what is defined as "valorising" persistent waste streams.

A note of optimism can be found in the radical shifts toward biodegradable and recyclable plastics. Many business models for food waste valorisation will take the precedent of successful plastic reduction initiatives and the mantra of 'reduce, reuse, recycle.' Yet even here, there are complexities and systemic patchiness in plastic recycling that still require addressing. So with industrial agri-food waste, it is crucial to conduct a full life cycle analysis and dig into a deeper understanding of the real tradeoffs involved. Swapping out one flawed system for another is clearly problematic. Hence the importance of devising the right set of circular priorities from the outset.

Here is how Swiss multinational plant equipment manufacturer company, Buhler, evaluates circularity. Bühler uses three main indicators: Does this system help to reduce land and water use? Does this sidestream system minimise the carbon footprint of the primary product? Does this process bring a higher return for the same amount of input material, like bringing new products to market?

Cicular Economy *

is based on 3 key principles...



Indicators

Land Use/Water Use

- Prevent, reuse, recycle materials, so that fewer new resources need to be cultivated and part of the land-use/water use can be avoided
- More space for biodiversirty

Carbon footprint

- Minimize carbon footprint of primary product
- Avoid using fossil resources
- Do not create waste

Business Impact

- Higher return for the same amount of input material
- Added value through an additional business opportunities

*Source: Bühler waste to value white paper

Getting these questions right can help implement and manage business models for a circular bioeconomy. Similarly, investors can interrorage new circular ideas like those featured in this report with life-cycle related questions that help place an innovation's second order consequence within a given system.

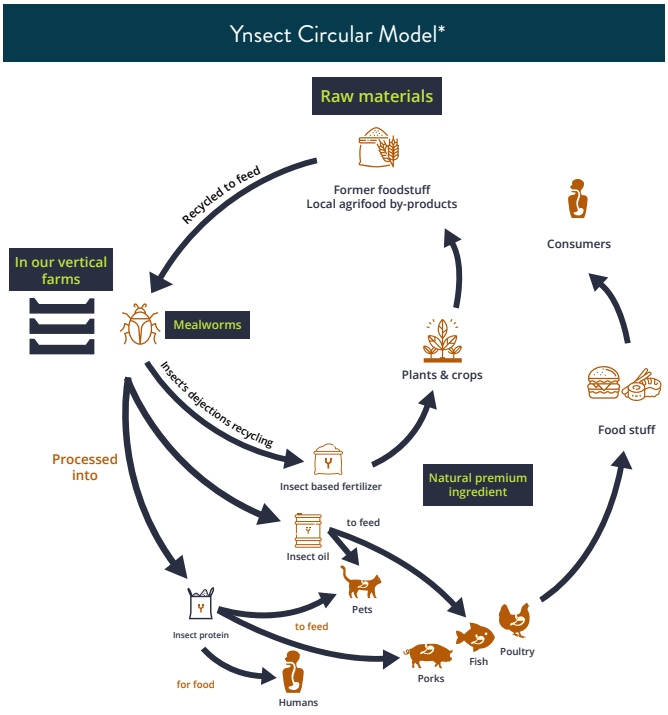
- Where and why has this innovation been hiding?
- Where are its active and nascent markets?
- Is a value addition process easily linked to these marketplaces?
- Is there adequate resilience of logistics and feedstock collection systems?
- What are the challenges linked to seasonal availability of resources?
- Who are the rival claimants for a feedstock sidestream?

For companies eyeing circularity in food waste systems, it is worth taking a few learnings from the projected rollout of insect farms as a classic case of valorisation dilemmas. Demand is expected to rise across Asia for some insects like the Black Soldier Fly (BSF), the Meal Worm, Crickets, or Grasshoppers. Which species to choose and why? Which waste stream feedstock? What breeding technologies? Centralised systems or distributed?

France's Ynsect is a prime case study for other growth stage, circular minded companies to take note of. Antoine Hubert, CEO and Chairman of Ynsect, points out some of his company's strategic thinking.

Feed for insects needs the following elements, according to Hubert:

- Protein source: Proteins are essential to foster insect growth;
- Energy source: Energy is essential to allow the animal to "work" properly (reproduce, digest, etc.)
- Fiber source: Fiber is needed to regulate the passage of food
- Minerals and vitamins: for the insects' growth and physiological processes
- Other elements: These determine texture and conditioning of the final products. Texture is a key difference with other animal feed requirements as insect live in their feed compared to vertebrates.



*Source: Ynsect

"Ynsect's mission is ultimately to lower the environmental impact of food in terms of climate and biodiversity," he says, and going after agrifood waste gives his company a number of feedstock advantages. "A key difference with other raw material that are also used by other bioconversion systems like insects, is that industrial agrifood waste are relatively safe and consistent over time as the result of a stable industrial process with high quality schemes. Post-consumers waste are for instance highly heterogeneous and carry different food safety risks. Industrial agrifood waste could also be more affordable than agricultural side streams and byproducts. Its affordable value, large volume, safety and stable composition made them a feed of choice for insects."

But then the question of which agri-industrial feed should Ynsect goes for, which has opted for the building of large centralised facilities and the rearing of yellow mealworm beetles, also known as Tenebrio Molitor. Not all side streams are created equal for species like these.

Scouting Asia's feedstocks, Ynsect is expressing interest in palm oil and sugarcane, though comes back to issues of quality control being paramount in feedstock evaluation.

"An immediate action that comes to mind is the sorting of side streams," says Hubert.

"It would be immensely beneficial if the feedstock source were sorted out based on our nutrition requirements listed above — that is, sorted into Protein Streams vs Energy Streams vs Fibres etc."

To get there, he notes that it would be helpful to learn from the Recycling industry where recyclables are sorted into Paper, Plastics, Cardboard. The sorting would mean less money is wasted on sorting waste downstream, less Carbon is emitted through transporting undesirable elements and the whole process would gain in effectiveness and efficiencies, resulting in more competitively priced, faster produced products.

Southeast Asian industry, is also less consolidated than European and American ones, and the volumes per site are in general much smaller then in EU or the USA, leading to more logistics and transportation to collect similar quantities of raw material for a certain insect farm capacity.

Then again, following empirical evidence on feed opportunities for insects, "Scientific literature has already shown multiple times that these materials could be well digested by different insect species," he says. "There would be then two options, either undertaking proper testing and analysis of these materials on well-known and at-scale species like mealworm, or see how a local insect species, which would be well known to digest these materials, could be scale-upped with Ynsect Vertical Farm technologies to reach price competitiveness of its protein and oil eventually."

On the question of whether a central model is the best route to circularity in the Asian context, Hubert says his team assess the effect of scale, expressing a preference to "match feedstock availability with supply as physically close as practically possible. While larger scales of production would naturally tend to result in more competitively priced products, there is a trade-off to be made against transporting feedstock over large distances and sullying the carbon footprint that we set out to achieve."

Finally, the team sees genetics and AI as the two technologies that can help the insect industry leapfrog existing food industrial processes. "Our vertical farms are being designed to collect billions of data points every day and it is our intention that this data enable future optimization in every element of insect farming," he says. "Specifically on genetics, Ynsect has announced recently a 10M€ research program (Ynfabre, 50% financed by a French grant) aiming at developing new mealworm strains following last year major milestone of full mealworm genome sequencing achieved by Ynsect and CEA Genoscope."

At the Food-Water-Energy Nexus: integrating agrifood waste into a carbon-neutral food system

The water-food-energy nexus is central to sustainable development. Demand for all three is increasing, driven by a rising global population, rapid urbanization, changing diets and economic growth. Agriculture is the largest consumer of the world's freshwater resources, and more than one-quarter of the energy used globally is expended on food production and supply.

The inextricable linkages between these critical domains require a suitably integrated approach to ensuring water and food security, and sustainable agriculture and energy production worldwide.

CIRCULAR CASE STUDY FOR THE FOOD-WATER-ENERGY NEXUS:

800 Super, a Singapore company and its joint venture partner in Cambodia, GAEA Waste Management, is a prime example of the food-water-energy nexus in action. The team were recently awarded the contract for waste collection and transportation for one of the three zones in Phnom Penh City by the Phnom Penh Capital Administration, Cambodia.

Specialising in waste and recyclables collection, 800 Super incorporates technology in its operations in Singapore to improve productivity and increase efficiency, with support from Enterprise Singapore (ESG). An example is the use of real-time operation monitoring powered by RFID tags on trucks and bins that ensures that trucks are efficiently performing their duties and bins are properly emptied. Such technologies, including those developed by Singapore start-ups, will also be incorporated throughout the contract's tenure to support the long-term needs of Cambodia's growing urban centres.

For a start, 800 Super will be introducing the GPS fleet management system that it currently uses in Singapore to better track and manage its assets and enhance its workers' safety in Phnom Penh City. Combined with GAEA's local experience, 800 Super is confident that the joint venture would deliver satisfactory waste collection and transportation service for the residents in Phnom Penh.

The Dole Promise

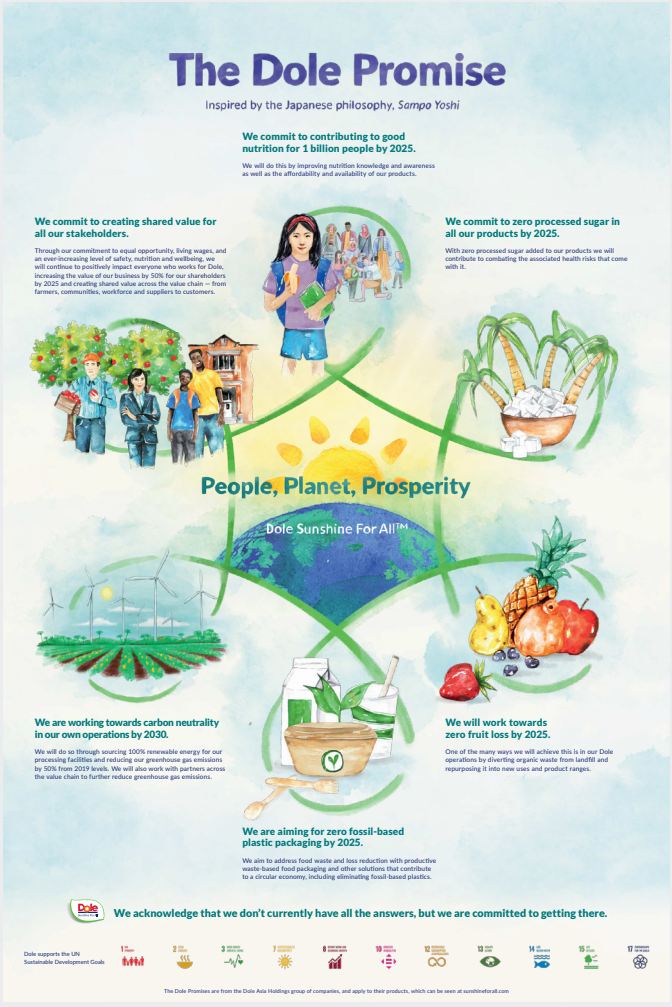
The Sunshine for All® Fund

The “Sunshine for All® Fund” will support strategic partnerships and strategic investments in these crucial areas of access and waste around the world.

In the first year, the US$2 million investment fund will work with innovators, start-ups and progressive partners to help deliver on the ‘Dole Promise’ in key areas such as materiality, advisory and implementation of crucial practices to help achieve the ambitions we have set.

“When we decided to move towards zero fruit loss, we realized that there is a whole set of new capabilities we would need to acquire. And that in some instances it would make more sense to partner with the best-in-class in their domain” says Barbara Guerpillon, Global Head of Dole Ventures. “We strongly believe that collaboration with external partners will be the key to unlock the Dole Promise.” The target is to engage with the entire ecosystem from startups to social enterprise, NGO, influencers, investors, or R&D networks. Technology has revolutionized our world and daily lives and the food and agricultural tech industry is moving quickly as the world needs to rethink their entire food system ‘farm to plate’.

SFA fund is not a CVC and doesn’t take equity when engaging with startups. The primary aim is to develop pilots that will potentially scale into to longer term



relations. The $2M fund is a commitment to provide resource pilots, research and partnerships in order to bring access to nutrition and reducing waste.

FOCUS AREAS

Crop Nutrition, Health & Protection

Technologies that will boost, but also ensure sustainability of the food and agriculture value chain, including solutions to regenerative agriculture, carbon sequestration, or fight diseases like fusarium touching our banana trees.

Food Safety & Traceability

Supporting the increase in consumer demand for transparency, traceability and clean and safe food from farm to fork.

Environmental Impact & Packaging

Reducing our use of fossil-based plastic in our farms and packaging with fully compostable material, as well as helping to reduce our environmental impact with novel formats, and business models.

Food & Water Waste

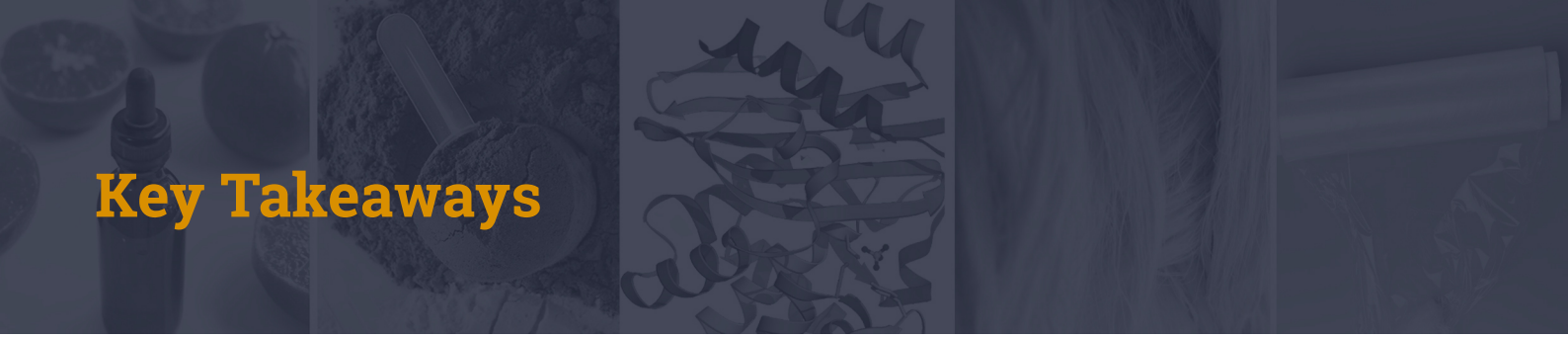
Upcycling solutions that would divert waste from landfill or animal feed to higher value chains to help us reduce fruit loss and waste.

Nutrition & Ingredients

Bringing more nutritious food to 1 billion people via novel foods, formats, and ingredients. Increasing awareness and education about the importance of good nutrition in our daily and making it affordable to everyone.

Labor

Improving farm labor productivity through technology from precision agriculture to sensors, automation and robotics.



Key Takeaways

1. Asia's food waste is both excessive and undervalued. Expect that to change rapidly in the years to come, thanks to a mix of new tech and policy resolve. Investors, policy makers, and corporations eying 'circular solutions' for agri-industrial food valorisation stand to make major gains.

2. Industrialised Asian economies like Japan, Singapore or South Korea offer strong testing beds for experimental upcycling pilot schemes with emphasis on high tech automation and an ever-widening access to early stage and institutional capital.

3. Emerging Asian economies with a greater agrarian focus like Indonesia or the Philippines offer opportunities for waste-to-energy biofuel systems, textile manufacturing from Agri residues, and functional ingredients from perishable fruits.

4. Another breakthrough has been how the use of breeding, AI and computer vision is assisting in the development of a new type of livestock husbandry: that of insects. With selective breeding, these insects are capable of not only breaking down huge amounts of food waste while growing with great resource efficiency but themselves becoming useful in pharmaceutical applications, fertiliser, and even bioplastics.

5. We see major investment opportunities at the agri-industrial level of food waste, as it is here that waste can be collected, stored, and processed with greater ease and scale.

6. Distributed solar powered waste separation and drying systems are set to make food waste management simpler, cheaper and less carbon intensive.

7. The transition to sustainable fashion — led by artists, fashion designers, and influencers — is cultivating feedback loops between consumers and companies. The more demand is there, the more companies will react. The time is nigh for pineapple trainers.

8. New fermentation technologies and hydrolysis are of particular interest for agrifood waste valorisation.

Calls to Agri-Food Waste Action

1. Jurisdictions that regulate carbon emissions, or have carbon emission caps or reduction targets, should consider providing tradable credits for rescue of food or other beneficial reuse.

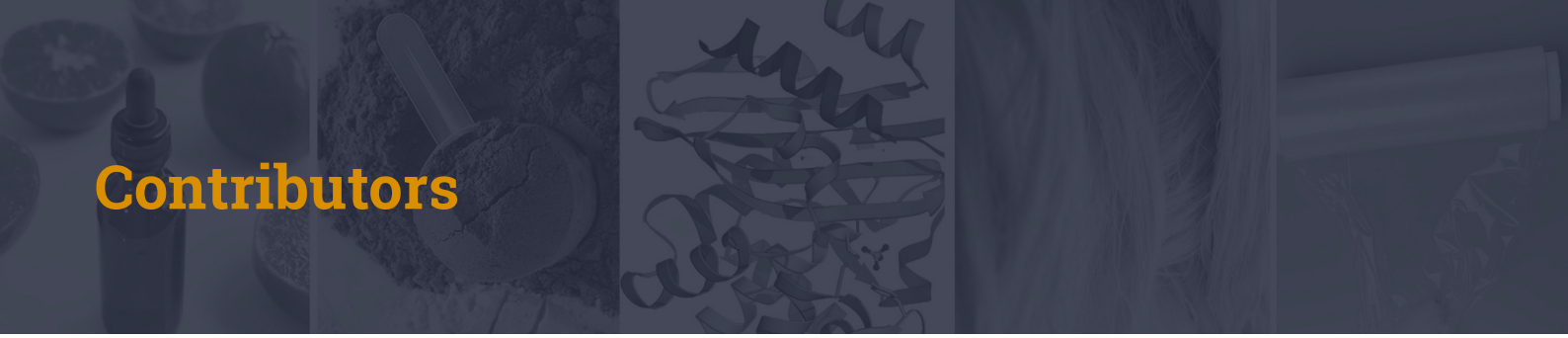
2. Governments should legalise and incentivise the rollout of insect farming across Asia, both to help handle food waste, and to provide nutritious and sustainable feed to a growing aquaculture industry.

3. Food companies must work with smallholder farmers to build out more agro processing at the farm level. This could provide chances for farmers to boost their own revenues and incentivise agri-residue collection and storage.

4. The circular bioeconomy represents an economic opportunity and an environmental imperative. But that does not make for many quick and easy wins. Investors need to offer patient capital to business models that in many cases still remain experimental and unproven.

5. And it is not all about tech startups with consumers or private investments; do not underestimate the national educational or policy level. In education Japan, for example, has rolled out national programs to retune the next generation's attitude to food waste and is a yardstick for others to follow, just like South Korea's smart vending machines for food waste.

6. Governments must prioritise food waste valorisation research with specific university grants and public-private partnerships.



Contributors

We would like to thank the following upcycling and food waste management experts for their time and insights that helped inform the views of this White Paper.

Editor: Richard Martyn-Hemphill

Akbar Vahidi, CTO & co-founder, Allozymes

Alex Min, CEO & Founder, RE:Harvest

Andreas Bauman, Head of Market Segment Insect Technology, Bühler

Ankit Alok Bagaria, Co-founder, Loopworm

Antoine Hubert, CEO & Chairman, Ynsect

Beatrice Conde-Petit, Food Science Officer (Future Foods), Bühler

Christian Hermansen, Team Lead Circular Bioeconomy, A*STAR's SIFBI

Deepak Raghothaman, Director Business Development, Allozymes

Friedrich Witschi, Business and Application Development Officer, Bühler

Gina Daypuyart, Manager-Business Innovation and Sustainability, Dole Phils

Harold Koh, CEO& Founder, NextEvo

Jan Meyer, Owner & CEO, Rutherford & Meyer of New Zealand, Upcycled Grain Project

Jeremy Lee, Head of Sales, Westcom Biotech

Jonathan Low, Sustainability and Life Cycle Engineering, A*STAR's SIMTech

Jordy Kay, CEO & Co-founder, Great Wrap

Kevin Vandewalle, Sales Director, VYNCKE

Lara Ramdin, Chief Innovation Officer, Dole

Mark Kahn, Co-founder, Omnivore

Melanie Weingarten, Deputy Director, Biotransformation, A*STAR's SIFBI

Milton Ng, Chief Operating Officer, 800 Super

Ninna Granucci, CEO, Greenspot Technology

Noemi Kaufmann, Project Manager Circular Economy, Bühler

Peter Fusarelli, Founding Director, UAG BioNutritent

Peter Tomich, CEO & Co-founder, Sustinent

Peyman Salehian, CEO & co-founder, Allozymes

Ramnath Vaidyanathan, Good and Green team, Godrej

Raquel Prado, Head of Research and sustainability, Ananas Anam Ltd

Rupen Desai, Global Chief Marketing Officer, Dole

Stuart (Stu) Nixon, Business Development Director, CoffeeFruit Pure

Turner Wyatt, Chief Executive Officer, Upcycled Food Association

Wei Tze Ooi, Managing Director, Dole Specialty Ingredients, Dole Sunshine Company, Dole

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A Future Food Asia Initiative

In partnership with

For any enquiries contact us at ffaa@idcapital.com.sg