Nanyang Technological University

62 Nanyang Drive, Block N1.2-01-12
Singapore 637459

Telephone: 6904 7132/ 6790 6741 / 6908 1959
Email: fst@ntu.edu.sg
Website: www.ntu.edu.sg/fst

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

TECHNOLOGY INNOVATIONS FOR FOOD SECURITY

Food Science and Technology Programme

MAIN CONTRIBUTORS AND ACKNOWLEDGEMENTS

MAIN CONTRIBUTORS

LEAD AUTHORS
Prof. William Chen, NTU
A/Prof. Yong Ken Tye, NTU

OTHER CONTRIBUTORS
Dr. Jaslyn Lee Jie Lin, NTU
Mok Wai Kit, NTU
Tan Yong Xing, NTU
Serene Kng, NTU

ACKNOWLEDGEMENTS

The authors and contributors thank NTU for funding and infrastructure support for NTU Food Science and Technology (FST) Programme, and participating Schools, namely School of Biological Sciences (SBS), School of Chemical and Biomedical Engineering (SCBE), and School of Physical and Mathematical Sciences (SPMS) for resource support.

The authors thank NTU College of Engineering (CoE) for funding support of the technology primer grant.

The authors thank Agri-Food & Veterinary Authority of Singapore, as well as Enterprise Singapore for funding support of technology innovations by NTU FST.

The authors thank NTU Development Office for engaging external support for the NTU FST Programme.

The authors thank NTUitive, NTU's innovation and enterprise company, for facilitating engagement of NTU FST with the food industry.

The authors thank NTU Corporate Communication Office for support in media exposure of NTU FST and media outreach on FST matters.

The authors thank Agri-Food & Veterinary Authority of Singapore, Singapore Food Standard Committee, and A*STAR for support of NTU FST's involvement in various national food initiatives.

TABLE OF CONTENTS

DISCLAIMER, LIMITATION OF LIABILITY

This report represents the personal opinions of the contributors. The contributors and the Nanyang Technological University (NTU) exclude any legal liability for any statement made in the report. In no event shall the contributors and NTU of any tier be liable in contract, tort, strict liability, warranty or otherwise, for any special, incidental or consequential damages, such as, but not limited to, delay, disruption, loss of product, loss of anticipated profits or revenue, loss of use of equipment or system, non-operation or increased expense of operation of other equipment or systems, cost of capital, or cost of purchase or replacement equipment systems or power.

EXECUTIVE SUMMARY

With the world's population projected to reach 9 billion in 2050, food security is becoming an increasingly important global issue. Apart from the increase in population, changing consumer taste, climate change as well as water scarcity makes meeting the potential 60% increase in demand for food even more challenging.

Food security is generally defined as to provide population with readily available and safe food of appropriate nutrition level at an affordable price. Enhancing food security for Singapore is even more important considering the limited farming capacity and, as a result, heavy dependence on food import (more than 90%) for local consumption. Disruption of food supply and cost fluctuations in food import are real challenges to be addressed. The impact on the environment by the amount of food waste (800,000 tonnes) and plastic packaging waste (800,000 tonnes) generated yearly in Singapore needs to be reduced. In addition to ensuring food safety, three critical areas for food security in Singapore may include primary production, post-harvest processing and nutrition for the ageing population.

Technology innovations are key to enhance food security in Singapore. These may include new ways to monitor food supply chain and enhance food fraud traceability (blockchain and artificial intelligence), integrated system for urban farming (sensor for real time monitoring of farming conditions), technology-driven food waste management (zero waste food processing), new ways to measure gut microbiome as indicator of food nutrition (non-invasive measurement of gut microbiome functionality), and platform technology to develop alternative and unconventional food sources (insects and microalgae).

NTU's strength in interdisciplinary research, and particularly the College of Engineering (CoE) with their strong credentials in technology innovations, make us strong leaders for this important endeavour. Progress made by NTU Food Science and Technology Programme (NTU FST) has been encouraging, and generated significant interest and investment from food industry and government agencies. Established in 2014 in partnership with Wageningen University & Research from the Netherlands, NTU FST has developed food technology innovations in the area of valorisation of food waste, biodegradable packaging materials and zero waste food processing.

This Technology Primer comprises a review of market and research trends of relevance to Singapore food security (primary production, post-harvest processing and nutrition), as well as technology capabilities from various Schools within CoE. It also projects a cohesive CoE ecosystem, with NTU FST as a focal point, integrating relevant capabilities for a collective and synergistic effort in technology innovations for Singapore food security.

Photo credits: Agrilife

OVERVIEW OF SINGAPORE'S FOOD SECURITY LANDSCAPE

Food security is an important national issue for many governments aroundthe world.

The key elements of Singapore's food security include availability of food from either domestic production or global market, accessibility of food by Singapore consumers, affordability and safety and nutrition standards for consumers. Singapore's food security index was ranked top in the world in 2018, with food affordability as one of the key assessment criteria. However, our ranking in food security would drop to number 16 if the assessment criteria cover climate changes and fluctuation in food price. Extreme weather conditions (severe flooding and/or long lasting droughts) on agriculture have caused damage to production of food crops. Incidences of sudden increase in food price seen in 2008 would also affect the stability of food import. As such, Singapore is particularly vulnerable in terms of food security, as we rely heavily on food import for local consumption.

Land allocated to agriculture in Singapore has been reduced over the years as a result of our rapid industrialisation and urbanisation, from approximately 25% in the 1960s' to less than 1% at this point in time. More than 90% of food for local consumption has been imported in recent years. The list of some countries that Singapore imports food from are shown in Figure 1.

EXAMPLES OF COUNTRIES SINGAPORE IMPORTS FOOD FROM

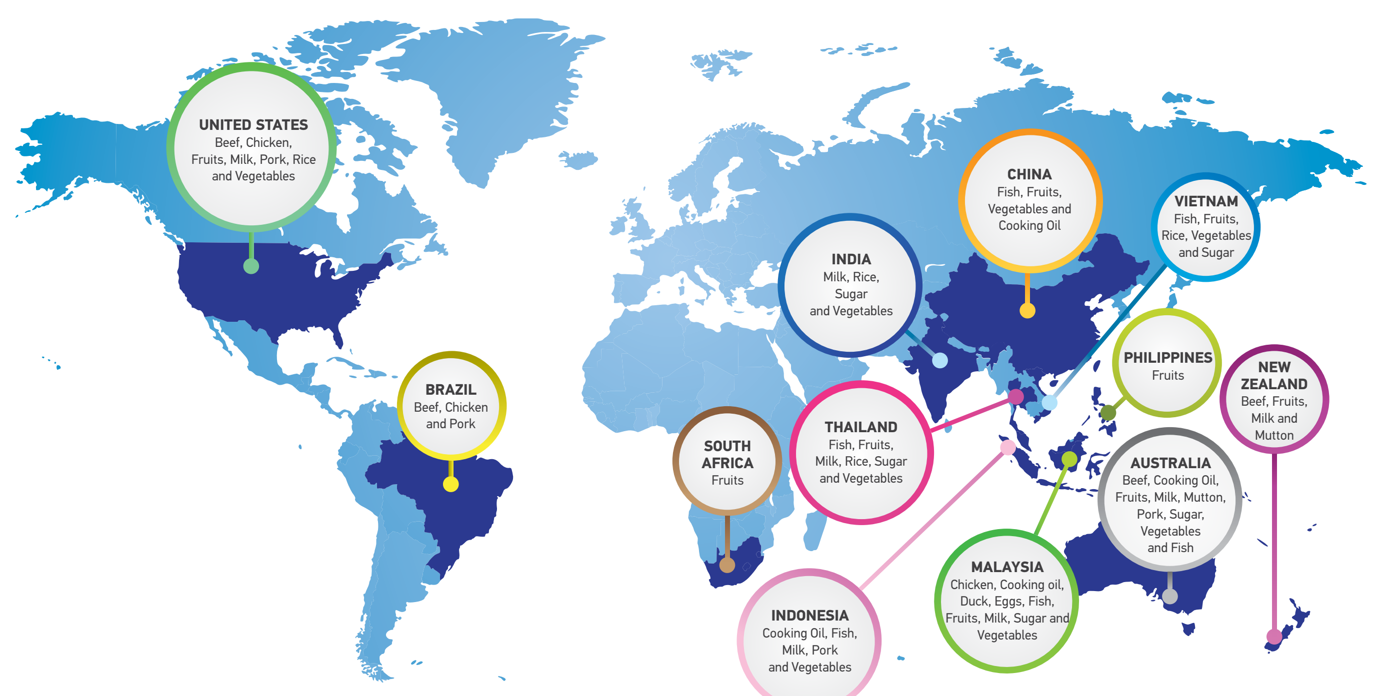


Figure 1 - List of countries that Singapore imports food from
Photo credits: Today Online

Even though our food import network is much wider (more than 180 countries) than water supply (only from Malaysia), the above-mentioned challenges (unpredictable food crops production and food price) remain. Technology-driven solutions are urgently needed to improve local primary production to provide Singapore with a buffer to soften the impact of any sudden disruption in food supply. These solutions may include modification of crops which are more resilient to climate change (for example Temasek rice), and high production yield farming systems which are resilient to changes in weather conditions (urban and indoor farming). Leafy vegetables would be a good choice for urban farming given their potential for high production yield in constant lighting conditions.

One important food supply for Singapore which is not affected by land constraints would be the aquaculture. Surrounded by seas, Singapore's aquaculture sector has strong potential for growth and has been identified as a key food source for its food security. In recent years, offshore fish farming is experiencing new challenges as a result of global warming and extreme weather conditions, with increasing incidences of algae bloom in the Johor Strait affecting fish production yield. Technologies innovations for land-based aquaculture have been successfully developed

Photo credits: Barramundi

Photo credits: Agrilife

in Singapore by AVA on St John's island, as well as by Apollo Aquaculture Group, and the production yield has been further enhanced by the latter with the introduction of a vertical aquaculture system. The new challenges would be to integrate urban farming for leafy vegetables with land-based aquaculture, commonly referred to as Aquaponics. The integrated system would allow an efficient way of food production, in which water can be cleaned up through the absorption of nutrients in fish discharges by the vegetables thus promoting their growth. In addition, the cost of aquaculture can be reduced by replacing feed ingredients with those from low cost sources such as food waste.

New natural food sources may also be considered to strengthen Singapore's food supply. These may include insects and microalgae. Unlike conventional animal farming (for example cattle and poultry), insect and microalgae farming offer high nutritional value with a much lower cost. It is estimated that half of the cattle feeds is used to maintain its body temperature and the land utilisation for cattle farming has not been optimal. In contrast, insect farming can be vertical thus overcoming any space constraints. It is also more efficient as insects are cold blooded and have a much wider range of low cost feeds. Likewise, microalgae farming can be operated cost-efficiently as they are photosynthetic and resilient to their growth environment.

Effective food safety assessment is of critical importance considering the diverse sources of food import. In addition to ensuring quality requirements of the sources of food production, new technology is needed for effective monitoring of supply chain as well as pre-emptive detection of new chemical and microbial contaminations in the imported foods.

Another area of concern in the context of food security is the large amount of food waste and plastic packaging waste generated every year in Singapore, estimated by NEA to be around 800,000 tonnes for each of the two types of waste materials. In addition to the general food waste, there are also side-streams generated from food processing industry such as soybean residues (commonly known as Okara), brewer's spent grain and waste cooking oil. The amount of side-streams is significantly lower than the general food waste (around 20,000 tonnes for any one of the three types), but not negligible. Unlike countries with sizeable animal farms can use the food waste as animal feeds after processing, such waste is mostly ended up in incinerator and landfill in Singapore. In recent years, general food waste has been converted into fertilisers and compost by bio-conversion. In food waste processing value chain, this useful conversion is considered to be a recycle endeavour with relatively low value add. More can be achieved in extracting value from food waste, including food ingredients (amino acids, micronutrients among others) and high value additives (for example

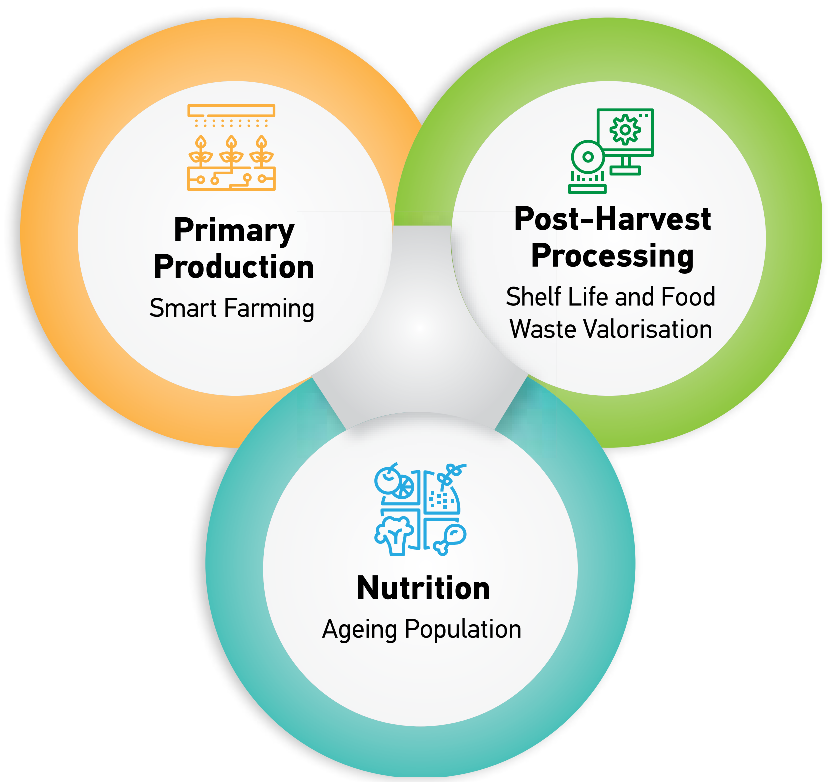


Figure 2 – Singapore food security redefined

carotenoids). Nutrients recovered from food waste can be reconnected back to the food chain, as animal feeds or consumer consumption. Technology-driven food waste management would lead to better utilisation of imported foods, reduced food waste and environment pollution, and more importantly less pressure on food import.

Similarly to most industrialised countries, Singapore is going through changes in the demographic profile with a fast ageing population. Food nutrition for the elderly, both in terms of appeal of the food and effective digestion, is not the same as compared with younger individuals. This is compounded by various chronic diseases more often seen in the elderly. Innovations are needed to produce food not only for basic nutrition requirements but also for prevention of chronic disease onset in the elderly. Monitoring of the effectiveness of such innovations may well be achieved through new ways of monitoring the activities of the gut microbiome under the influence of food.

Taken together, Singapore food security can be redefined to include 3 main areas: Primary Production, Processing Technology and Nutrition as shown in Figure 2. Despite limited land available for agriculture, technology driven farming practices should provide the nation with a buffer zone to tide over sudden disruption in food supply from other countries. Processing technology should lead to less food wastage and thus reducing the pressure on food import. Proper nutrition for our fast ageing population can be monitored through gut health.

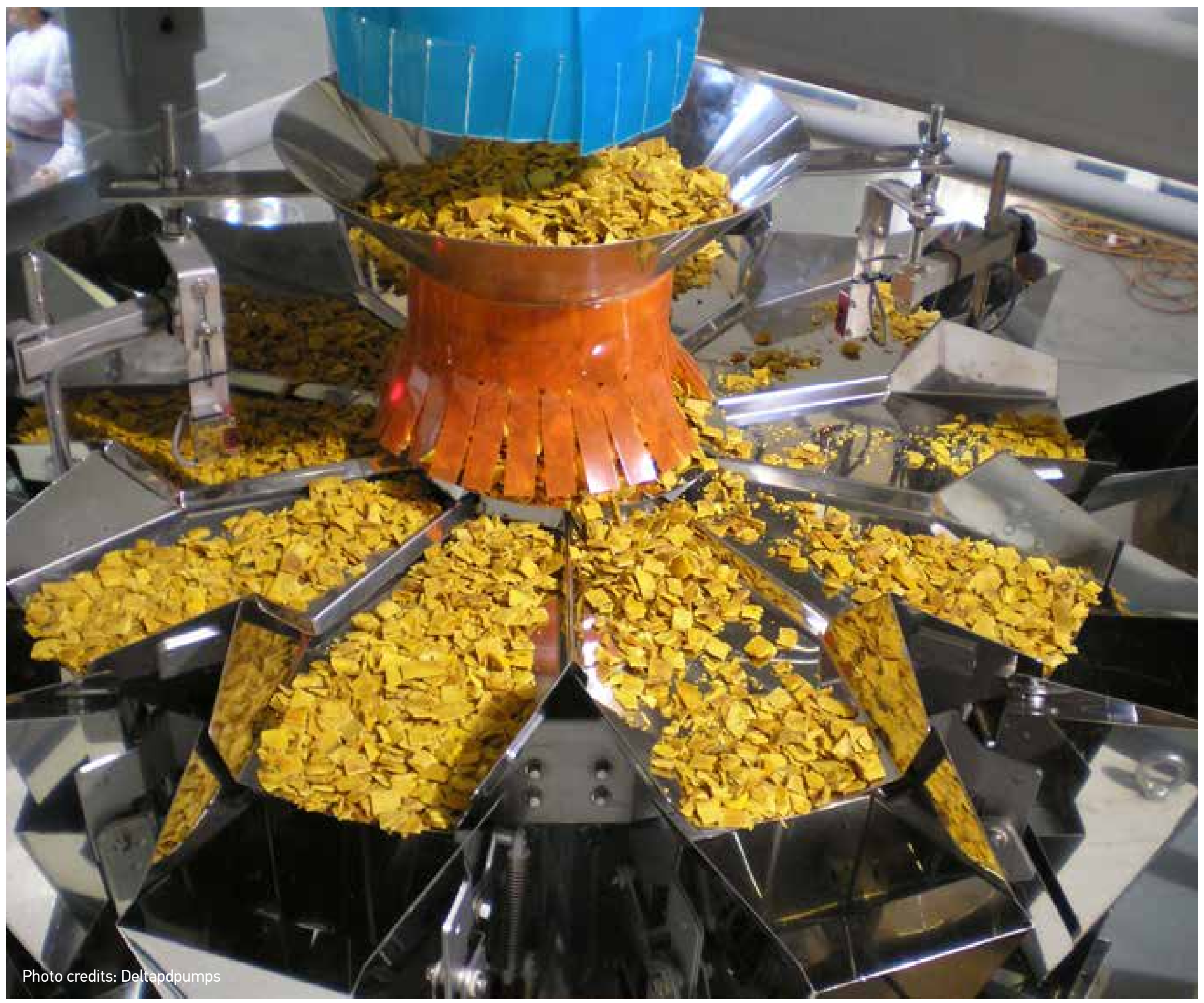


Photo credits: Deltapdpumps

CHALLENGES TO GLOBAL AND SINGAPORE FOOD SECURITY

PRIMARY PRODUCTION

Traditional farming is largely land-based at industrial scale. Its adequacy and efficiency in meeting the demand from the increasing world population are in need of improvement. There are a number of factors affecting the traditional farming. These may include climate change with extreme weather conditions, rapid urbanisation leading to shortage of farming manpower, energy issue on storage and transportation, food waste from storage and transportation, and consumers' demand for fresh and nutritious food produce. Technology innovations are needed to address these challenges. These may include primary production, zero waste food processing, and nutrition including alternative food sources. In present-day Singapore, current farming practices remain largely traditional, entailing farming methods that are both labour- and land-intensive. These practices are not viable against the reality of rapidly shrinking farmland.

In 1960, land allocated to agriculture in Singapore was around 25% of total land area. Today, this has shrank to less than 1% (see Figure 3).

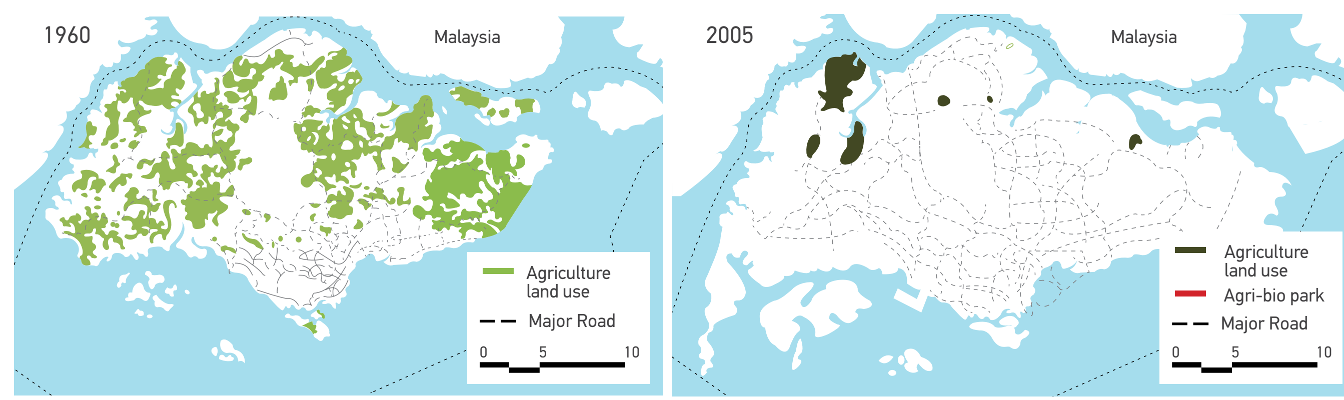


Figure 3 – Shrinking land allocated for agriculture in Singapore

Figure 4 - Plastic waste in Pacific Ocean.

POST-HARVEST PROCESSING

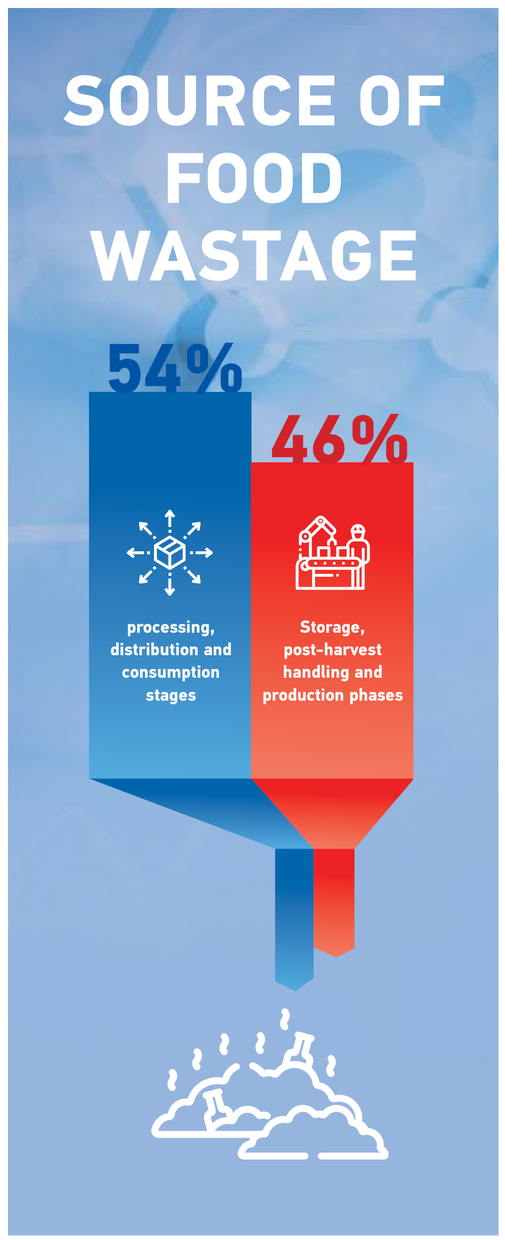
Food processing allows longer storage of foods and provide consumers with greater variety of food products.

Key aspects of enhanced food processing technology may include
1. Smart packaging with reduced plastic waste
2. Natural food preservative with less chemicals in food products
3. Zero waste food processing with less food waste from processing

Food wastage is a global issue with a huge price tag. Each year, the wastage of food leads to massive economic losses as well as serious climate and environmental problems.

Annually, about 1.3 billion tonnes of food produced in the world for the consumption of humans go to waste. In other words, roughly one-third of the global amount of food produced is lost or wasted. Of this wastage, roughly 222 million tonnes of food are wasted by consumers in affluent countries. This amount is almost equal to the total annual amount of food produced in sub-Saharan Africa (230 million tonnes).

Food produced that is ultimately not consumed uses up nearly 1.4 billion hectares of land, or more than 30% of the world's agricultural land area. Almost 46% of the global food wastage occurs in the processing, distribution and consumption stages while 54% of wastage happens during the storage, post-harvest handling and production phases.



In Singapore, food waste makes up 10% of the total waste generated in the country. And only 16% of this food waste is recycled while the rest is sent to waste-to-energy incineration plants.

In an average Singapore household, approximately 2.5kg of food waste are thrown away weekly. On top of that, each household throws away approximately S$170 worth of food and beverages a year. This means that, as a nation, we throw away over S$200 million worth of food annually. A survey conducted showed that at least half the time, 27% of the households in Singapore had leftovers after a meal while 24% of households have thrown away food that has spoilt or expired because families either bought too much or were unaware of food hidden at the back of the refrigerator.

It is a growing problem; over the past decade, the total amount of food waste generated in Singapore has increased by roughly 40% (see Table 1). This figure is expected to rise even further with Singapore's expanding population, greater affluence and accelerated economic activity.

Plastic waste is another colossal problem in Singapore. A Straits Times report in March 2018 revealed that, on average, each Singaporean threw away 13 plastic bags every day in 2016. National Environment Agency (NEA) data shows that in 2017 plastics constituted the largest amount of waste disposed in Singapore at 763,400 tonnes. Only 6% of this waste is recycled.

NEA data also revealed that over the last 15 years, plastic waste per capita has increased by nearly 20% in Singapore.

It is not just a local problem. The world is suffering the consequences of excessive plastic waste. The shocking amount of plastic waste in the Pacific Ocean is captured in the picture shown in Figure 4.

Year	Food Waste Disposed of (tonne)	Food Waste Recycled (tonne)	Total Food Waste Generated (tonne)	Recycling Rate (%)
2017	676,800	133,000	809,800	16%
2016	679,900	111,100	791,000	14%
2015	681,400	104,100	785,500	13%
2014	687,200	101,400	788,600	13%
2013	696,000	100,000	796,000	13%
2012	618,100	85,100	703,200	12%

Table 1 - Statistics for food waste generated in Singapore over the past decade

NUTRITION

Increasingly, consumers and government are paying more attention to food, nutrition. Healthy diet has been proposed to have positive impact on overall wellbeing with reduced rate of chronic disease onset. In addition, the role of increasing evidence points to a strong relationship between diet, human health and gut microbiome activity.

The importance of appropriate food nutrition is particularly relevant to Singapore society with a rapidly ageing population. Globally, looming competition for food supply as a result of population growth also demands for alternative and non-traditional food sources including microbes and insects.

The human gut is a host of trillions of bacteria. The entire gut microbiota is estimated to contain 150-fold more genes than our host genome. Tremendous progress has been made in linking human gut microbiota with health and disease. Imbalance in normal gut microbiota has been associated with inflammatory and metabolic disorders including inflammatory bowel disease, irritable bowel syndrome, and obesity. Therefore, an understanding of what constitutes a health-promoting or disease-promoting microbial group has turned into the concentration of huge research. Gut microbiota composition varies among individuals within and between communities. Several factors such as diet, geography, host genetics and physiology, and drug usage, influence gut microbial composition but diet has been considered as the most prominent factor amongst all. Moreover, diet is simplest to modulate and provides the easiest route for therapeutic intervention. Recent studies have linked diet and microbiome with health. Changes in gut microbiota reported in experimental animals fed a high fat diet that induces obesity. Moreover, controlled diets consist of non-digestible carbohydrates gave to overweight men actuate remarkable changes in certain dominant species, although the responses vary among subjects.

Over the last two decades, microbiome analysis of faecal samples using culture-independent methods, such as high-throughput DNA sequencing has emerged as a non-invasive tool to study nutrition and health. The development of tools has enabled researchers to explore the interaction between diet and gut microbiota, but this relationship still needs to be fully characterized. Novel non-invasive tools of gut microbiome activities can be developed to monitor the health benefits of food nutrition for general or ageing population, developed from either traditional or alternative sources.

Photo credits: TheWorldNews

ROADMAP FOR FOOD TECHNOLOGY INNOVATIONS

To tackle the threat of food shortage brought on by the world's exponentially growing population, the College of Engineering (CoE) is actively engaged in developing innovative new technologies that would ensure a sustainable food future. Figure 5 below shows the three main key areas in Singapore that call for technology innovations: primary production, post-harvest processing and nutrition. The sections that follow highlight the innovations that the CoE is pursuing in these three areas.

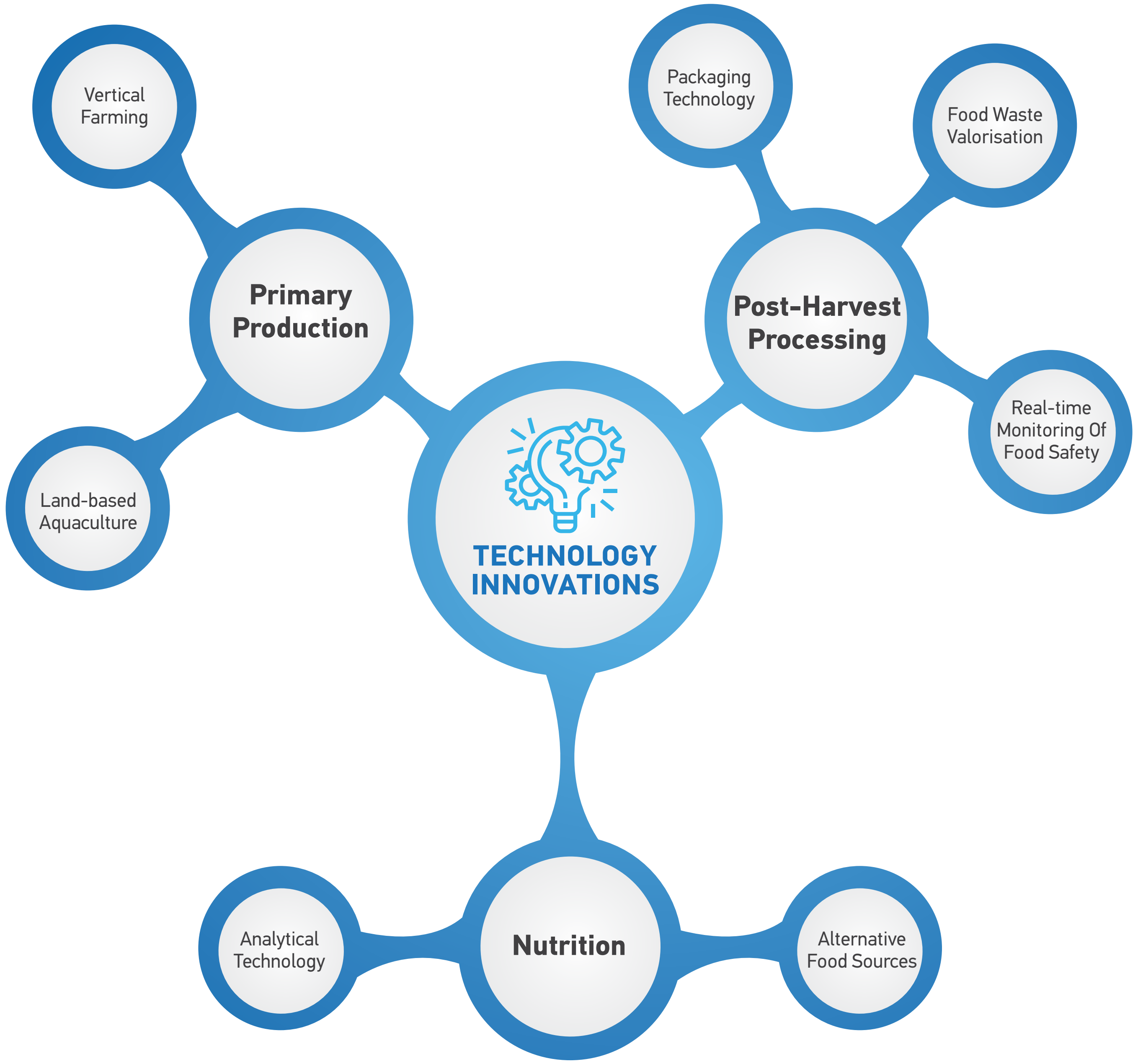


Figure 5 - Proposed R&D roadmap for food technology

PRIMARY PRODUCTION

TECHNOLOGY SURVEY

Primary production is the production of chemical energy in organic compounds by living organisms. It refers to plants or crops that make their own food through photosynthesis.

The traditional way of farming is an old-fashioned type of primary production system practiced for many decades. Today, primary production involves other technologies and practices such as crop rotations, intercropping, biological pest control and the use of compost or dung fertilisers.

In crop rotation, different types of crops are grown on the same plot of land in sequenced seasons. Figure 6 shows an example of crop rotation.

This practice brings many benefits. Crop rotation reduces pests and diseases, lowers the chance of soil erosion, minimises weeds and increases crop yield. By strategically growing multiple crops on the same land, land usage is also maximised. At the same time, the farmer mitigates his risk of any one crop failing. Finally consumers get to enjoy diverse agricultural produce.

In crop rotation, agricultural products are often a mix of fruits and crops such as vegetables and cereal grains.

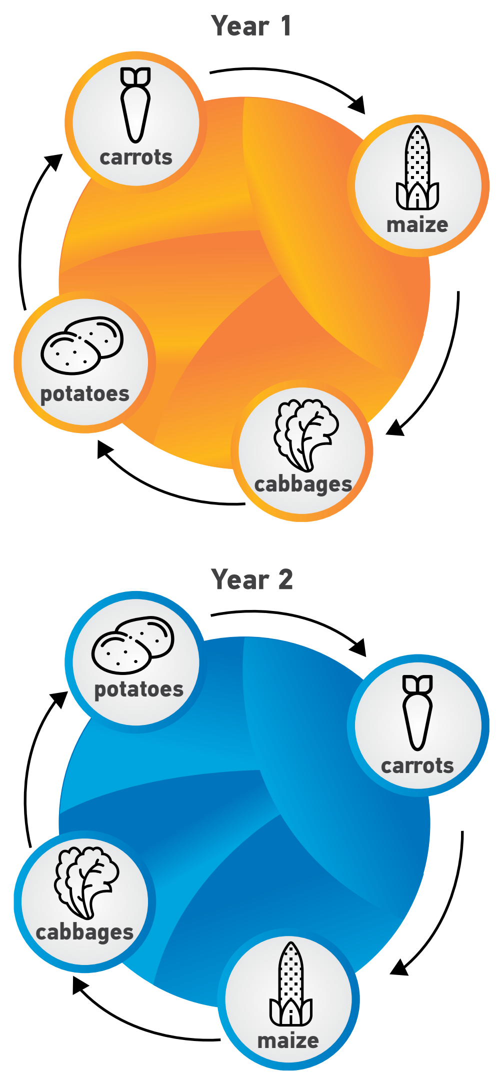


Figure 6 - Crop Rotation

There are many downsides to traditional farming. One of them is the large amount of land utilised relative to the amount of crop yield. Other limitations of traditional farming include the intensive use of land and labour, its vulnerability to climate change and the long haul needed to transport food crops to consumers.

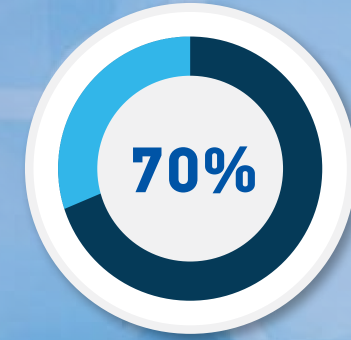
MARKET TRENDS

Food security is a rising global issue due to our increasing population and affluence. There is also a growing consumer demand in the city areas for greater supply of fresh produce. Intensified agricultural activity has allowed us to significantly improve crop output in order to meet the demands of the world's growing population. However, the limitations of traditional agricultural practices mentioned earlier make it an imperative to develop innovations in the domain of primary production in order to meet rising consumer demand.

The answer to overcoming this limitation is to shift from traditional farming to urban farming. Urban farming has key advantages. It requires little land space for growing crops, is unaffected by climate change and its crops are grown near city consumers. In Singapore, urban farming systems such as aquaponics and vertical farming can potentially be explored on a larger scale for future primary production purposes.

Photo credits: Skygreens

VERTICAL FARMING



Vertical farming also reduces the amount of water required (a reduction of as much as 70%)

COE CAPABILITIES

URBAN FARMING

The School of Materials Science and Engineering (MSE) of NTU has been working closely with the National Parks Boards (NParks) to develop an innovative substance in solution that releases water back to the soil. During prolonged periods of drought or when rainfall is scarce, spraying this substance will allow retention of water in soil for the plants to continue growth. The substance is tested to be environmentally safe and used across a variety of plants. Results from the tests showed that plants cultivated on treated soil used 50% less water than those grown on non-treated soil. This is due to its ability to retain the water. Unforeseeable climatic conditions is an ongoing problem traditional farming faces, and such an innovation can provide a way out to this problem.

VERTICAL FARMING

Vertical farming typically leverages high-tech and high-yield technologies to overcome the limitations of land-based farming. It can be conducted indoor for greater resilience to climate changes.

In vertical farming, LED light is used to help crops, vegetables and fruits grow without sunlight. This leads to much higher production yield as the growth is continuous.

Vertical farming also slashes the amount of water required (a reduction of as much as 70%), and its stacked structure translates to considerable savings in space and soil.

Overall, vertical farming reduces significantly the size of land needed as compared to traditional farming. It also helps urban areas gain self-sufficiency in food supply.

More significantly, vertical farming represents a paradigm shift, as the food can be produced in urban areas. This means that both quality and flavours would be superior to food produced from traditional farming, which typically has to be hauled over long distance to urban consumers, losing freshness and flavour in the transit. Also traditional farming tends to take place away from the urban areas. This is inefficient as energy would be needed to transport agricultural produce from the farms to urban areas and store them there. Traditional farming is also increasingly threatened by climate change, which has already led to lower production yield.

Vertical farming is an attractive option for land-scarce Singapore as it optimises land use and can be carried out using minimal manpower.

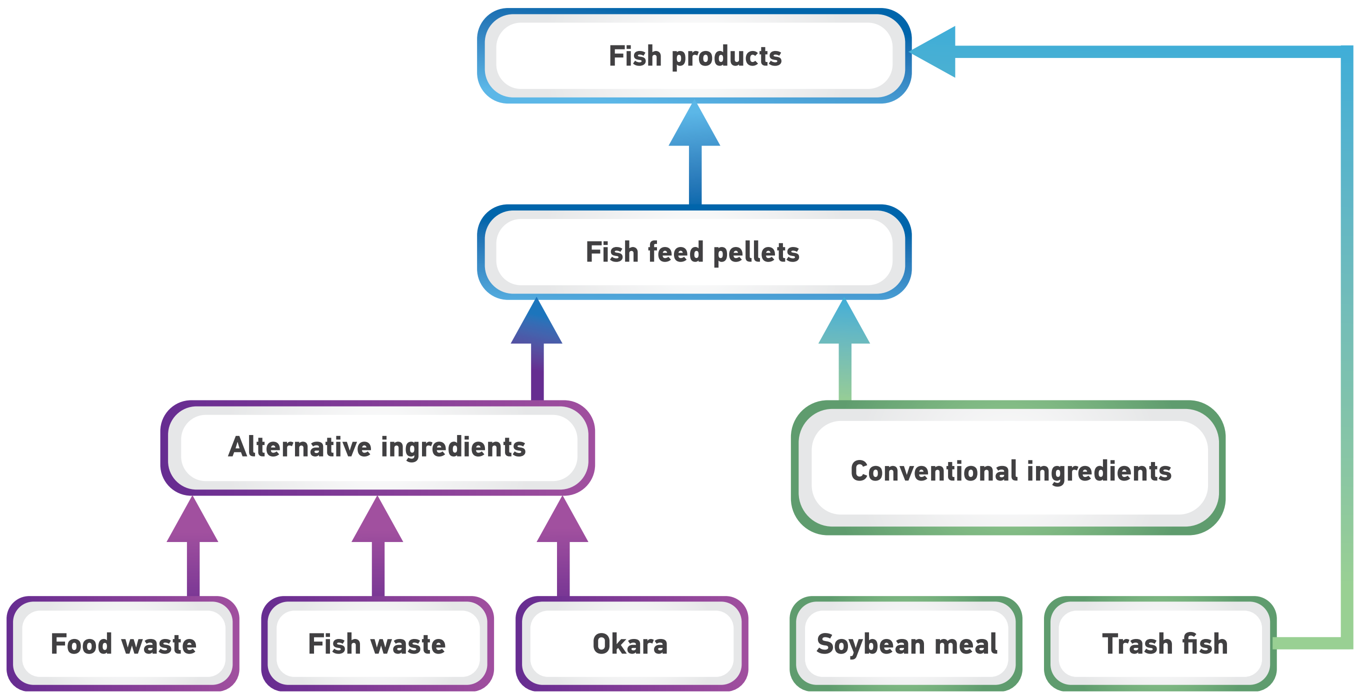


Figure 7 – Alternatives for fish feeding

Various schools in NTU are working together to develop urban farming innovations. NTU FST is designing modern technology for urban farming (in the spheres of agriculture and aquaculture). The School of Civil and Environmental Engineering (CEE) & Nanyang Nanyang Environmental and Water Resources Institute (NEWRI) is working on water quality control technology, which can be used in aquaponics. LUMINOUS! Centre in the School of Electrical and Electronic Engineering (EEE) is exploring ways to realise high energy efficiency in LED lights for indoor farming, as LED lightings used in indoor farming currently consume a lot of energy.

Other areas to be developed for primary production includes the usage of food waste for fish feed, which can amount to 50% of operation cost for fish farmers. There is likelihood that current fish feeds will be partially replaced by nutrients recovered from food waste. For example, fermented okara contains amino acids, vitamins, anti-oxidants and lipids. **NTU FST has been working since 2015 on a project funded by AVA, to replace poultry feeds with fermented okara.**

Fish that consumed diets consisting of food waste showed no difference in growth performance to those that consumed diets with 0% food waste. An overview is shown in Figure 7 below.

Another alternative is insect-based feed derived from black soldier flies, which can be used to grow salmon. The insect-based feed can replace current salmon feeds. One of the challenges of using insect-based meal is the cost **NTU FST has been working since 2016 with local farmers to explore the possibilities of using insect protein as fish feeds.**

Photo credits : Oceanoculus

AQUAPONICS

Aquaponics is a combination of two farming practices: hydroponics, or the producing of vegetables, and aquaculture, or the farming of fish, all in the same ecosystem. In general, aquaponics requires no land and can be conducted in a vertical manner. Hence it requires less space. There is also significantly lower demand for water when compared with the conventional farming. Aquaponics can be developed in a contained indoor environment, which means high production yield and more resilience to climate change.

In an aquaponic system, waste excreted by fish is degraded by bacteria. It then becomes nutrients for the vegetables. This close system ensures good water quality for the fish while providing nutrients for the vegetables. Under optimal conditions, aquaponics can lead to increased production yield for both vegetables and fish, the two critical primary production targets for Singapore food security. The aquaponics system is summarised in Figure 8.

AQUAPONICS

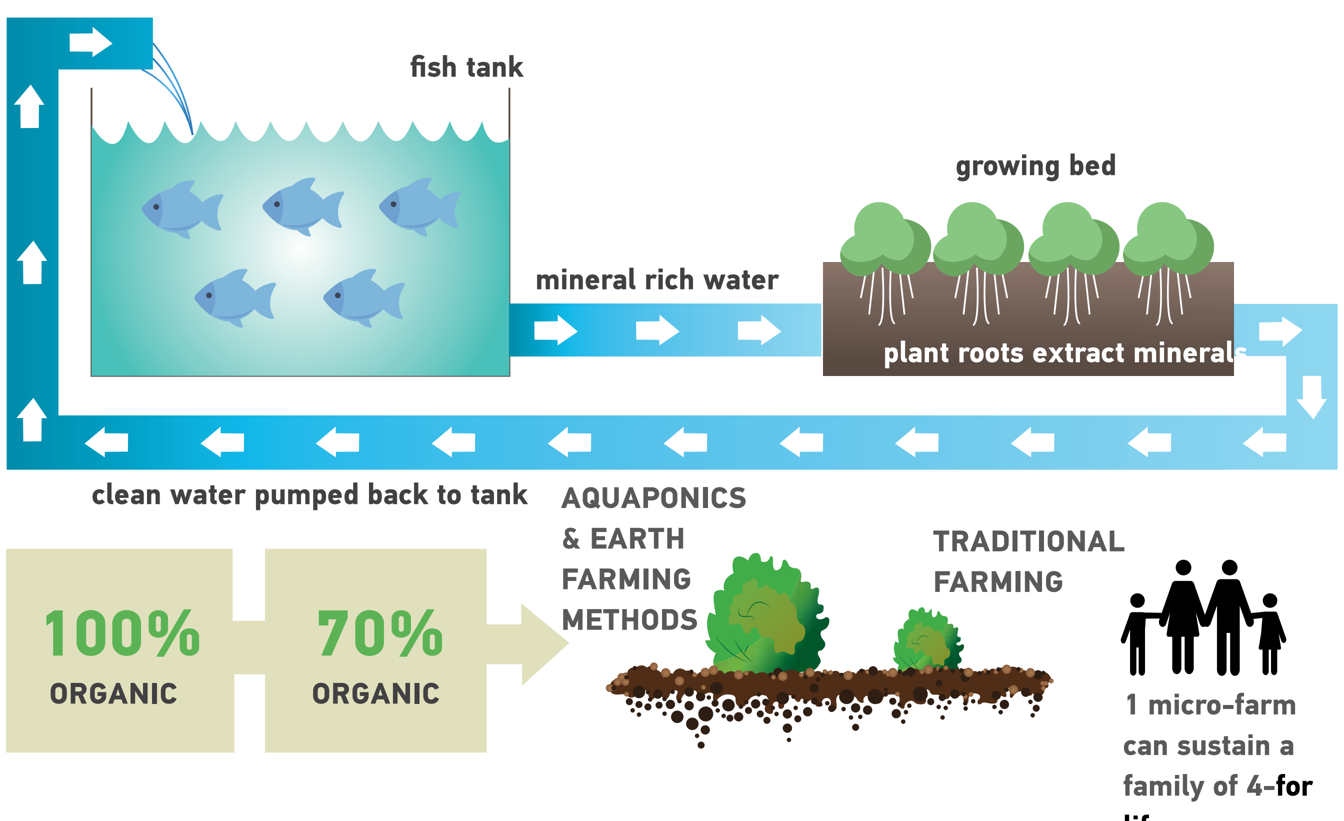


Figure 8 – Illustration of aquaponics process

POST-HARVEST PROCESSING

TECHNOLOGY SURVEY

Post-harvest food losses are a measure of the quantitative and qualitative food lost along the food supply chain from the time that food is harvested to the time that it is consumed or used. This loss can be due to food wastage or occur during transport.

Currently most side stream products from food processing such as okara, brewers' spent grain and pomace are disposed of in landfills or sent to incineration plants. Apart from the tremendous wastage, this creates extra pressure on our land and on the climate.

As mentioned previously, approximately one-third of the food produced globally goes to waste. On top of losses due to consumers and other end users, such losses can also occur from the time of harvesting such as from mechanical damage or spillage during harvesting, from degradation during handling, storage and transportation, from crop selection during processing as well as losses when food are handled along the distribution channels.

Most side streams generated by the food processing industry still contain significant amount of nutrients that could be recovered as nutrients through a variety of microbial/enzymatic processes. Currently these side streams are used as animal feed. This process can be further optimised through technology development for nutrient recovery.

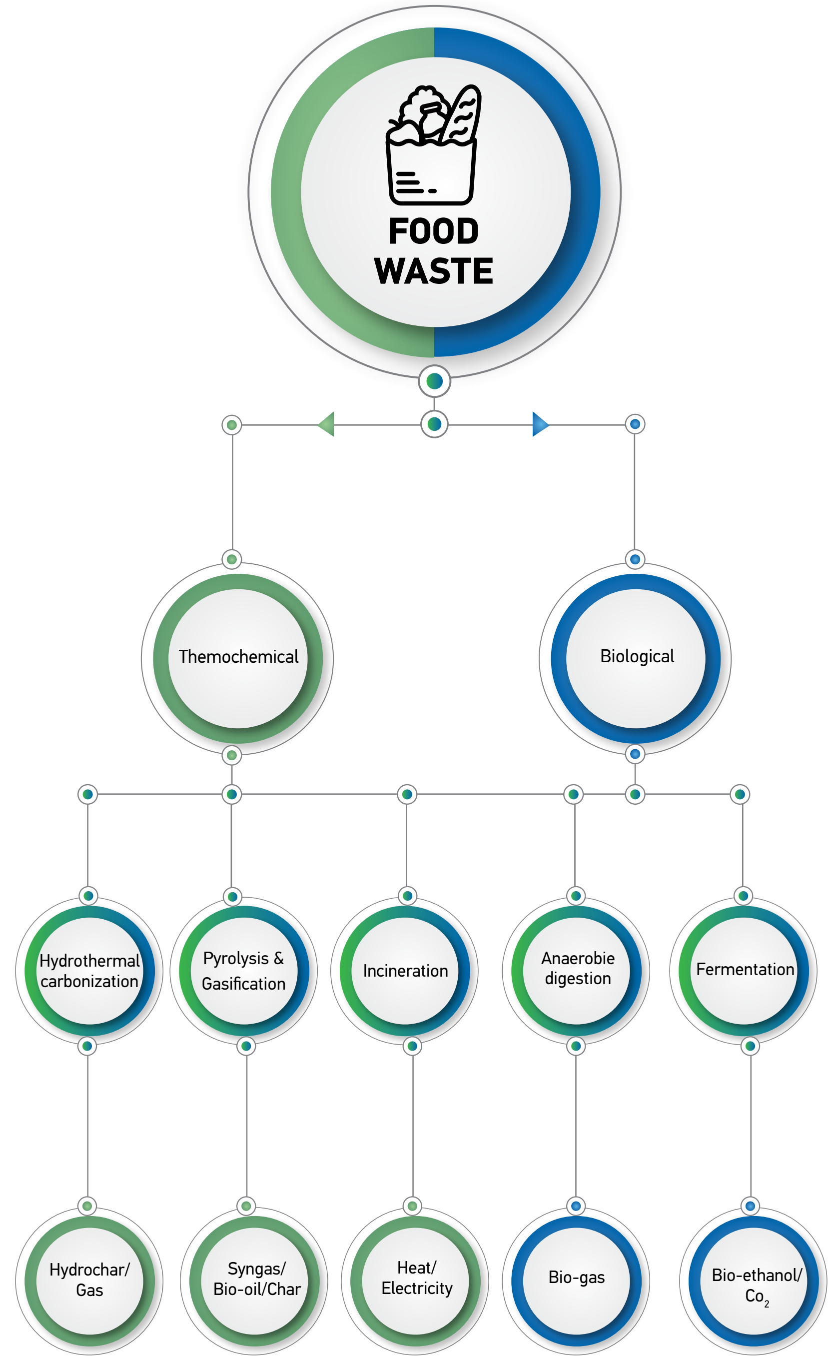


Figure 9 - Existing Technologies for converting food waste into energy

In other instances, the side streams were discarded in the environment, incinerated or sent to landfills. There is great opportunity here to rescue these side streams and add value to them through technology innovation.

Current technologies for processing of food waste mainly centre on food-waste-to-energy conversion. These include biological conversions such as anaerobic digestion and fermentation; and physical or chemical technologies such as incineration, pyrolysis, gasification and hydrothermal oxidation (see Figure 9).

The EU produces three million tonnes of animal by-products every year. Traditionally by-products like fat and grease are used in the manufacture of cosmetic products and animal feeds.

Recently a UK company invented a process to retrieve oil and fats from food waste and turn them into biodiesel (see Figure 10).

However, more can be done to recover high value components from food waste as well as to make better use of recovered components.

Our existing level of technology utilisation in the post-harvesting stage is not enough to address the growing issue of food security. Nor is there enough awareness of the importance of addressing this issue. It is imperative that the public and shareholders in the food industries are educated on the importance of food security. At the same time, there must be greater embrace of innovation and adoption of advance technology to alleviate this issue.

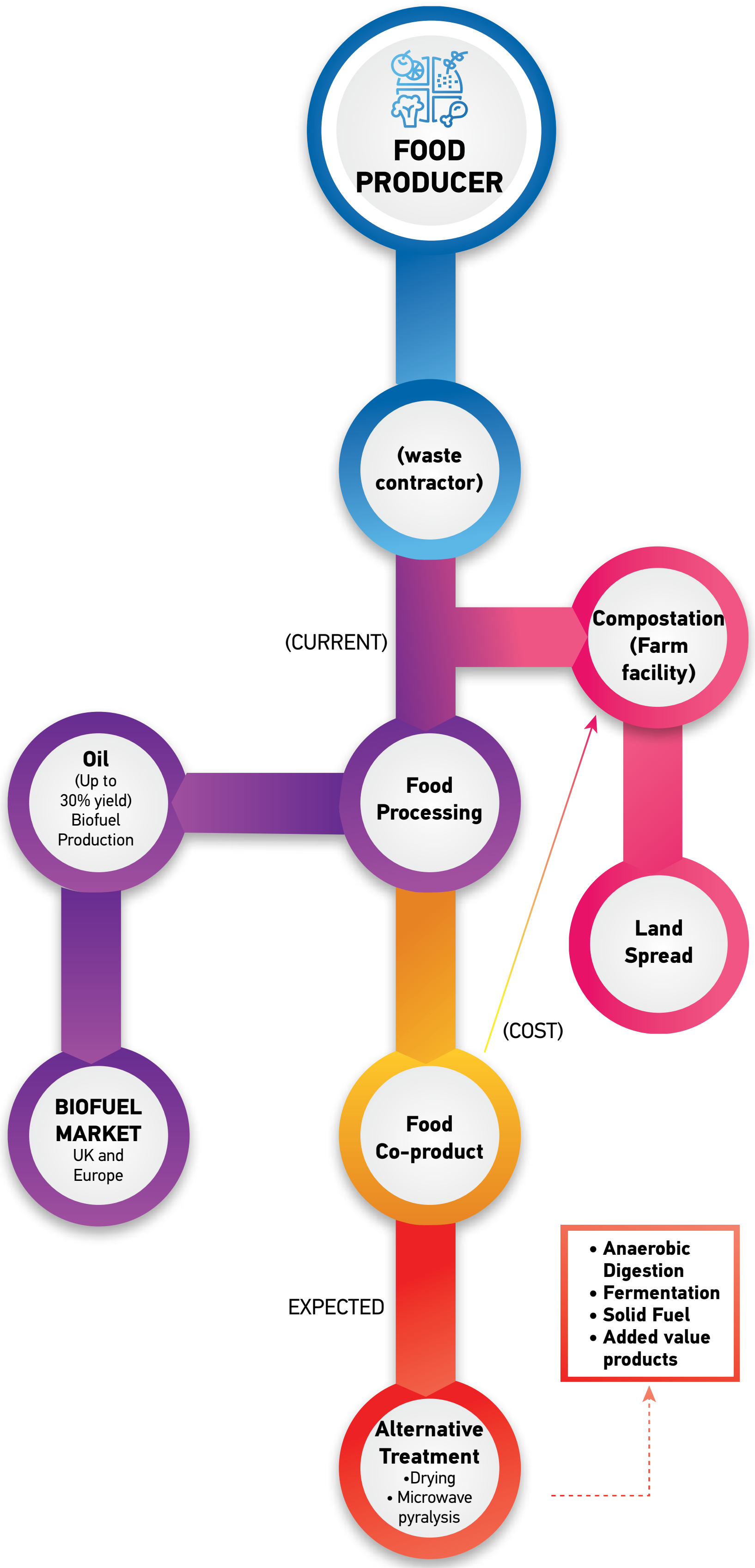


Figure 10 - Current food waste processing chain

MARKET TRENDS

Expanding industrial activity worldwide has led to greater demand for fuels and chemicals. However these fossil-based resources are already under pressure from decreasing supply, with availability further affected by the effects of global warming. What the world needs is stepped-up exploration of sustainable and innovative strategies for industrial production.

One solution that shows promise is the converting of the traditional linear industry production into a circular economy, where waste products are reintegrated back into the production chain. This would reduce the amount of waste generated as well as ease the demand for raw materials.

Photo credits : Eco-business

Photo credits: geppertrecycling

Scientists and the food industry have been actively looking to develop new technologies that would reduce food wastage. For example, side stream products from food processing that are normally disposed of can be valorised through a variety of methods to recover their nutrients and reduce the total waste output.

For Singapore, the valorising of food waste can help to reduce its reliance on food imports, thereby increasing its self-sustainability.

Apart from the valorisation of food waste, industrial players have also been trying to increase the shelf life of food products by employing various technologies such as using packaging material that has antimicrobial and antifungal properties.

COE CAPABILITIES

What is needed is new technology that prolongs the shelf life of food produce while reconnecting the food waste back to the food chain through nutrient recovery.

Fermentation technology is one answer to this problem. NTU FST has demonstrated the viability of food waste valorisation using fermentation technology. And NTU's School of Chemical and Biomedical Engineering has shown that this process can be scaled up.

In addition to innovations in post-harvest processing technology, analytical technologies are needed for real-time monitoring of food safety including food fraud traceability. These analytical technologies can be developed from existing expertise residing in the Nanyang Environmental and Water Research Institute and NTU FST. Meanwhile data analytics and blockchain solutions for more efficient supply chain monitoring can be developed by NTU's School of Computer Science and Engineering (SCSE).

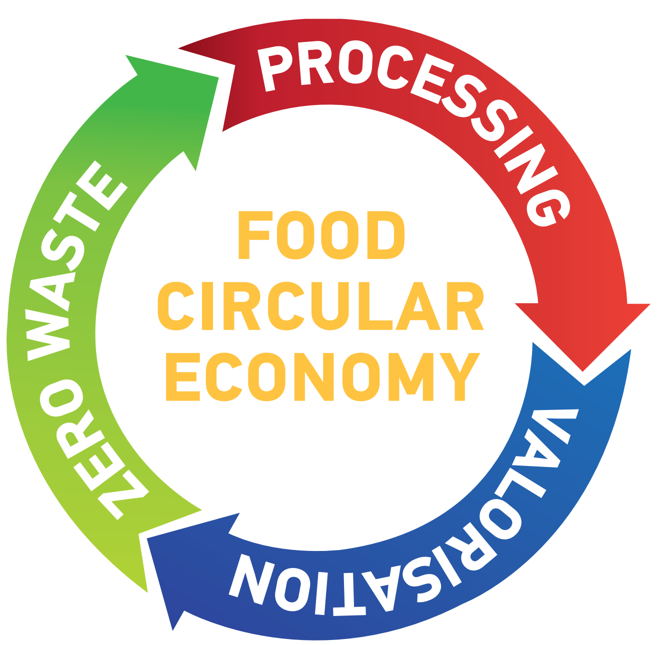
FOOD CIRCULAR ECONOMY

A circular economy is a regenerative system in which resource input and waste, emission and energy leakage are minimised by slowing, closing and narrowing energy and material loops.

The reduction of food waste or food side streams is a key area where innovations can support the creation of a circular economy in the food industry.

NTU FST has made significant progress in this direction demonstrating feasibility of integrating processes such as fermentation and green extraction to turn food side streams into useful products and materials.

A few prominent projects include the reusing of food waste such as okara and brewers' spent grain by fermenting these wastes. Essential nutrients extracted out are then used to grow other microorganisms. The food waste that is left after nutrient extraction can be turned into food packaging, to minimise the total disposable waste produced.



Some examples of food side streams are waste oil, okara from soy beans, brewers' spent grains from beer production. Figure 11 below shows the circular economy cycle.

The main work on food waste by NTU FST revolves around homogenous food waste or side streams such as soybean waste and spent grains waste. Homogeneous food waste offers one advantage in the ability to scale up production.

Heterogeneous food wastes are known as debris, solid waste, trash or rubbish and they are commonly used as fertilisers. To valorise and scale up such food waste would be difficult.

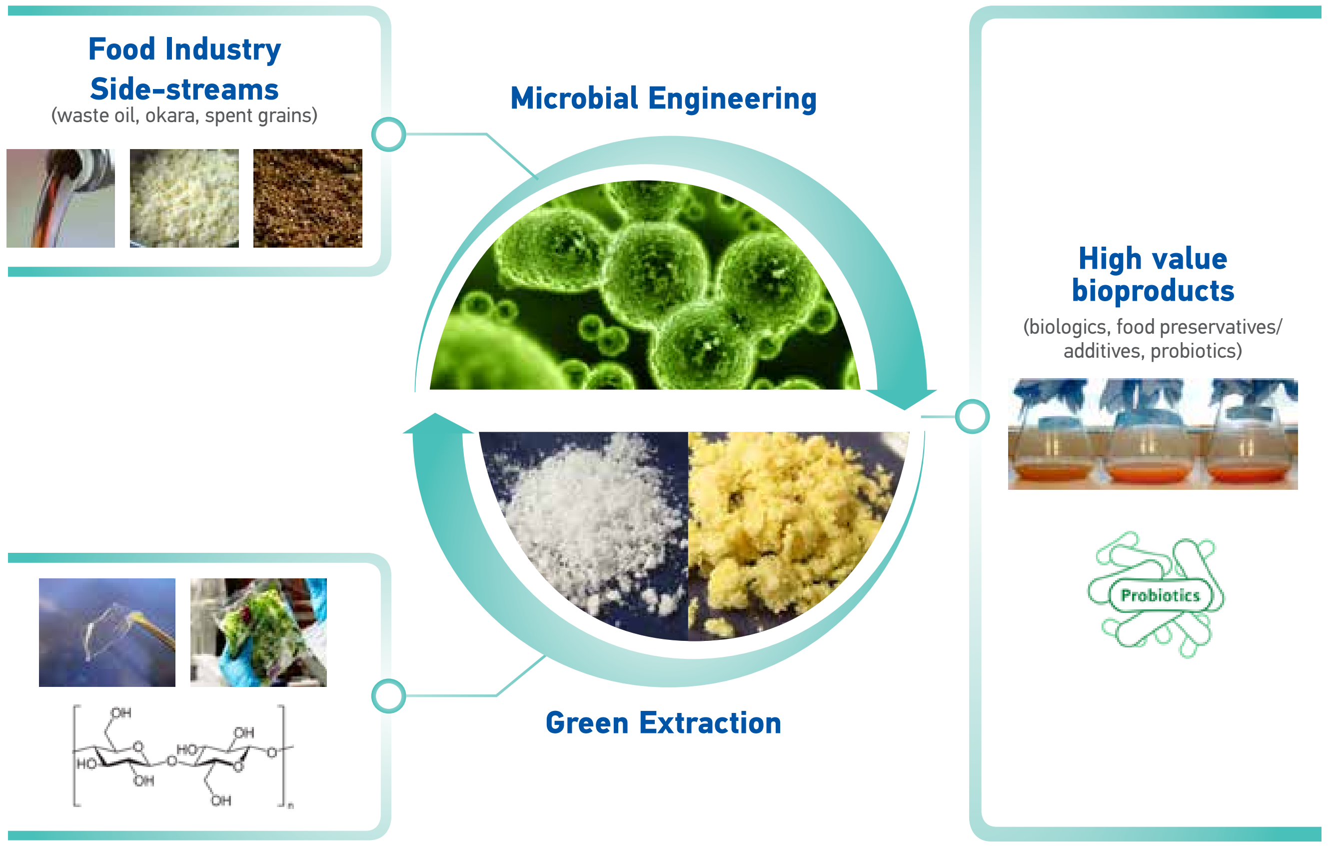


Figure 11 - Overview of circular economy of food

FOOD WASTE VALORISATION

One strategy deployed to combat the rising problem of food wastage is to valorise such wastes. Food waste valorisation refers to recovery of high value components from food waste.

While basic valorisation strategies are largely accepted worldwide and they are practices in a wide range of application, the recovery capacity and the effectiveness in creating value from wastes remains limited.

There are great spurs for the world to put into practices more advance valorisation strategies. They include the tremendous quantities of food waste generated every day, the growing need for chemicals, materials and fuels and mounting environmental concerns.

The benefits of an effective waste management strategy include less gas emissions from landfills, less competition for fuels, fewer ethical conflicts in using non-food crops, increased food supply, greater preservation of natural resources and more cost-saving routes for surplus.

Photo credits: Allgrains

To realise this vision, researchers and food producers are exploring chemical, biochemical and thermochemical conversion strategies using approaches involving extraction, fermentation, and enzymes technologies.

The following section offers a few examples of food waste valorisation.

FERMENTATION FOR NUTRIENT RECOVERY

NTU FST's team of researchers successfully turned okara and brewers' spent grain into a culture medium for the growing of yeast. This is done by fermenting with an enzyme-secreting microorganism that breaks down the components in the food waste into amino acids essential for yeast growth.

Test results have shown that baker's yeast is able to grow at the same rate in the food waste medium as it would in a commercial medium. And the cost would be much lower. A litre of the okara and spent grain medium would cost an estimated S$3 compared to the S$11 to S$36 for a commercial medium.

USING OKARA AS FOOD PACKAGING

NTU FST has developed biodegradable cling wrap derived from okara, the pulp left behind after the processing of soybean.

NTU FST researchers have developed a technique that involved adding a low cost chemical that removes the lipids and proteins present in okara. This leaves behind just cellulose which can be used to create packaging materials. The new method is a cost-effective alternative to the more common and costlier method of using alkali and enzymes to remove lipids and proteins respectively from okara.

SUSTAINABLE PRODUCTION OF NATURAL PRESERVATIVES

NTU FST researchers have made breakthrough in sustainable production of natural preservatives known as flavonoids.

While these flavonoids are naturally occurring plants, using them as preservatives would not be sustainable due to the limited amount in plants and the lack of bioactivity.

Test results have shown that meat and fruit juices treated with the natural preservatives developed by the team stayed fresh for up to 48 hours at room temperature. In the control batch, untreated meat and fruit juices grew bacteria within six hours.

It is estimated that approximately S$2 worth of flavonoids can be effective as preservative for up to 1,000 litres of fruit juice

TECHNOLOGIES FOR FOOD SAFETY

One important component of building a farm-to-fork food safety framework is the development of microbial intervention technologies that reduce, control or eliminate foodborne pathogens in food products and on contact surfaces.

It is well established that there is no silver bullet technology that will eliminate pathogens from food. However, in the past several years significant advances have been made both in improving existing intervention tools and in developing novel microbial inactivation technologies.

USE OF GENOMIC SEQUENCE DATA IN FOOD SAFETY

Phenotypic as well as molecular subtyping methods have been key tools in food safety and have played important roles in detecting foodborne disease outbreaks, in identifying pathogen sources responsible for food contamination along the food chain and in source attribution. Traditional phenotypic subtyping methods include serotyping as well as phage typing and biotyping.

However the development of molecular and nucleic acid-based subtyping methods has revolutionised the field of subtyping.

While the tremendous impact of PulseNet and other molecular subtyping methods on food safety is well recognised, there is no doubt that the rapidly emerging use of genomic sequence data for foodborne pathogen subtyping will provide another major improvement in our ability to detect foodborne disease outbreaks and define pathogen sources throughout the food chain.

SMART PACKAGING FOR THE MONITORING OF FOOD SPOILAGE

In recent years, there has been growing demand for “smart” food packaging
that are able to report actual freshness of a food product.

This demand is spurred by the global food waste problem.

Traditional methods of measuring food freshness are applied only randomly or in suspected cases. They are cost-intensive, time-consuming and require sampling that unavoidably compromises the integrity of the package.

The latest development is a new sensor based on fluorescent dyes. The working principle of this novel sensor is based on the change in pH value of fish's juice as bacteria starts to grow. The sensor can be easily attached to the surface of packaging materials to allow remote signalling through the package. One advantage of the fluorescent sensor is that its high sensitivity means that only a few micrograms of dyes is needed for a sensor, far below established toxicity levels. This removes safety concerns and lowers the cost of the sensor.

Photo credits : Commons

SMART SENSOR TO DETECT RIPENESS OF FRUIT

Ethylene is a volatile naturally occurring hormone produced by plants such as fruits.

This hydrocarbon gas is released when a fruit ripens or whenever the fruit is injured in any way. Ethylene causes a fruit to undergo changes in texture and colour. It may also cause the plant to die, when the plant has been damaged.

Ethylene plays a major role in the ripening of fruits as it regulates the plant’s growth and development, as well as the speed at which the plant grows and develops.

Monitoring the atmospheric ethylene level in food storage facilities would alert facility owners of over-ripe fruits stored in the facility and prevent the wastage of fruits in horticultural industries.

The School of Electrical and Electronic Engineering in NTU has successfully developed a chemo-resistive sensor that can detect the concentration levels of ethylene from fruits. The device is based on the high sensitivity of resistance of single-walled carbon nanotubes and their reactions to a change in their electrical properties recorded through a potentiometer.

The school is now carrying out further research to enhance the portability of the device, which would pave the way for the device to be incorporated into a “smart” packaging. With this, consumers would get a visual indication of the ripeness of a fruit from the packaging.

MILLIONS
Suffering from
food poisoning

Photo credits : Angel.co

BLOCKCHAIN TECHNOLOGY FOR FOOD FRAUD TRACEABILITY

The World Health Organization gauges that each year, one in 10 individuals gets sick from eating contaminated food, with 420,000 dying from food poisoning.

However tracing the origins of the contamination is a challenging task. Our worldwide food supply has developed into a network so complex and intricate that it is now highly difficult for food suppliers and retailers to ensure the provenance of their items.

Because it is hard to establish culpability and hence difficult to prosecute culprits, food supply is under consistent risk of adulteration. This is reflected in the increasing number of food fraud incidents.

These incidents are costly to organisations. Just one instance of food fraud can wipe out up to 15% of an organisation's income for the year and tarnish the image of the organisation so much that brand loyalty is diminished.

The blockchain is a possible solution to this problem.

Blockchains are decentralised digital ledgers that record transactions and store this data on a worldwide system in a way that counteracts the data from being changed at a future point.

For food producers, the blockchain allows for the prompt identification of any endeavour to meddle with a food item as it travels through the inventory network. The fraudulent act can then be counteracted before the food reaches retailers.

For retailers, the blockchain makes it possible to identify a potentially contaminated food item that has somehow made it onto store shelves and remove the contaminated item without having to dispose of the entire batch. This prevents wastage.

THE COMPLEX GLOBAL FOOD SUPPY CHAIN

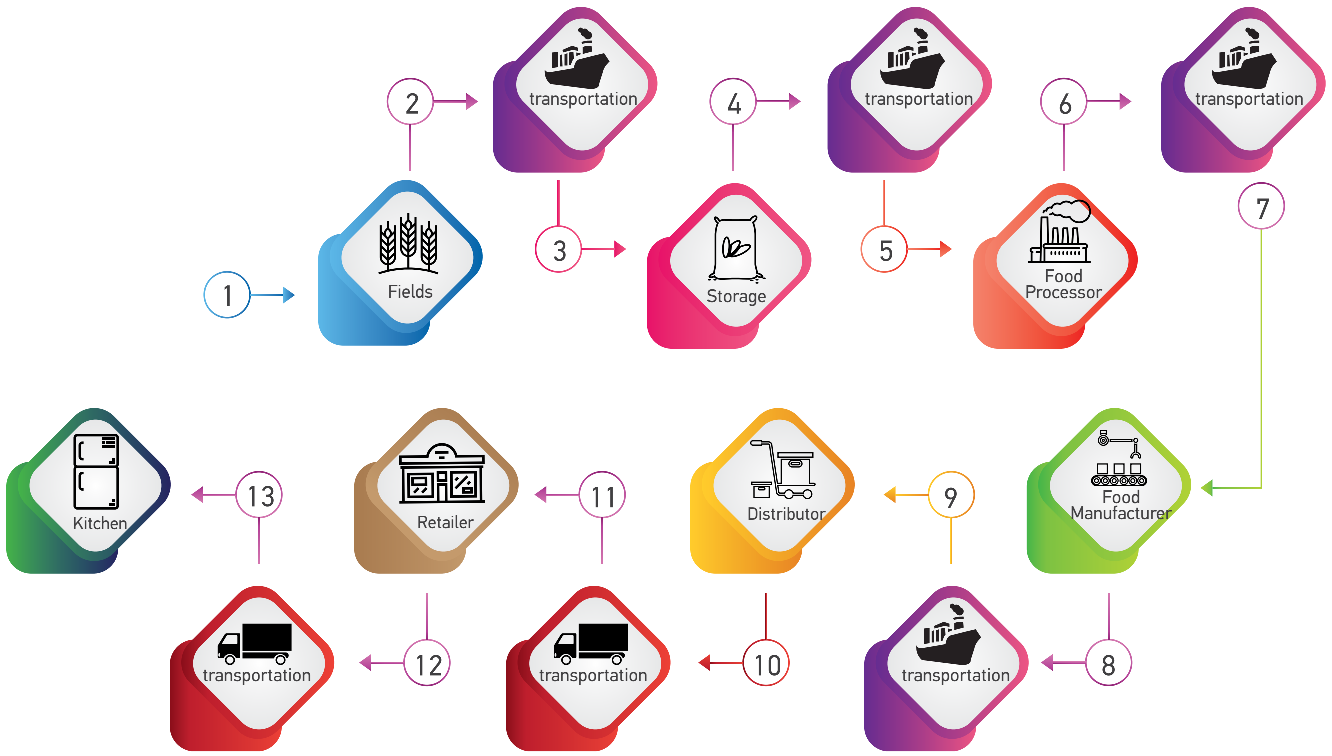


Figure 12 – Global food supply chain

Photo credits : leee

For consumers, the blockchain offers the promise that the food they eat is actually what the label says it is.

NTU SCSE is currently engaged in developing innovative blockchain technologies. The Blockchain Initiative at NTU is an inter-collegiate initiative that seeks to integrate cross-domain expertises in blockchain. In addition to working actively on solving the pressing issues of blockchain today such as scalability, security and privacy, the Initiative is also involved in partnerships with industry to research and test-bed projects for real-world use cases, such as supply chain management.

Photo credits : Foodinsight

NUTRITION

TECHNOLOGY SURVEY

A 2016 survey carried out on 9,000 participants revealed that 57.5% of the respondents' calorie intake is derived from ultra-processed food. This is defined as food that contains ingredients not used as part of the culinary preparation and includes such items as flavourings, sweeteners, colourings and emulsifiers. This is shown in in Figure 13 below.

The survey findings indicate that while there is increasing focus on health and wellbeing, many are still relying on processed food for their nutritional needs. Fish, a key food source, has been known to contribute up to 180 kcal of a diet on a per capita per day basis but it is consumed in such quantity only in a few countries where there is a lack of alternative protein foods grown locally or where there is a strong preference for fish (some examples are Iceland, Japan and some small island states).

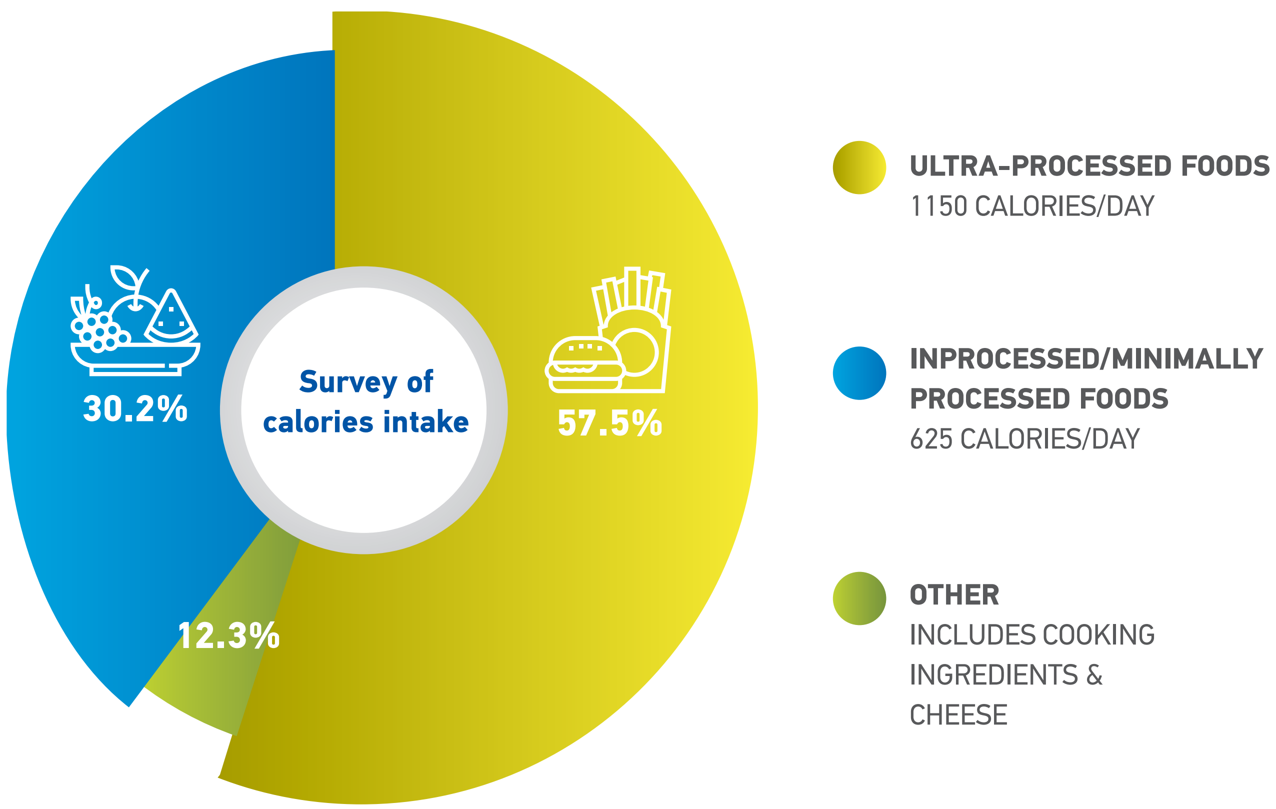


Figure 13 - Survey of calories intake

MARKET TRENDS

While a large portion of the global population obtains nutrients from processed food, it is undeniable that increasingly people are looking for more natural and organic food. This is evident in the current plight of traditional processed food and snacks powerhouses such as the Kraft Heinz Company, Mondelez International and Campbell's. These companies are facing significant headwind due to emerging consumers' preference for less processed food. Instead they are seeking more organic food from smaller niche brands.

Moving forward, it is important to cater to the changing dietary preferences of the population by using more natural ingredients such as natural preservatives.

It is also important to develop alternative food and nutrition sources such as microalgae and insect proteins so as to reduce reliance on our current food sources.

As technology improves, food would also become a way to prevent or delay the onset of diseases. For example, by understanding how food affects the gut microbiome of the elderly, special formulations can be developed such that food becomes a preventive medicine rather than simply a source of nutrients.

Photo credits : Cooperpharma

Photo credits : Foodrevolution

COE CAPABILITIES

AGEING POPULATION AND GUT MICROBIOME

Today's ageing population is made up of a highly diverse group of people who want to live a healthy, satisfying life. Seniors increasingly view eating healthy and delicious food in a pleasant environment as key to happiness and well-being.

Future trends in technological development will most likely focus on meeting the sensory and nutritional needs of this ageing populace. For this group, more effective and wholesome strategies will have to be devised to compensate for age-related impairments in odour, flavour, trigeminal mouthfeel and texture perception.

Understanding the gut microbiome is vital to developing and applying food innovations and technologies for this ageing population.

By studying host gut microbiota, one would understand gut microbiome. Gut microbiota refers to the full complement of microorganisms colonising the human gastrointestinal tract. Figure 14 below shows the impact of foods on the gut and how it eventually affects the brain and bodily functions.

Study of the gut microbiome offers insights into the impact of food components on health. Research work in this sphere allows players in the food industry to engineer new food products that are custom-built for the aged.

The gut microbiota of each individual is unique. Factors such as diet, geography, host genetics and physiology and drug use influence gut microbial composition, with diet the most influential factor. Diet is also the simplest factor to modulate among them. For example, probiotics have been shown to benefit those with severe food poisoning, as the repopulation of the gut with probiotic microbes inhibits the growth of harmful ones found in contaminated foods.

NTU FST has recently developed non-invasive tools to monitor gut microbiome activities.

Nutrition assessment is also required for food supply from alternative sources. Alternative food sources refer to food from non-traditional farming, and may include insects and microalgae among others.

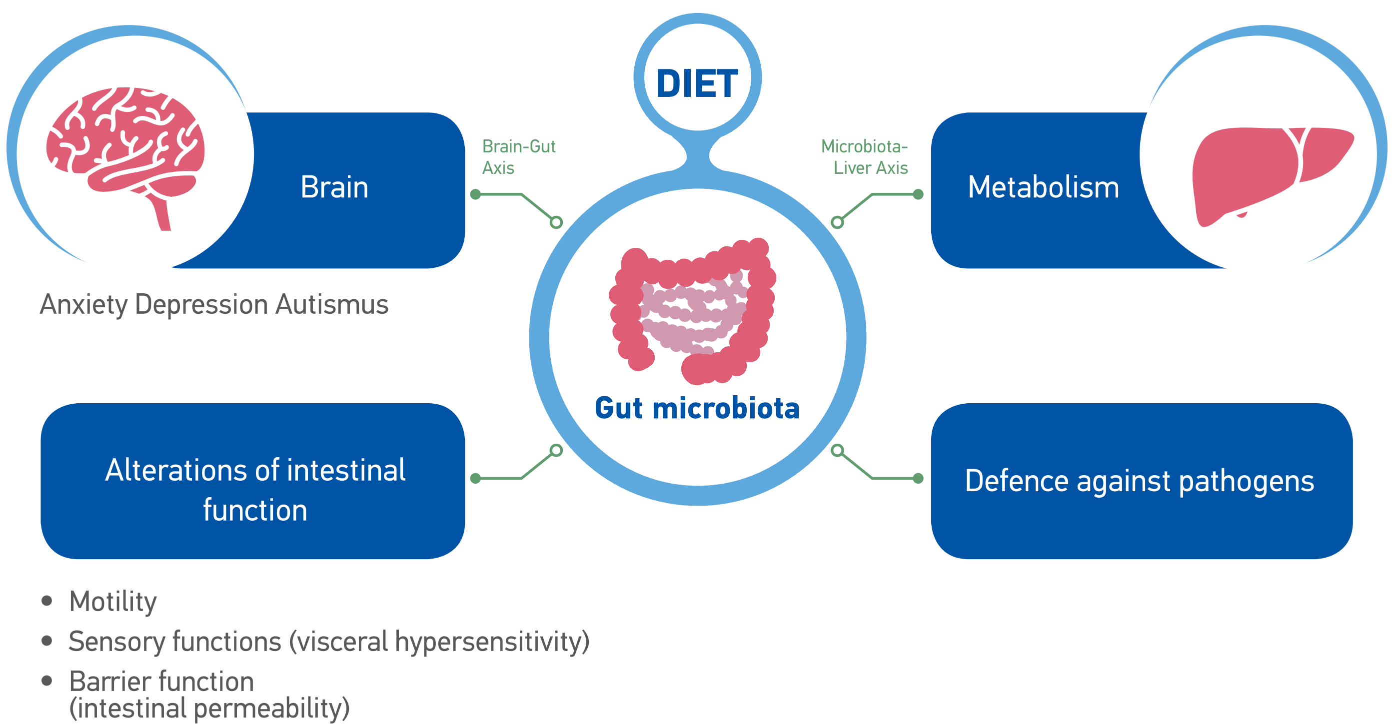


Figure 14 - The relationship between diet, gut microbiota and subsequent effects on the body.

ALTERNATIVE FOOD SOURCES

INSECT FARMING

Edible insects are excellent as a sustainable food source as they emit lesser greenhouse gases during their production and require little water. These insect-based products are used in wild harvesting and semi-domestication farming practices owing to their organic properties which in turn enhances the individual and industrial farming techniques, thus increasing demand. It is projected that by 2024, the market for global edible insects may surpass US$240 million.

Grasshoppers are among the most popular insect-based food items. They are often sold as snacks in the markets. They are also nutritionally packed, with a nutritional profile that is high in protein, potassium, amino acid, vitamin, zinc and calcium. Their popularity is helping the edible insect industry grow.

Meanwhile, cricket-based protein products are regarded as a healthy snack option as crickets are nutritionally very low in saturated fats and carbohydrates.

The advantages of insects as a food source over beef, a meat source, are illustrated in Figure 15 below.

Photo credits: Food Navigator

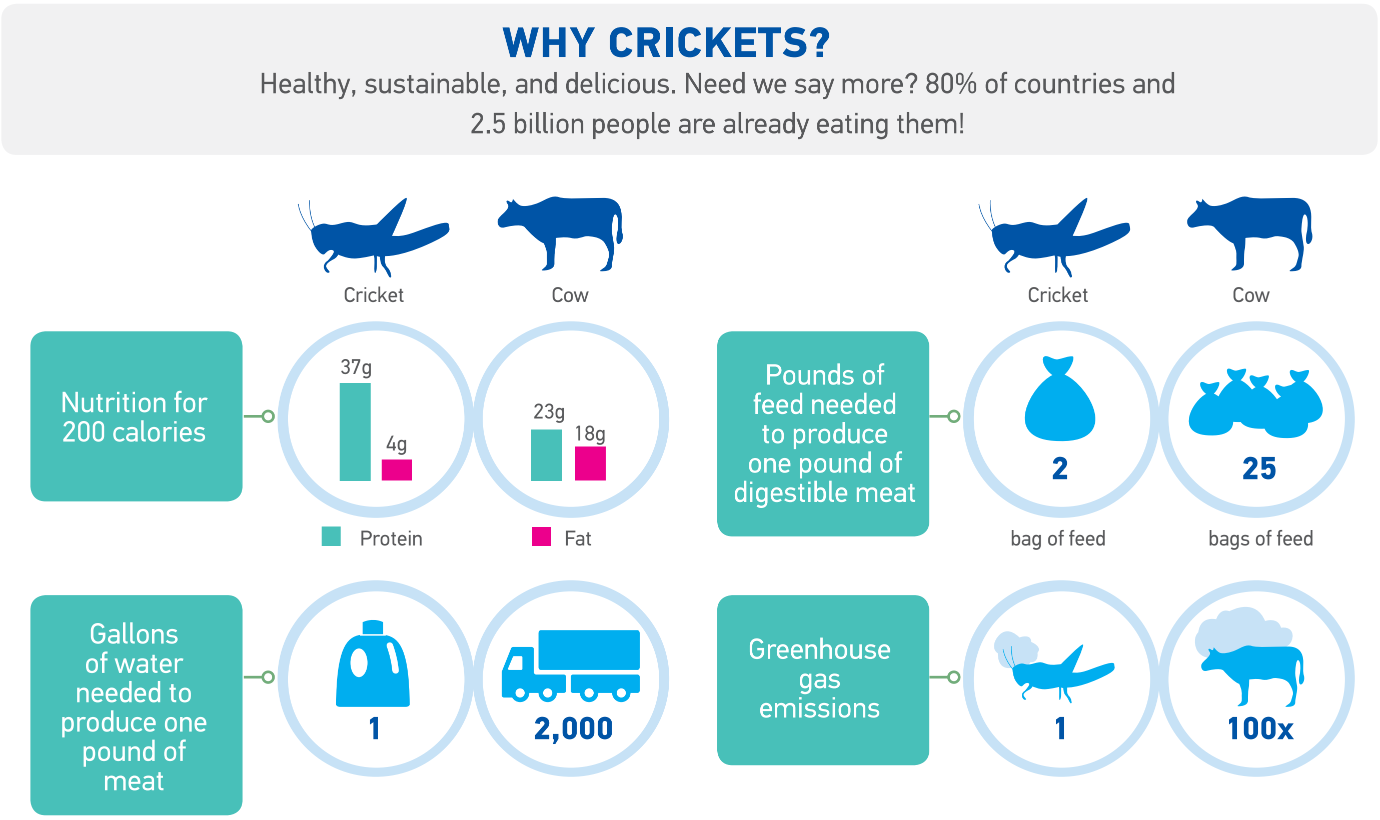


Figure 15 – Comparison between cricket and beef in terms of nutritional profile and the environmental cost of production

As Figure 15 illustrates, it takes far less feed to cultivate insects compared to cattle. Insects are cold-blooded creatures and are able to convert feed very efficiently. The conversion efficiency can be measured by the amount of feed needed to add on 1 kg in body weight. On average, insects are able to convert 2 kg of feed into 1 kg of body mass. On the other hand, it takes 8kg of feed for cattle to convert into an increase of 1kg in body mass.

Another compelling argument is that the nutritional value of insects is comparable to animal sources of meat. Most insects are very rich in protein and fatty acids. For this reason, insects are good food supplement option for malnourished children.

In addition, insects are great sources of fibre and essential micronutrients such as copper, iron, magnesium, manganese, phosphorus, selenium and zinc.

MICROALGAE

Microalgae are regarded as viable sources of protein for humankind because of its high yield.

Microalgae are tiny photosynthetic plants that efficiently convert sunlight, carbon dioxide and water to sugars and proteins, absorbing and converting carbon dioxide in the process and expelling oxygen. In fact, marine microalgae, known as phytoplankton, are responsible for creating half the world's oxygen. Some species of seaweed and microalgae are known to contain protein levels similar to those of traditional protein sources like meat, soybean and milk.

Consuming microalgae as protein presents several benefits over traditional high-protein crop in terms of productivity and nutritional value.

Photo credits: Algae Consortium

Obtaining our protein from microalgae would be far more efficient than obtaining it from other high-protein sources. Widely grown crops like soybean (0.6 – 1.2 tonnes/Ha/year), pulse legumes (1 – 2 tonnes/Ha/year) and wheat (1.1 tonnes/Ha/year) produce much lower yields compared to microalgae, which boost a yield of 4 – 15 tonnes/Ha/year.

One way to compare protein production in animals, plants and microalgae is the land and water required to produce the same amount of essential amino acids from each food. As depicted in Figure 16 below, 148,000 litres of freshwater and 125 square metres of fertile land are required to produce one kilogramme of beef-sourced essential amino acids. In comparison, it takes only 20 litres of freshwater and 1.6 square metres of non-fertile land to produce one kilogramme of microalgae-sourced essential amino acids.

NTU FST is currently working with US Food Company to product microalgae-based protein and lipids as alternative food sources.

Photo credits: ift

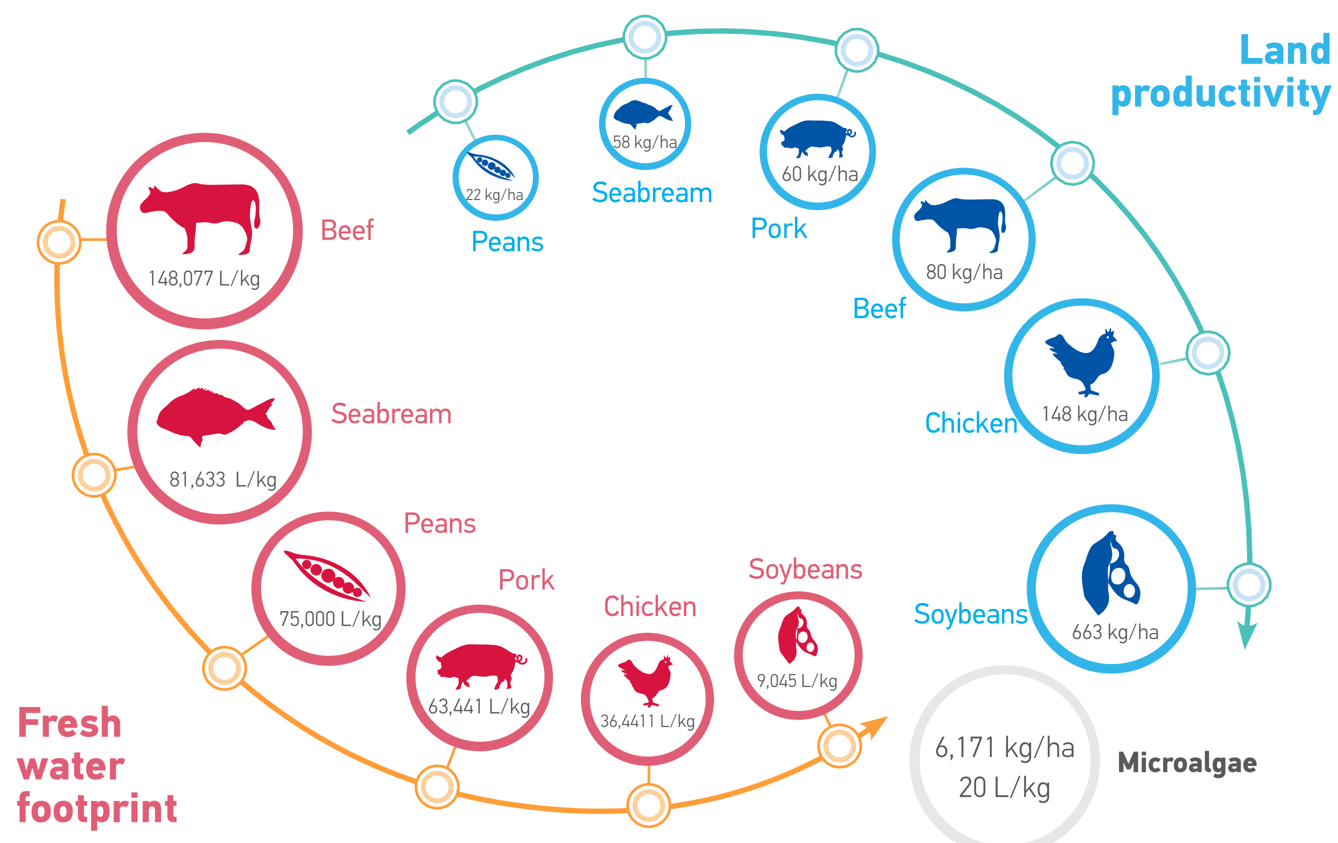


Figure 16 - Comparison of protein production from animals, plants and marine algae with regards to the amount of land and water needed to produce an equal quantity of essential amino acids from each type of food

Obtaining our protein from microalgae instead of other high-protein sources also offers dietary benefit.

Microalgae are a viable alternative to fish oil. Fish obtain their healthy omegas by feeding on the plankton. By consuming an extract made directly from microalgae, we get the same healthy omegas without involving fish as the middleman.

Photo credits : Medium


Photo credits : Agronomag

CONCLUSION AND RECOMMENDATIONS

Enhancing food security for Singapore is of crucial importance considering the limited farming capacity and heavy dependence on food import for local consumption. The impact on the environment by the amount of food waste (800,000 tonnes) and plastic packaging waste (800,000 tonnes) generated yearly in Singapore needs to be reduced.

In addition to ensuring food safety, three critical areas for food security in Singapore may include primary production, post-harvest processing and nutrition for the ageing population.

Technology innovations are key to enhance food security in Singapore. NTU's strength in interdisciplinary research, and particularly the College of Engineering (CoE) with their strong credentials in technology innovations, make us strong leaders for this important endeavour. Established in 2014 in partnership with Wageningen University & Research from the Netherlands, NTU FST has developed food technology innovations of relevance to Singapore's food security namely in the area of valorisation of food waste, biodegradable packaging materials and zero waste food processing. The relevance of technology innovations by NTU FST is reflected by their successful engagement with both food industry through joint lab as well as government agencies through national food initiatives.

We propose to establish a cohesive CoE ecosystem, with NTU FST as a focal point, to integrate relevant capabilities from various Schools for a collective and synergistic effort in technology innovations for Singapore food security. These may include new ways to monitor food supply chain and enhance food fraud traceability (blockchain and artificial intelligence), integrated system for urban farming (sensor for real time monitoring of farming conditions), technology-driven food waste management (zero waste food processing), new ways to measure gut microbiome as indicator of food nutrition (non-


Photo credits : Podaima Performance

invasive measurement of gut microbiome functionality), and platform technology to develop alternative and unconventional food sources (insects and microalgae). Specifically, colleagues from MAE may be engaged to provide automation for urban farming, whereas those from SCBE and EEE may be involved in sensor development for real time monitoring for urban farming. Colleagues from SCSE would be able to play a critical role in data analytics and blockchain application in food supply chain monitoring. Colleagues from SCBE would be able to contribute to industry scale-up of food waste valorisation, new analytical technology for food safety monitoring including the toxicology profiling of new food ingredients, and novel investigation tools for gut microbiome functionality for nutrition associated wellbeing for the elderly. Last but not least, colleagues from SCBE and MSE would be working together to further develop new future packaging technology (biodegradable packaging materials, smart sensing of food freshness among others).

Working together with food industry and government agencies, it is to be hoped that NTU CoE would be able to make significant contributions to Singapore's food security.

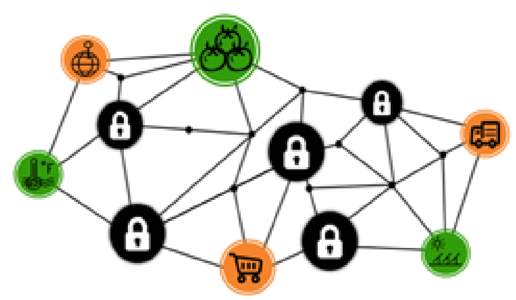


Photo credits : Cgiar

Photo credits : Cestrian

NTU FOOD SCIENCE AND TECHNOLOGY PROGRAMME

The Food Science and Technology Programme at Nanyang Technological University (NTU FST) is a collaborative effort with the world renowned Wageningen University and Research (WUR) from the Netherlands. The Food Technology programme at WUR has been in place for more than 50 years and is considered one of the best and most innovative programmes in its field in Europe. WUR offers high-level courses and research in all areas of food science; ranging from advanced technical fields, such as Process Engineering or Chemistry, to fields with a more economic or sociological focus, such as Marketing and Gastronomy.

Considering the complexity of Singapore's food security, a cross-disciplinary effort would be required to develop solutions for challenges arising from any of the three key areas described in this Tech Primer (primary production, post-harvest processing, and nutrition). NTU FST has therefore been established in 2014 as an inter-school and interdisciplinary strategic initiative at NTU, and aims to train students with adequate skills needed for the demands of national food security.

NTU FST programme is offered as a Second Major Programme to selected and motivated students from four NTU existing degree programmes in Bioengineering (School of Chemical and Biomedical Engineering), Chemical and Biomolecular Engineering (School of Chemical and Biomedical Engineering), Biological Sciences (School of Biological Sciences), and Chemistry and Biological Chemistry (School of Physical and Mathematical Sciences).

Students are selected from each school to join the FST from the 2nd year of their BEng/BSc programmes. 5 core courses of this major (consisting of both theoretic and practice parts): Food Chemistry, Food Physics, Food Microbiology, Food Process Engineering, and

Food Quality Design, will be taught by the faculties from WUR with coordinators at NTU. Students will be able to choose prescribed electives from SCBE, SBS and SPMS. The interdisciplinary nature of the programme will benefit students who are interested in NTU BSc/BEng programmes and at the same time have a strong curiosity about food process with engineering and industrial point of view. In addition to their education training, the NTU FST Programme Office has direct internships arrangements with more than 40 food companies in Singapore and beyond. This provides students with needed exposure to real world situation in food industry. The FST Student Society also organises, with the help from FST Programme Office, regular lecture series to provide students with an interactive platform with leaders from food industry.

After the success of the second major programme in FST, NTU has partnered with WUR once again to introduce a joint PhD programme for students from both universities in 2016. This marks a significant milestone in the continual collaboration effort between NTU and WUR in establishing a platform to tackle critical issues in the area of food processing technology.

To cater to the rising demands in the emerging areas in food industry, NTU has signed a new Memorandum of Understanding with WUR in 2018 during Singapore President Halimah Yacob's State Visit to the Netherlands to introduce a Graduate Certificate programme in FST. The main target would be working professionals. The aim of this proposed Graduate Certificate Programme is to strengthen the skills of the working professionals in the food industry and to adapt to fast evolving food industry. This study model of this programme is designed to provide the flexibility through a modularized and technology-enhanced delivery. This programme will be linked to SkillsFuture Singapore. This programme is offered in a range of stackable modular courses with credits that can lead to a Graduate Certificate Structure upon completion. This is a collaborative effort with PACE College to introduce this programme which includes our NTU courses and those from our

ABOUT NTU & FST INTERNATIONAL COLLABORATIONS (AUSTRALIA, CHINA,MEXICO, UK, USA)

partner University WUR. A Graduate Certificate will be issued upon successful completion of all courses within the Graduate certificate. A Certificate of Completion will be issued for each course completed. Students may consider pursuing a Master's degree in Wageningen with the accumulated courses from our Graduate Certificate programme. The courses will be delivered in blended learning approaches to enhance the learning experience with inclusion of interactive networking opportunities and sharing sessions on their working experience. It is anticipated that this programme will be beneficial to the working professionals who wish to upgrade their skillsets to keep pace with the fast evolving food industry.

The vibrant education partnership between NTU and WUR has created a conducive environment for the development of research in FST at NTU. Starting from the research collaboration under the Joint PhD Programme in food processing technology, NTU FST researchers have successfully developed technology innovations of relevance to Singapore food industry. For example, fermentation technology has been developed for nutrient recovery from side-streams of food processing industry, including Okara (https://www.straitstimes.com/singapore/education/turning-soya-bean-waste-into-a-medium-for-yeast-to-grow-on) and brewer's spent grain (https://www.straitstimes.com/singapore/ntu-scientists-reuse-beer-brewing-by-product-to-grow-yeast-to-make-more-beer). NTU FST has further developed green extraction technology to extract cellulose from the remaining solid residues after fermentation, and developed biodegradable packaging materials (https://www.straitstimes.com/singapore/turning-soya-bean-waste-into-packaging). Similar green processing technology has been developed by NTU FST to convert waste cooking oil into natural carotenoids which are high value food additives (The Straits Times, 11 June 2015, page B2). To further reduce chemical substances in processed food products with extended shelf life, NTU FST has recently developed innovation to sustainably produce natural food preservatives (https://www.straitstimes.com/singapore/ntu-team-develops-natural-preservative-from-flavonoids-that-can-keep-food-fresh-a-lot).

The technology innovations developed by NTU FST have contributed to Food Circular Economy scenario, in which all raw materials for food processing industry would be fully utilised thus showcasing the feasibility of Zero Waste Food Processing.

NTU FST technology innovations have also been featured internationally, including in IFTNEXT Newsletter. IFT (Institute of Food Technologists) is an international, non-profit scientific society of professionals engaged in food science, food technology, and related areas in academia, government and industry. It has more than 17,000 members from more than 95 countries. IFTNEXT Newsletter published every Tuesday explores what are, arguably, the next big things in the science of food (http://www.ift.org/Home/IFTNEXT/?cat=Newsletter). Our featured innovations include zero waste food processing (http://www.ift.org/IFTNEXT/011618.aspx) as well as natural food preservatives (http://www.ift.org/IFTNEXT/100218.aspx).

In addition to partnering WUR in FST education and research, NTU FST has been engaged in international collaborations on food technology innovations. These include Joint International Research Institute under Sino-Singapore Knowledge City in Guangzhou (China), US Food System Leadership Institute, Monterrey Institute of Technology and Higher Education (Mexico), University of Sydney (Australia) among others.

NTU FST has now been engaged by food industry for commercialisation of their innovations, either through joint laboratory, with either industry's direct investment or jointly with government co-funding support. One such engagement is the opening of the F&N-NTU F&B Innovations Lab in January 2019 by Singapore Minister for Education Mr. Ong Ye Kung. It is F&N's first long-term joint research partnership with an academic institution in their 135 years of history.

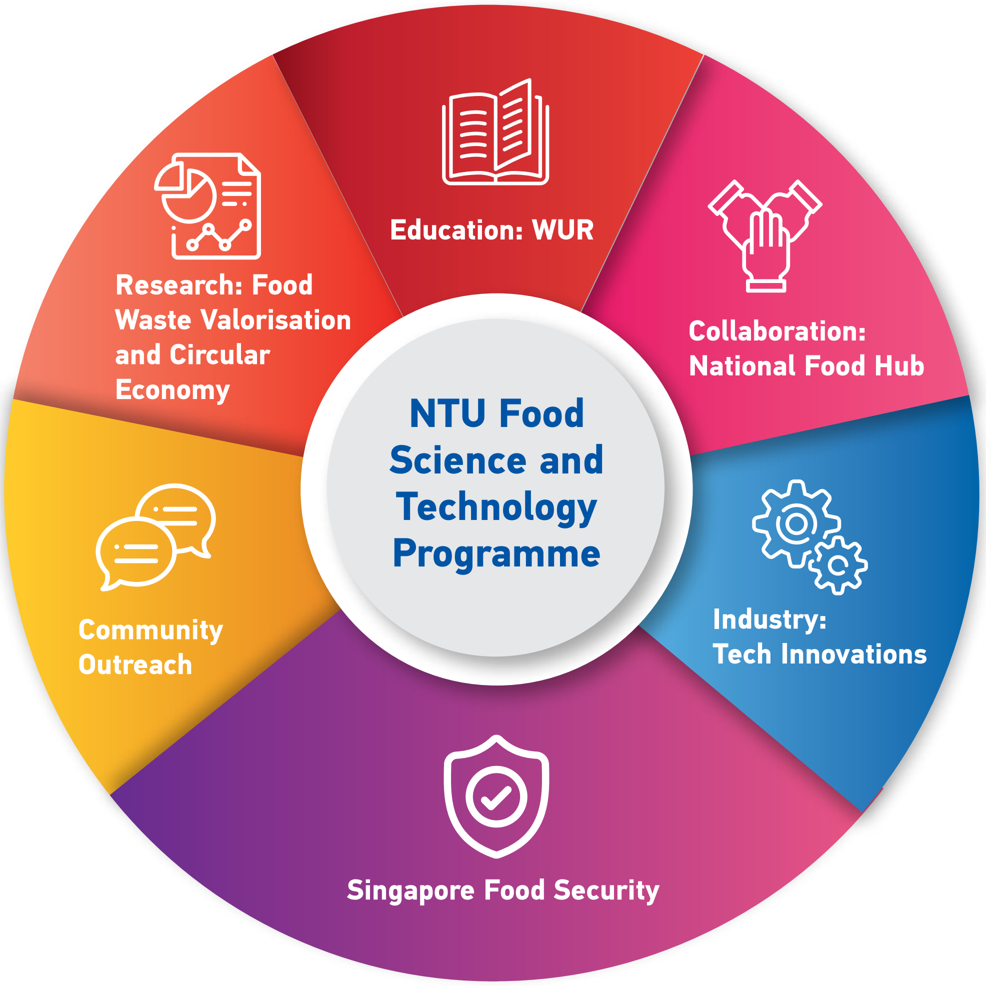
NTU FST has also been identified as technology partner in Food Innovate, a new initiative by Enterprise Singapore. NTU FST has also been a key driver in a national food hub on food safety and innovations.

Photo credits: Nuffoods Spectrum

NTU FST has been actively engaged in community outreach, with regular media appearances (newspapers and television) to showcase our innovations as well as explaining food matters to the general public. In addition, NTU FST technology innovations have been used to organise workshops for students and food industry.

Taken together, NTU FST has evolved from an education programme in FST into a vibrant platform offering education training, research on food technology innovations, government collaboration, food industry engagement and community outreach.

Photo credits: The Group Advertising



REFERENCES

1. "3. Global and Regional Food Consumption Patterns and Trends." World Health Organization, World Health Organization, 6 Aug. 2008, www.who.int/nutrition/topics/3_foodconsumption/en/index5.html.

2. "6 Benefits of Urban Farming vs. Traditional Farming." Click & Grow Asia, asia.clickandgrow.com/blogs/news/38039556-6-benefits-of-urban-farming-vs-traditional-farming.

3. "Aquaponics Market Segmentation By Product - Fish, Vegetables; by Equipment - Tank Systems, Rafts, Liners and Medium, Pumps, Airstones and Aeration Systems, Plumbing Equipment and Material, Others; by Technique - DWC, NFT, MFG." Future Market Insights, 27 Jun. 2018, www.futuremarketinsights.com reports/aquaponics-market.

4. Baker, Jalelah Abu. "Ensuring the Elderly Eat Enough: The Health Implications of a Better Diet." Channel NewsAsia, 18 Dec. 2017, www.channelnewsasia.com news/singapore/ensuring-the-elderly-eat-enough-the-health-implications-of-a-9499186.

5. "Black Soldier Fly Larvae: a Key Livestock for the 21st Century." Futures Centre, 1 Dec. 2016, thefuturescentre.org/articles/9424/black-solider-fly-larvae-key-livestock-21st-century.

6. Boh, Samantha. "NTU Scientists Reuse Beer-brewing By-product to Grow Yeast to Make More Beer." The Straits Times, 29 Aug. 2017, www.straitstimes.com/singapore/ntu-scientists-reuse-beer-brewing-by-product-to-grow-yeast-to-make-more-beer.

7. Boh, Samantha. "Turning Soya Bean Waste into a Medium for Yeast to Grow On." The Straits Times, 22 Apr. 2016, www.straitstimes.com/singapore/education/turning-soya-bean-waste-into-a-medium-for-yeast-to-grow-on.

8. Boh, Samantha. "Turning Soya Bean Waste into Packaging." The Straits Times, 9 Mar. 2017, www.straitstimes.com/singapore/turning-soya-bean-waste-into-packaging.

9. Brady, Heather. "Why Salmon Eating Insects Instead of Fish Is Better for Environment." National Geographic, National Geographic Society, 5 Feb. 2018, news.nationalgeographic.com/2018/02/salmon-insect-feed-fish-meal-netherlands/

10. Bleakley, S., & Hayes, M. (2017). Algal Proteins: Extraction, Application, and Challenges Concerning Production. Foods, 6(5), 33. doi:10.3390/foods6050033

11. Breene, Keith. "Food Security and Why It Matters." World Economic Forum, 18 Jan. 2016, www.weforum.org/agenda/2016/01/food-security-and-why-it-matters/.

12. Caporgno, M. P., & Mathys, A. (2018). Trends in Microalgae Incorporation into Innovative Food Products with Potential Health Benefits. Frontiers in Nutrition, 5. doi:10.3389/fnut.2018.00058

13. Cameron, Amanda. Coffee Ground Recovery Program Summary Report. Jan. 2016, planetark.org/documents/doc-1397-summary-report-of-feasibility-study-april-2016.pdf.

14. Charlebois, Sylvain. "How Blockchain Technology Could Transform the Food Industry." The Conversation, The Conversation, 23 Oct. 2018, theconversation.com/how-blockchain-technology-could-transform-the-food-industry-89348.

15. Charlebois, Sylvain. "How Blockchain Technology Could Transform the Food Industry." The Conversation, The Conversation, 23 Oct. 2018, theconversation.com/how-blockchain-technology-could-transform-the-food-industry-89348.

16. Chew, Wei Chun. "Perfecting Food Safety: How China Does It with IoT and Blockchain." Hacker Noon, Hacker Noon, 30 Jan. 2018, hackernoon.com/perfecting-food-safety-how-china-does-it-with-iot-and-blockchain-9948ceb7ce9c.

17. Clendaniel, Morgan, and Morgan Clendaniel. "Hope You Like Algae, Because It's Going To Be In Everything You Eat." Fast Company, Fast Company, 7 Sep. 2017, www.fastcompany.com/3067961/hope-you-like-algae-because-its-going-to-be-in-everything-you-eat.

18. Crossey, Sean. "How the Blockchain Can Save Our Food." New Food Magazine, May 2018, www.newfoodmagazine.com/article/36978/blockchain-can-save-food/.

19. "Department Sanitation, Water and Solid Waste for Development." Forum Chriesbach - Eawag, www.eawag.ch/en/department/sandec/projects/mswm/black-soldier-fly-biowaste-processing/.

20. DiBenedetto, Bill. "Food Waste Has a Big Impact on Climate, Water, Land and Biodiversity." Triple Pundit: People, Planet, Profit, Triple Pundit: People, Planet, Profit, 7 Feb. 2015, www.triplepundit.com/2013/09/food-waste-big-time-hit-climate-water-land-biodiversity/.

21. Dong, Y., Liu, J., Wang, S., Chen, Q., Guo, T., Zhang, L., . . . Tan, T. (2015). Emerging Frontier Technologies for Food Safety Analysis and Risk Assessment. Journal of Integrative Agriculture,14(11), 2231-2242. doi:10.1016/s2095-3119(15)61123-6

22. "Edible Insects Market Will Register Phenomenal Growth of 43.5% to Beat $710 Mn by 2024: Global Market Insights, Inc." GlobeNewswire News Room, "GlobeNewswire", 21 Jun. 2018, globenewswire.com/news-release/2018/06/21/1527673/0/en/Edible-Insects-Market-will-register-phenomenal-growth-of-43-5-to-beat-710-mn-by-2024-Global-Market-Insights-Inc.html.

23. FAO/INFOODS (2013). FAO/INFOODS Food Composition Database for Biodiversity Version 2.1 – BioFoodComp2.1. FAO, Rome.

24. "Farming in Singapore." Meeting Singapore's Food Supply | AVA, 24 Jan. 2018, www.ava.gov.sg/explore-by-sections/farms/land-farms/farming-in-singapore.

25. "Food and the City: Overcoming Challenges for Food Security." Urban Redevelopment: From Urban Squalor to Global City, www.clc.gov.sg/research-publications/publications/urban-systems-studies/view/food-and-the-city.

26. "Food Waste Management." Overview, www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/food-waste-management.

27. Fougier, Eddy. "The Social Acceptability of Disruptive Food Innovations - Paris Innovation Review." RSS, 24 Oct. 2017, parisinnovationreview.com/articles-en/social-acceptability-disruptive-food-innovations.

28. Galey, Patrick, and Marlowe Hood. "Pacific Plastic Dump Far Larger than Feared: Study." Phys.org - News and Articles on Science and Technology, Phys.org, 22 Mar. 2018, phys.org/news/2018-03-pacific-plastic-dump-larger.html.

29. Geddie, John. "In Singapore, Where Trash Becomes Ash, Plastics are Still a Problem." Reuters, Thomson Reuters, 6 Jun. 2018, www.reuters.com/article/us-singapore-waste/in-singapore-where-trash-becomes-ash-plastics-are-still-a-problem-idUSKCN1J20HX.

30. "Global Aquaponics and Hydroponics Systems and Equipment Market: Focus on Systems (Nutrient Film Technique, Deep Water Culture, Media Filed Grow Beds, Ebb & Flow), Equipment (Grow Light, HVAC, Irrigation Systems) and Produce-Analysis & Forecast 2017-2022." MarketWatch, MarketWatch, 15 May 2018, www.marketwatch.com/press-release/global-aquaponics-hydroponics-systems-equipment-market-focus-on-systems-nutrient-film-technique-deep-water-culture-media-filed-grow-beds-ebb-flow-equipment-grow-light-hvac-irrigation-systems-and-produce-analysis-forecast-2017-2022-2018-05-15.

31. "Healthy Diet." World Health Organization, World Health Organization, 23 Oct. 2018, www.who.int/news-room/fact-sheets/detail/healthy-diet.

32. Heid, Markham. "Diet May Be the Best Way to Boost the Microbiome." Time, Time, 8 Aug. 2018, time.com/5360407/microbiome-diet-gut-health/.

33. Hermes. "Singapore Faces 'Demographic Time Bomb'." The Straits Times, 7 Dec. 2017, www.straitstimes.com/business/economy/spore-faces-demographic-time-bomb.

34. Hong, Jose. "NTU Team Develops Natural Preservative That Can Keep Food Fresh a Lot Longer." The Straits Times, 16 Aug. 2018, www.straitstimes.com/singapore/ntu-team-develops-natural-preservative-from-flavonoids-that-can-keep-food-fresh-a-lot.

35. "Edible Insects Market Will Register Phenomenal Growth of 43.5% to Beat $710 Mn by 2024: Global Market Insights, Inc." GlobeNewswire News Room, "GlobeNewswire", 21 June 2018, globenewswire.com/news-release/2018/06/21/1527673/0/en/Edible-Insects-Market-will-register-phenomenal-growth-of-43-5-to-beat-710-mn-by-2024-Global-Market-Insights-Inc.html.

36. Insights, Future Market. "Aquaponics Market Is Anticipated to Expand at a CAGR of 7.4% in Terms of Value During 2018-2028." PR Newswire: News Distribution, Targeting and Monitoring, 5 July 2018, www.prnewswire.com/news-releases/aquaponics-market-is-anticipated-to-expand-at-a-cagr-of-7-4-in-terms-of-value-during-2018-2028-834659953.html.

37. "Key Facts on Food Loss and Waste You Should Know!" International Rice Commission Newsletter Vol. 48, FAO of the UN, www.fao.org/save-food/resources/keyfindings/en/.

38. Kiryukhin, M. V., Lau, H. H., Goh, S. H., Teh, C., Korzh, V., & Sadovoy, A. (2018). A membrane film sensor with encapsulated fluorescent dyes towards express freshness monitoring of packaged food. Talanta, 182, 187-192. doi:10.1016/j.talanta.2018.01.085

39. Kronsberg, Matthew. "If You'Re Concerned About Food Waste, Try This Beer." Bloomberg.com, Bloomberg, 11 Oct. 2017, www.bloomberg.com/news/articles/2017-10-10/toast-ale-a-uk-beer-that-turns-surplus-bread-into-heady-brews.

40. Lin, C. S., Pfaltzgraff, L. A., Herrero-Davila, L., Mubofu, E. B., Abderrahim, S., Clark, J. H., . . . Luque, R. (2013). Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global

41. Lombardo, Giulio. "Aquaponics: the Future of Agriculture?" Fine Dining Lovers, 25 Aug. 2015, www.finedininglovers.com/blog/news-trends/aquaponics-farming/.

42. Mo, W. Y., Man, Y. B., & Wong, M. H. (2018). Use of food waste, fish waste and food processing waste for Chinas aquaculture industry: Needs and challenge. Science of The Total Environment, 613-614, 635-643. doi:10.1016/j.scitotenv.2017.08.321

43. Moomaw, William. "How Marine Algae could Help Feed the World." Phys.org - News and Articles on Science and Technology, Phys.org, 20 Oct. 2017, phys.org/news/2017-10-marine-algae-world.html.

44. Neethirajan, Suresh. "New Nanotechnology Platform Developed for the Rapid Detection of Foodborne Viruses." Food Safety Magazine, Apr. 2018, www.foodsafetymagazine.com/magazine-archive1/aprilmay-2018/new-nanotechnology-platform-developed-for-the-rapid-detection-of-foodborne-viruses/.

45. Ong, K. L., Kaur, G., Pensupa, N., Uisan, K., & Lin, C. S. (2018). Trends in food waste valorization for the production of chemicals, materials and fuels: Case study South and Southeast Asia. Bioresource Technology, 248, 100-112. doi:10.1016/j.biortech.2017.06.076

46. Otles, Semih & Kartal, Canan. (2018). Food Waste Valorization. Sustainable Food Systems from Agriculture to Industry. 371-399. 10.1016/B978-0-12-811935-8.00011-1.

47. Peshev, D., Mitev, D., Peeva, L., & Peev, G. (2018). Valorization of spent coffee grounds – A new approach. Separation and Purification Technology, 192, 271-277. doi:10.1016/j.seppur.2017.10.021

48. Pham, T. P., Kaushik, R., Parshetti, G. K., Mahmood, R., & Balasubramanian, R. (2015). Food waste-to-energy conversion technologies: Current status and future directions. Waste Management, 38, 399-408. doi:10.1016/j.wasman.2014.12.004

49. Qin, J & Li, R & Raes, Jeroen & Arumugam, Manimozhiyan & Tims, Sebastian & , Vos & Zoetendal, Erwin & Kleerebezem, M. (2010). A Human Gut Microbial Gene Catalogue Established by Metagenomic Sequencing. Nature. 464. 59-65.

50. Rouse, Margaret. “What Is Vertical Farming? - Definition from WhatIs.com.” WhatIs.com, May 2017, whatis.techtarget.com/definition/vertical-farming.

51. Rupp, G., & Jones, R. (1992). Characterizing Heterogeneous Wastes: Methods and Recommendations. 1-159.

52. Safaryan, Artur. “Food You Trust: How Blockchain Will Reinvent the Supply Chain.” Hacker Noon, Hacker Noon, 1 Nov. 2017, hackernoon.com/food-you-trust-how-blockchain-will-reinvent-the-supply-chain-1d6ae601ae53.

53. Sean. “How the Blockchain Can Save Our Food.” New Food Magazine, www.newfoodmagazine.com/article/36978/blockchain-can-save-food/.

54. “Singapore Department of Statistics (DOS).” Singapore Department of Statistics (DOS), www.singstat.gov.sg/.

55. Singh, Bryna. “Vertical Farms on the Rise in Land Scarce Singapore.” The Straits Times, 8 Aug. 2016, www.straitstimes.com/lifestyle/vertical-farms-on-the-rise-in-land-scarce-singapore.

56. Smithers, Rebecca. “Raise a Toast! New Beers Made from Leftover Bread Help to Cut Food Waste.” The Guardian, Guardian News and Media, 28 Apr. 2018, www.theguardian.com/lifeandstyle/2018/apr/28/new-beers-made-from-leftover-bread-marks-and-spencer-adnams.

57. Teo, Joyce. “Fermented Foods Have Burst onto the Health Scene, but Experts Say No Evidence Probiotics Benefit the Healthy.” The Straits Times, 28 Oct. 2018, www.straitstimes.com/lifestyle/ferment-for-a-healthy-gut.

58. Thursby, E., & Juge, N. (2017). Introduction to the human gut microbiota. Biochemical Journal,474 (11), 1823-1836. doi:10.1042/bcj20160510

59. “Traditional Farming vs Vertical Farming.” RSS, www.urbanseedinc.com/solution.

60. University, Cornell. “Transforming Last Night’s Leftovers into Green Energy.” ScienceDaily, ScienceDaily, 19 June 2017, www.sciencedaily.com/releases/2017/06/170619151619.htm.

61. “Vertical Farming: Definition and Background.” Vertical Farming, www.verticalfarming.com/definition-and-background/.

62. Vyas, Kashyap. “13 Vertical Farming Innovations That Could Revolutionize Agriculture.” Interesting Engineering, 4 July 2018, interestingengineering.com/13-vertical-farming-innovations-that-could-revolutionize-agriculture.

63. Wiedmann, Martin. “Use of Whole-Genome Sequencing in Food Safety.” Food Safety Magazine, 2015, www.foodsafetymagazine.com/magazine-archive1/junejuly-2015/use-of-whole-genome-sequencing-in-food-safety/.

64. Wong, Wendy. “‘Closed Loop’ Urban Farm in Queenstown Tackles Food Waste with Insects.” Channel NewsAsia, 26 Nov. 2017, www.channelnewsasia.com/news/singapore/closed-loop-urban-farm-in-queenstown-tackles-food-waste-with-9441898.

65. Wong, Wendy. “‘Closed Loop’ Urban Farm in Queenstown Tackles Food Waste with Insects.” Channel NewsAsia, 26 Nov. 2017, www.channelnewsasia.com/news/singapore/closed-loop-urban-farm-in-queenstown-tackles-food-waste-with-9441898.

66. Zhang, Lim Min. “$200m Worth of Food and Beverage Waste Discarded by Singapore Households Yearly: Survey.” The Straits Times, 17 Oct. 2017, www.straitstimes.com/singapore/200m-worth-of-food-and-beverage-waste-discarded-by-singapore-households-yearly-survey.