The Circular Economy, Biocycles within Agriculture

Closed loop farming using waste streams

A report for

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Executive Summary

The United Nations (UN) (2017) is forecasting a total of ten billion people on this planet by 2050, with a requirement of 55% more food. Large challenges lie ahead for food production including water scarcity, land degradation, higher input costs and climate change. The waste generated from agriculture and food production is difficult to quantify, but the figures are around one trillion tonnes per annum, and contribute to 13% of total global greenhouse gas (GHG) emissions (World Resources Institute, 2014).

This report explores the concepts, applications and solutions of the circular economy and closed looped agriculture systems on a sub five-hectare farm basis. Separating waste, repurposing it and recycling it are not new concepts, and more recently the waste is being identified as a resource rather than a costly problem, and environmental polluter. This report highlights solutions which can be integrated into current farming systems with relatively little technical know-how and infrastructure. By turning organic waste into a source of added value, farms can essentially move towards a triple bottom line in operations and build in more resilience when facing an uncertain future.

Although circular economic fundamentals remain in their infancy, they are just a macro-based system of the micro/small scale subsistence farming that has taken place for centuries. With careful future urban planning, emerging technology and global governmental commitment, agriculture can be remodelled to be regenerative by design and bring on a second green revolution.

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Foreword

As a former member of the Australian Army based in Canberra, I worked within the Australian Intelligence Community. During that time I read many reports on geopolitical situations, highlighting water and food crises, regional tensions and displacement through climate change. This was a trigger for me to begin my path towards sustainable agriculture. Over the next few years I studied regenerative agriculture and particularly permaculture. Permaculture is defined as: The development of agricultural ecosystems intended to be sustainable and self-sufficient.

Over the next few years I applied techniques learned to our backyard, volunteered at a local community garden, and shared my knowledge with other friends and family. In 2011, my wife Amanda and I purchased 21 acres on the Clohesy River on the Atherton Tablelands. Within a short period of time I met a lot of neighbours, some of whom had large acreage and were making out a living selling pumpkins, melons, and citrus to middlemen, only to see their product to be sold at ten times that on the supermarket shelves. This system is neither sustainable nor fair, and I desired to be part of the solution. I increased my knowledge of regenerative farming practices, and also took a keen interest in nutrient density. As a long term sprouter for personal health and nutrition, I found the answer was right under my nose. As a proof of concept, I started a business – Cairns Microgreens and Exotics – and supplied North Queensland with a range of micro herbs, and other specialty greens and edible flowers, which are generally used as garnishes in the restaurant and café industry. The business has grown well and now has expanded into exotic mushrooms and R&D with other nutrient dense specialty products. I am a passionate advocate for eating local, supporting farmers and food waste minimisation – hence the study topic *Closing the Loop*.

With my direct contact with chefs, I get a lot of feedback on consumer sentiment, and it is all trending towards local food production, waste minimisation and sustainability. A number of chefs have expressed interest for our business to take on their green waste as there are no economical green recycling solutions currently available for them. Six months ago we took on waste coffee grounds and it is now utilised on-farm forming 30% of our substrate for mushroom production. We are now commencing a pilot project recycling food waste through a black soldier fly larvae (BSFL) bioreactor, with the intention of procuring a protein feedstock and high value nutrient substrate.

The current agriculture and consumer models are both very linear, and wasteful. The ‘take, make and dispose’ economic model currently relies on plentiful, cheap and easily accessible materials and energy. There are multiple models out there that include biomimicry and regenerative agriculture techniques.

I chose to study this subject because these technologies and practices need to be integrated into farms, and I want our business to be part of a multi-faceted solution. During the scholarship process, I contacted a number of farms and facilities working with Duckweed, BSFL and advanced waste management with the intent of collaboration. Unfortunately there were quite a large number of declines for visits or information. There appears to be a lot of intellectual property rights being protected and little scope for collaboration at this stage, which is unfortunate due to the urgent need of these systems and technology. This report highlights these technologies and how they are and can be applied to small farm scale.

Acknowledgments

First and foremost, I would to thank and acknowledge my wife Amanda for encouraging me to take on this scholarship, and then holding the fort with our 4-month old daughter when I first headed off to the Contemporary Scholars Conference (CSC) and subsequent four months of travel.

Thanks must also go to my mother and father in law for helping Amanda with the farm and our baby and general maintenance around the property in my absence; Richard Zivkov, my leading hand on the farm, for managing the microgreens operation despite flooding and other tribulations whilst I was overseas; and Hort Innovation for supporting the Nuffield program and investing in my scholarship.

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- Rick Wieggers at Wageningen University (Netherlands)
- AeroFarms (New York, USA)
- INIFAT (Cuba)
- Life Cykel mushroom (Byron Bay, Australia)
- Mycosphere (Philippines)

Abbreviations

BSFL – Black Soldier Fly Larvae

CEA – Closed Environment Agriculture

CSIRO – Commonwealth Scientific Industrial Research Organisation

DWC – Deep Water Culture

EU – European Union

FAO – Food and Agriculture Organisation

FCR – Feed Conversion Ratio

FDA – Food and Drug Administration (USA)

GRAS – Generally Recognized as Safe

GFP – Global Focus Program

GHG – Green House Gas

HACCP – Hazard Analysis and Critical Control Points

IFWMS – Integrate Food and Waste Management System

NPK – Nitrogen, Phosphorous, Potassium

pH – Logarithmic scale of acidity from 0-14

R&D – Research and Development

UN – United Nations

UNEP – United Nations Environment Program

UTS – University of Technology Sydney

WUR – Wageningen University & Research

WHO – World Health Organisation

WWF – Worldwide Fund for Nature

ZERI – Zero Emission Research Institute

Objectives

The objectives of this study are to:

- Seek out ways to recycle waste nutrients, and integrate and close the loop for agricultural by-products and food waste.
- Investigate the options and feasibility in implementing nutrient cycling systems on smaller farms, under five hectares.
- Visit and research various working models.
- Identify opportunities for Australian farms to valorise their waste streams.

Chapter 1: Introduction

Globally, 800 million people are still classed as undernourished, whilst in the west there is a new problem of malnourishment from a lack of nutrient dense and available produce (American Heart Association, 2018). A cascade effect of high food miles, prolonged shelf life, and nutrient loss is creating this problem, and increasing the divide.

The way that food is produced can be categorised in two ways: the industrial chain and the smallholder farmer system. The distinction allows to define concisely the problem that exists: the industrial system produces 30% of food, but uses 70% of the resources, while at the same time greatly degrading the environment. The smallholder farm system produces 70% of the food and only uses 30% of resources, with a much lower environmental impact. Australia is part of the industrial farming system (FAO, 2015).

The UN Conference on Trade and Development and the UN Food and Agriculture Organization (FAO) recently published a report concluding that only organic, smallholder farms could feed the world in the future. Currently 72% of the world’s farms are less than one hectare, and these provide 70% of the food that is consumed (FAO, 2015).

It is estimated that between 20-40% of farm produce is rejected or discarded prior to reaching the supermarket (for example, Figure 1 shows estimated wastage across different food industries). On top of this, Australian households also waste an average of 200kg per person of food per year (equating to 4 million tonnes) (Queensland Farmers’ Federation, 2017). It is evident that there is a clear need to pivot towards a local and sustainable food system as opposed to a centralised industrial food system. The waste generated from industrial systems is extremely high, and is putting pressure on resources, such as soil, nutrients and fresh water.

Cairns Microgreens and Exotics have found itself in a position to be able to capture and reuse multiple waste streams. The intention for the business is to demonstrate smallholder techniques for cycling these resources and closing the loop.

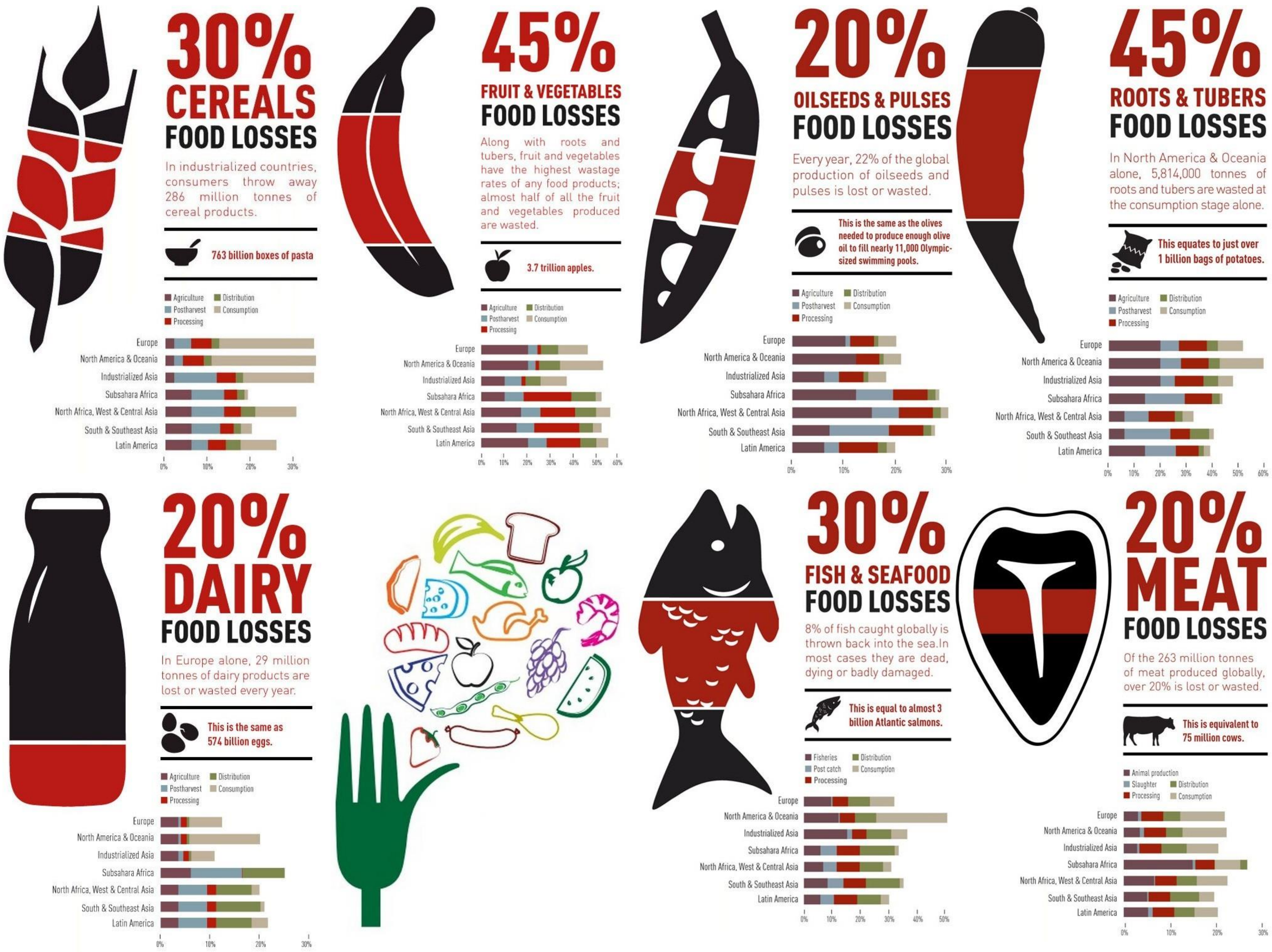

Figure 1: World food wastage chart (FAO, 2017).

Chapter 2: Circular Economy, Agrocycles and Closed loops

2.1 Circular Economy

A circular economy is defined as a regenerative system in which resource, input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing energy and material loops; this can be achieved through long lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, recycling and upcycling (Government Europa, 2018).

Gunter Pauli, director and founder of Zero Emissions Research and Initiatives (ZERI) coined this term “Blue Economy”, and in 2009, presented his book, *The Blue Economy: 10 years – 100 innovations – 100 million jobs,* to the Club of Rome, which is an organisation of individuals who share a common concern for the future of humanity and strive to make a difference. Members are notable scientists, economists, leaders in business, high level civil servants and former heads of state from around the world. Their mission is to promote understanding of the global challenges facing humanity and to advocate solutions through scientific analysis, research and development (R&D), and communication.

The Blue Economy model has since been adopted by the United Nations Environment Program (UNEP), World Wide Fund for Nature (WWF) and World Bank. Global businesses and world governments are now beginning to adopt and implement circular economic strategies. A circular economy is an overarching plan for resource and waste management whereas the blue economy is focused on more local and regional activities and solutions (Figure 2). The *Blue Economy* website contains and promotes over 100 open source breakthrough technological innovations available to businesses and entrepreneurs alike. Gunter Pauli already cites 200 projects implemented, US $4 billion invested and three million jobs created. One of the most popular innovations is coffee waste being converted into mushrooms, with over 1000 growers now up taking this open source method, of closing loops of nutrient, reducing disposal cost, creating revenue and providing a healthy medicinal and nutritionally dense food product (Blue Economy, 2015).

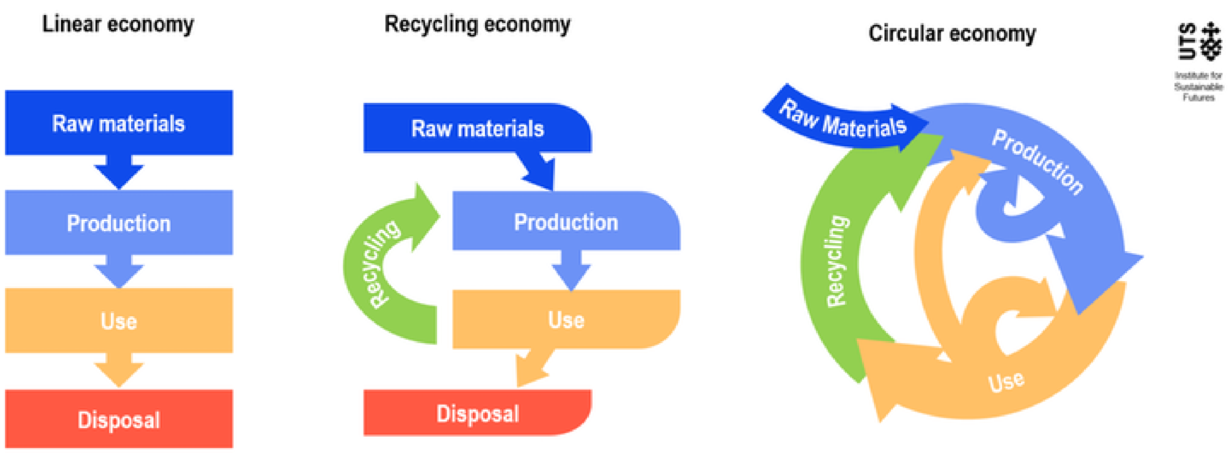

Figure 2: Economic models (University of Technology Sydney, 2018).

2.2 Agrocycles and Closed Loops

"Agrocycle" is a new term, as well as the title of a large research and innovation project addressing the recycling and valorisation of waste from the agri-food sector. Led by the School of Biosystems and Food Engineering at University College Dublin, the consortium of 26 partners globally. The project takes a holistic approach to understanding and addressing how to make best use of the 700 million tonnes of waste streams associated with the agri-food industry in the EU. It will deliver the EU AgroCycle Protocol, a blueprint for achieving sustainable agri-food waste valorisation by strongly endorsing anaerobic digestion systems, which are currently heavily subsidized.

According to the Australian national waste management review it is estimated that between 20-40% of fruit and vegetable is being rejected prior to reaching the supermarket. 5.3 million tonnes of food waste is created per annum at a value of $20 billion (Australian Waste Management Review, 2018). Improvements can be made in logistics, storage and shelf life, however a waste stream will remain a constant (Figure 3). A circular economy within Australian agriculture needs to be implemented to capture these valuable resources.

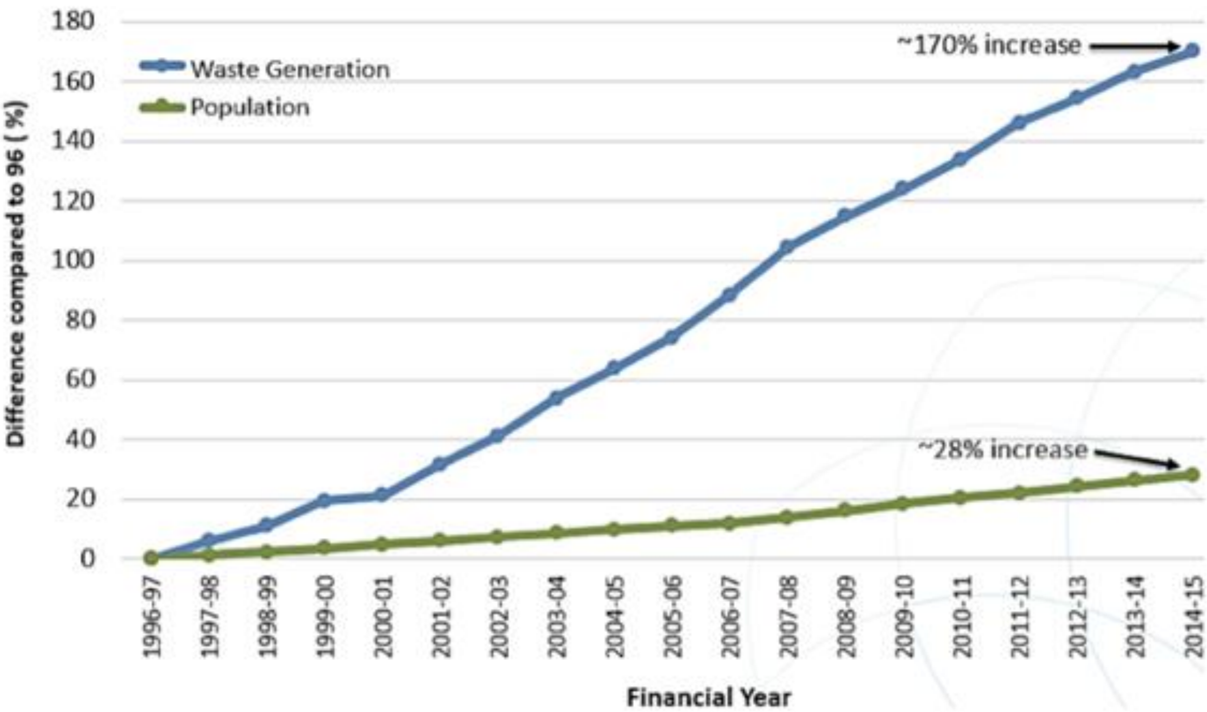

Figure 3: ***Comparison of Waste Generation and Population Growth in Australia, MRA Consulting Group, October 2015***

The late Professor George Chan of ZERI conceptualised the Integrated Food and Waste Management System (IFWMS). This form of sustainable and regenerative agriculture optimizes nutrient cycles whilst synergistically turning waste into profit. IFWMS or "Zero waste agriculture" is optimally practiced on small farms under five hectares, and generally requires some capital infrastructure which can be a barrier of entry for many. Many rice farmers in Asia have been practicing this integrated farming method for centuries, using ducks for fertilizer, pest control and egg production, whilst growing rice in a paddy. IFWMS aren't and don't need to be high tech solutions – They are generally techniques that have been used in subsistence farming for hundreds of years.

The green revolution of fertilizers, pesticides and machinery has favoured production and profit over custodianship and holistic land management. Reinventing these Agro cyclical and IFWMS techniques with modern technology could herald in a second green revolution and help solve many problems that agriculture faces today. Integrated Farming is now recognised as a new European organic agricultural standard which raises the bar over organic for beyond sustainable and regenerative farming practices.

Circular economy, blue economy, agrocycles, IFWMS and biocycles are essentially all the same thing, and can become quite confusing. Moving forward it is important that some of these labels and terms align to avoid being misunderstood, and falling into the same trap as the word 'sustainability' and the 'greenwashing' it is being brandished as.

2.3 Reduce, Reuse and Recycle.

Reduce, reuse and recycle are the three R's of waste management. Australia is a very coastally dispersed country with 85% of the population living within 50kms of the coastline. With a centralised food logistics system this poses extra challenges for waste management. In Australia, an estimated 12 million tonnes of agricultural waste is left to rot, generating millions of tonnes of methane gas, contributing to climate change (Australian Bureau of Statistics, 2004). In 2016, the Australian Government committed to develop a National Food Waste Strategy. This strategy establishes a framework to support actions that work towards halving Australia's food waste by 2030. This ambitious goal aligns with the United Nations Sustainable Development Goal 12 for sustainable consumption and production patterns (United Nations, 2018). New techniques, technologies and innovation will continue to provide solutions as this farm based movement continues to expand.

Chapter 3: Concepts and Technologies

3.1 Coffee Waste

In 2009, the world consumed 126 million bags of coffee, or 7.5 million tonnes of beans ready to be roasted. Few people realise that harvesting, processing, roasting and brewing coffee discards an estimated 99.7% of the biomass. While only 0.2% acquires value on the market, the remainder is wasted (International Coffee Organisation, 2009). This makes coffee one of the most wasteful consumer products.

100% of coffee waste material can be diverted into mushroom cultivation, as opposed to being bagged in plastic and dumped in landfill, and due to a global growing demand in culinary and medicinal mushrooms, this market is set to hit US $50 billion in 2019 (Fastcompany, 2018). This case was the third open sourced innovation put forward by Gunter Pauli in 2009 and now has over 1,000 adoptions of the technology.

Coffee waste is also being made available to home gardeners via a number of retails outlets like petrol stations in New Zealand where customers can take it from collection bins for free. The coffee grounds have a range of micronutrients, promote beneficial bacteria and are a slightly acidic by product which could also help Australian gardeners with alkaline soils.

3.2 Duckweed

**The author attempted contact with, and to visit, the three leading companies working with Duckweed, unfortunately all three cited Intellectual Property concerns and declined visits or an interview.*

70% of the earth consists of water, and today only 17% of food comes from fisheries and aquaculture. The FAO (1999) has identified Duckweed (Lemnoideae) as having enormous potential for future protein sources. Duckweed is an aquatic plant found worldwide and often seen growing in thick, blanket-like mats on still or slow moving, nutrient-rich fresh or brackish waters, often mistaken for algae. The plant can provide nitrate removal, if cropped, and the duckweed is important in the process of bioremediation because it grows rapidly, balancing pH, and absorbing excess loose mineral nutrients, particularly nitrogen and phosphates. It grows to a maximum size of 10mm, and in water temperatures between six and 33°C, which, in optimal conditions can double their biomass in less than 24 hours (Wieggers, pers comm; 2018). Harvesting can be as simple of scooping the weed with a net, or otherwise using large scale floating mechanized harvesters, built by companies like *Aquamarine* based in Canada.

With a crude protein average of 40% and lipid content of 5% (FAO, 1999), this plant has a bright future in the animal feed stock space. No further preparation is required; it can be supplied fresh to cattle, poultry and other stock. Plant based proteins are proven to be a more bioavailable, and soluble form of protein for human nutrition also, which could greatly improve malnourishment problems in subtropical/tropical regions.

This relatively unassuming plant is commonly found in waste water lagoons where it thrives on high levels of waste nutrient. Commercialising it as a protein source and feedstock has brought a lot of interest of late with a number of companies and institutes like Parabel and NASA now bringing it into the spotlight (Vegconomist, 2019).

3.3 Food waste compost

Currently, a great majority of agricultural and food waste is left to rot causing it to convert to methane gas (Figure 4). Methane is 26 times more potent than carbon dioxide as a Greenhouse Gas (GHG) and is a significant contributor to global greenhouse gas emissions (Climate Council, 2016).

Composting is a well-known aerobic process of breaking down vegetative matter which reduces or prevents the release of methane during organic matter breakdown. The benefits of compost include enriching soil, adding soil carbon, and creating and environment for beneficial microbes, bacteria and fungi (FAO, 2019).

There are a number of different methods in composting, generally a static pile or actively aerated windrow, each method is subject to space, climate and available machinery. Compost quality can vary widely, with some farms believing they may be composting but are instead creating an anaerobic environment. Commercial compost facilities are coming online as they co-locate with municipal waste facilities, and the benefits of the compost products are being realised.

At a home consumer level, organic household waste management via composting has had mixed and low rates of success (Waste Management Review, 2017). Lack of real data exists, however it would most likely be a safe guess that a large proportion of home compost systems would become anaerobic with little benefit. Organic food waste generally makes up a small input into these commercial compost facilities.

Vermicomposting systems (using worms) are effective on a household scale as the worms assist with aeration of the material. Vermicomposting is becoming more popular as farmers move towards low till and regenerative practices. This is making worm farming viable as a larger commercial enterprise with worms, worm juice and castings being the two main saleable by-products.

Figure 4: ***Tomato wastage, photo supplied by University of Sunshine Coast***

3.4 Black Soldier Fly Larvae (BSFL)

Black Soldier Fly Larvae (Hermetia Illucens) (Figure 5), which are very different to the common house fly are indigenous to South America, but now found globally, are considered neither pests nor vectors of pathogens to humans. Insect proteins are becoming very popular in the animal feed and human nutrition space, and a number of companies and start-ups are scaling up production. An example of this is the BSFL, which are an excellent source of sustainable protein for aquaculture, animal feed, and pet and human nutrition. The larvae have voracious appetites and can be used for composting household food scraps and agricultural waste products. They are among the most efficient animals at converting feed into biomass, and can be raised easily in a simple bioreactor/propagation tank. In 432 hours, one gram of BSFL from eggs can convert organic waste into 2.4 kg of edible protein, with up to 42% protein, 29% fat, calcium and amino acids (Atlas of Living Australia, 2016). Another valuable resource is BSFL frass, an odourless residue which is valuable as an organic fertilizer (Birrell, pers comm. 2018).

Nutrient cycling systems such as BSFL and Duckweed can complement each other to close the loop on waste and provide beneficial by-products. It is interesting to note that duckweed and coffee grounds can be added to a healthy worm farm, and one would generally find a good population of BSFL co-existing in the same space. Worms add excellent humates and beneficial microbes, and the BSFL can rapidly break down some of the larger waste that worms take longer to digest.

Figure 5: Black Soldier Fly Larvae, Dipterra 2018.

Chapter 4: Case Studies

4.1 Life Cykel Mushrooms

Life Cykel, now based in Byron bay, was conceptualized and launched in 2015 by Ryan Creed and Julian Mitchell. Although growing mushrooms is not a new concept, the business is well timed and placed to take advantage of the global growth in mushroom demand. The company has a strong focus and ethos on working towards closing the loop, using waste coffee grounds to grow mushrooms, whilst providing the nutritional benefits of consuming a locally produced product.

Life Cykel has recently launched a National Mushroom Network recruiting over 30 growers who are all using waste coffee grounds as part of the base substrate for growing mushrooms. This initiative of “locavore” (consuming locally) eating and closed loop farming has grabbed the attention of business mentor Mark Bouris and Celebrity chef Pete Evans, and has propelled the company growth even further. An increase in vegetarian/vegan trends, coupled with new research on the large range of potent medicinal properties has also driven business sales into positive territory (Creed, pers. comm., 2018).

Current mushroom consumption for Australia stands at a low 2.8kg per person per annum, in stark contrast to China at 10kg per person per annum. The Australian Mushroom Growers Association is pushing a campaign to raise that to 4kg per annum by 2020, creating opportunity for growth (Hort Innovation, 2017).

With logistical tweaking, these smaller mushroom growers in Australia and globally can essentially divert and eliminate all coffee waste by incorporating waste pickup and transfer when they deliver their product. Further to this, mushrooms also grow on second grade or waste sorghum and other grains, absorbing yet another waste stream.

4.2 Circular Food

Nitrogen and Phosphate costs are rising and with four million tonnes of fertilizer being used in Australia each year and five million tonnes of food waste being created (Australian Bureau of Statistics, 2012b). Diverting waste streams, recycling and converting it to a fertilizer would economically benefit all parties involved in the process.

Circular Food (formerly Vermicrobe) is located in Somerton, Melbourne. The founder, Steve Morriss, was initially operating a vermiculture (worm farm) operation inputting food waste and selling live worms, worm castings and worm liquor as an organic fertilizer. The original intention was to scale and replicate this business model into an urban setting; however Steve has since realised that this is not a viable economic model (Morriss, pers. comm., 2017).

Circular Food has since partnered with local government, the Commonwealth Scientific Industrial Research Organisation (CSIRO), and industry to produce a truly closed loop certified organic fertilizer. The process simplistically involves food waste being dehydrated, processed through worm farms to enrich it with microbial life and then mixed with bio-digestate and biochar, to create BIG BIO fertilizer. Bio-digestate is the reclaimed nutrient from anaerobic commercial waste water management facilities and Biochar is a carbon rich soil amendment created from the pyrolysis (high temperature burning) of agricultural waste in an oxygen free environment. The product is free of contaminants unlike many standard types of compost, and is rich in Nitrogen, Phosphorous and Potassium (NPK) with the synergistic microbial amendments already bound.

Circular Food is now operating a pilot plant on a light industrial site strategically located close to a number of food processing and manufacturing operations to be able to capture their waste streams. The company is currently capital raising, and starting to licence out the technology with the intention of launching a number of BIG BIO fertilizer production sites strategically located across Australia. Circular food may prove to be the shining example of a circular economy business model supporting agriculture.

4.3 Goerra/DipTerra

GoTerra, is a newly formed waste management company based in Canberra. Working in the insect protein space, their mission is to provide regionally based waste management solutions to communities. They plan to do this by rolling out modular bioreactors capable of turning agricultural and food waste into BSFL, which in turn will be sold to the poultry and aquaculture industry. GoTerra is also developing a Hazard Analysis and Critical Control Points (HACCP) program to be able to supply BSFL as a food and protein powder for human consumption.

4.4 Organoponicos - Cuba

In 1959, Cuban national revolutionaries began fighting for an autonomous country, free from U.S. control. Fidel Castro and his cohort nationalised all assets, banking, manufacturing, agriculture and exports. The U.S., placing embargos on Cuba, isolated them, forcing the Cubans to rely on, then, Soviet Bloc support. The Cuban agricultural sector was advancing slowly, and with the disintegration of the Bloc in 1991, saw a severe reduction in food imports by over 60%. Between 1991-1995 food rationing was implemented to ensure equitable distribution and Fidel Castro proclaimed that “no piece of land shall be left uncultivated”, initiating the (autoconsumo) self-supply plan (Association for the Study of the Cuban Economy, 1999). The ministry of Agriculture set about to decentralize production and link new production to transport links and consumption patterns within the urban footprint. Urban agriculture in Cuba, and particularly Havana, is a high input high output system that requires careful water management and Integrated Pest Management (IPM) due to the prohibition of pesticides. In 1994 the Cuban government relinquished control of the state controlled farms, giving the workers management and ownership rights of the farm lots. The established Urban Agriculture Department would then make unused lands available to whoever wanted to cultivate them, on the proviso it was under production within 6 months.

Organoponicos are a feature of the Cuban capital Havana, generally a raised bed system on poor soils; they are used for intensive vegetable production and supply up to 30% of a local neighbourhood food supply (Figure 6) (Otto, pers. comm., 2018). These systems utilise of a mix of composted organic waste, vermicast (worm castings), liquid biofertilizers and local animal waste inputs. Using these inputs is second nature to the organoponico farmers, and they have a number of inventive ways of doing this. Due to the abundance of cheap labour and waste material, manures are manually moved and rotated through composting and worms farm systems. With chemical and fertilizer imports strictly controlled, and prohibitively costly, the current systems of production looks set to stay in place for the near future.

An organoponico or farmers market stall can easily be found in every neighbourhood or suburb, providing cheap, organic and seasonal produce. Cubans neither have the luxury of, nor the access to non-regional produce, which may seem limited at first, but an argument can be made that they have one of the lowest carbon footprints in the developed world. This Cuban socialist model with farms imbedded in their cities, may not be seem progressive but is possibly the worlds' most resilient food system, offering security, convenience, a reduced cost of nutrition and an overall a fresher and healthier product direct to the consumer. Regional farm, ownership, local employment and keeping money in the community are obviously clear benefits to the country. (Manuel, pers comm; 2018)

Figure 6: L-R Steve Grist, Fernando Funes, Otto Manue, Farm hand at Finca Marta Organoponico Cuba. A highly productive organic closed loop farm system.

4.5 Syntropic Farms Brazil

Syntropic farming is a relatively newly coined term coming out of Brazil. Traditionally, organic agriculture is based on using organic waste and composts for nutrients as opposed to conventional agriculture using base chemicals for fertilizer inputs. Conventional agriculture systems are generally entropic systems, changing the environment from complex to simple. Syntropic is the reverse, moving from simple to complex through agriculture design, it arranges and includes a polyculture of species, managing them to produce their own fertilizer, thus creating its own ecosystem.

Permaculture, a similar and more commonly heard Australian term, is defined as a Permanent Agri-Culture and is another holistic design system methodology. Permaculture as popular as it is, has become more of an idealistic alternate gardener collective with very few profitable commercial permaculture operations in existence. The two modalities have been compared as equal, but where permaculture fails in commercial application and execution, Syntropic farming can and does succeed.

In 1984, Ernst Gotsch, a Brazilian farmer, bought Fazenda de toca, 1,200 acres of deforested dry land on the edge of the rainforest. Ernst then replanted the land according to a system of natural succession, using a chop and drop, self-mulching and green manuring system, and now, years later has now reforested the entire farm creating its own microclimate. The land is multi-cropped and highly productive in tropical fruits, timber, tubers and some of the most highly awarded and priced coffee and cacao in Brazil.

Syntropic Farms are regenerative, beyond organic, and the best model of agroforestry to date. Essentially biomimicry, multiple species are alley cropped which helps reduce pest and disease pressure, whilst symbiotically supporting each other as part of a whole system. A careful balance of pioneer species, followed by the forestry component of this method, can allow for an endogenous self-fertilizing system within three years. Planting occurs in alleys or rows like conventional farming, and allows access for machinery to harvest. This may not be apparent from overhead observation due to the range of species in the system (Figure 7). Syntropic systems can be applied to sub-tropical and temperate environments, with the most productive being a tropical system. There are now a number of smaller pilot syntropic systems in Australia with some larger farms observing the results closely. Syntropic Farms Co. is now training and running workshops in Australia, and has begun to engage many farmers in the Northern NSW and North QLD region. (Barbosa, pers. comm., 2018)

Figure 7: Syntropic farm with a polyculture of mixed crops in Brazil.

4.6 Ourobourous farms & Pure Ponics

Aquaponics is the combination of Hydroponics and Aquaculture; it is a relatively new, complicated and expanding technology. With a fairly high failure rate, many operations have started and closed within a few years.

Ourobourous farms and education centre is an Aquaponics farm based in Half Moon Bay, San Francisco, and they are arguably one of the most successful in the industry, with many people seeking them out for consulting and training. Ourobourous farms currently grow out Tilapia and Perch in their aquaponics tanks. The nitrite waste from the fish is then circulated into their grow beds which comprises of a rafting system whereby vegetables are suspended in the water. Aquaponic systems have high infrastructure and setup costs, which once established can deliver fast vegetable growth times and water savings within this closed environment. Aquaponic systems generally have a more complex biological suite of micronutrients in comparison to standard hydroponics. Ourobourous farms also cycle the water through Deep Water Culture (DWC) beds rich with worms, therefore providing humates and fulvates.

In aquaculture operations one of the most highly criticized elements is the Feed Conversion ratio (FCR). This can swing wildly as high as 20:1 feed to fish ratio with farmed tuna, equating to 20kg of fish meal or shrimp to create 1kg of tuna (Armstrong, pers. comm., 2018). Ourobourous Farms are taking a further step toward creating a closed loop in creating their own fish feed. The farm is using waste vegetable matter and putting this into a small BSFL bioreactor to grow the larvae to then feed their fish. Other waste water run-off from general production and cleaning is then being captured and cycled through a pre-filter, and is being used to grow duckweed. The duckweed and BSFL with 40% protein, offers a complete suite of nutrients that is able to sustain fish population, fertilize the vegetable production and essentially represent a closed loop fish/food farming system.

PurePonics is another aquaponics enterprise based in Melbourne who have partnered with Deakin University. Although not quite as advanced in production as Ourobouros farms, there is a lot of focus on data collection and analysis. PurePonics also seeks to licence and expand their Aquaponic rafting systems regionally providing locally sourced fish and fresh vegetables (Figure 8).

Figure 8: The author at PurePonics Geelong. A Closed loop Aquaponic vegetable rafting system.

4.7 Parabel – Florida USA

Parabel is a Florida based food start-up taking advantage of the sustainable plant based "meat" movement. The company manages 700 acres of shallow open raceway ponds and as of 2018 currently cultivates over 4,000 tonnes of duckweed (Figure 9) for human and animal consumption. Duckweed has been utilized in Asian rice fields as a green manure for centuries, and some Dutch farmers grow it seasonally to sequester nutrient and then feed to dairy cows. Parabels' developments are a quantum leap past this, breeding the duckweed to be a more palatable and soluble form of protein for humans and animals. As stated on their website:

The crop requires relatively modest water, energy and fertilizer inputs - and our closed growth system keeps losses to an absolute minimum. It is the only cropping system in which 100% of the plant is harvested and 100% of that harvest is employed in the production of high value products. Not a drop of water is wasted, not an ounce of product is thrown away. Everything is either used or completely recycled back through the system (Parabel, 2018).

Parabel can replicate this production model on barren lands or lands that are low in agricultural productivity, and is now offering the best known solution to a plant based protein source, second only to spirulina. Parabels' disruptive technology is not new, with company CEO, Anthony Tiarks, stating that the knowledge has been in literature for years, but nobody has learned to develop or farm it well. The US Food & Drug Administration (FDA) has just granted the company a Generally Recognized as Safe (GRAS) letter allowing them to market the powdered protein for human consumption.

There are a handful of other companies working with duckweed, but most are holding their cards close with regards to global intellectual property.

Figure 9: Duckweed cultivation in a small hydroponic system

4.8 Agtech-X – Brooklyn, USA

Henry Gordon-Smith operates his consulting firm "Agritecture" from this office and has consulted for some large vertical farming and modular farming enterprises such as "Square Roots" in New York City. Agtech-X based in Brooklyn New York is the brainchild of Henry Gordon-Smith. It is setup as a collaborative workspace attracting some of the smartest minds in tech, and entrepreneurial capital, this is then applied to developing future solutions for food and Agriculture. Agtech-X has now become a hub of innovation offering classes and workshops in a range of modern and cutting edge agricultural techniques. There is a current focus on integrating circular economics into this space, such as food waste streams, BSFL, mushrooms and duckweed. Agtech-X is currently collaborating with "Re-Nuble", another company based in New York, which is turning food waste into a liquid hydroponic fertilizer. The Agtech-X think tank also has some forward thinkers working on modular and scalable waste nutrient recycling prototypes which could be deployed on farm, or near certain waste streams (Gordon-Smith, pers. comm., 2018). This future agriculture incubator is trailblazing and one to watch.

Chapter 5: Opportunities for Australian Farms

5.1 Waste Streams and Current Practices

In 2015, Apple recovered 2,204 pounds of gold, at a value of USD $40 million, from recycled iPhones (Cable News Network, 2016). In the same way these tech giants are looking at rare earth minerals as a recyclable product, agricultural innovators are coming up with solutions to recycling and reclaiming agricultural minerals, and absorbing loose nutrients. A number of agro cyclical practices are currently being practiced on Australian farms, such as composting, green manuring, companion cropping, and diversion to biogas production. In Europe there is a large subsidisation for Anaerobic Digestion (AD), which is not without its critics. Two main arguments are debated, one that AD would not be economically feasible if not subsidised and two, AD en masse provides another fuel to burn but inevitably leads to a net entropic loss of material. Horticultural waste burning always delivers more CO_2 into the atmosphere whereas correct composting builds stable soil carbon and provides much needed microbial life.

Many farmers continue to burn organic agricultural waste, stockpile it, or turn it into the ground, which can exacerbate and spread pest and diseases. Careful hot composting or waste cycling through worm/BSFL systems can reduce and eliminate these pressures.

5.2 Barriers to Implementation

Knowledge

The number one barrier to implementation of some form of composting or nutrient cycling system is knowledge. With composting systems, the techniques can be very simple however the inputs can influence the end product. Chemical and pesticide residue can also determine the end use for that product, possibly making it unsuitable for off-farm sale and application.

Cost

The most common on-farm nutrient cycling is in the form of composting. Generally, only larger farms have the equipment and machinery to be able to turn and manage this compost. There can be significant capital outlay with composting machinery, so an obvious economy of scale comes into play. Other infrastructure such as bioreactors, Worm composting systems, and sediment/water catchment may generally be newer technologies and be more costly in the initial installation, but are showing some impressive results. As input costs increase and technology improves, the economies of scale will improve and will make these practices widespread.

Will

With the average age of an Australian farmer at 56, (Australian Bureau of Statistics, 2012b), innovation can sometimes be a hard sell. The continual rise of fertilizer and transport costs, coupled with climate change and top soil loss is leaving Australian farmers with no choice but to adapt. Scores of new data, workshops and field data are being offered to farmers to show the added benefits of composting, sequestering carbon and building top soil. It is now down to the will of many farmers who can see what change is required for agriculture to advance in the 21st century.

5.3 Pieces of a Puzzle

In 2018, the Australian Government announce a $500 million reef rescue package, aimed at reducing agricultural run-off and coral bleaching causing damage to the Great Barrier Reef (Great Barrier Reef Marine Park Authority, 2018). North Queensland farmers now have access to advice, resources and funding to mitigate this problem.

Tropical environments are the perfect climate for duckweed cultivation and with a network of retention basins in heavy sugar cropping areas. Duckweed by itself composted is a good source of nitrogen and can also be used as a fodder to cattle. BSFL will also rapidly turn duckweed into frass and a protein source.

With land based Aquaculture growing in Australia, and protein feedstock being the most expensive and controversial input, mutually synergistic solutions are now available. BSFL, duckweed and composting easily interface with each other, and any concerns into toxicity levels can further be addressed through mycoremediation, which is the fungal remediation of long chain hydrocarbons, metals or toxins, by enzymes which can degrade and transform these substances (McCoy, 2016).

In any complex ecosystem all components are intertwined and interact with each other. Moving from a linear resource mining economy to a circular nutrient cycling economy requires many pieces to complete the puzzle. Duckweed, soldier fly larvae, mushrooms and compost do not initially come to mind as future solutions to save the world, but they are essential to the way the world will handle agricultural and food waste in the future. Solutions presented in this paper will be just as critical as robotics, precision agriculture and cloud based applications as we move towards the 21st century.

The schematic below is an example of an IFWMS, which may present as being very complex, but can be explained as follows: As waste transitions from a costly output, to a cost saving recycled input, these systems will be eventually be integrated into modern farming. Micro regional waste collection, resource and infrastructure sharing would be the most efficient and cost effective step forward to this new way of operating.

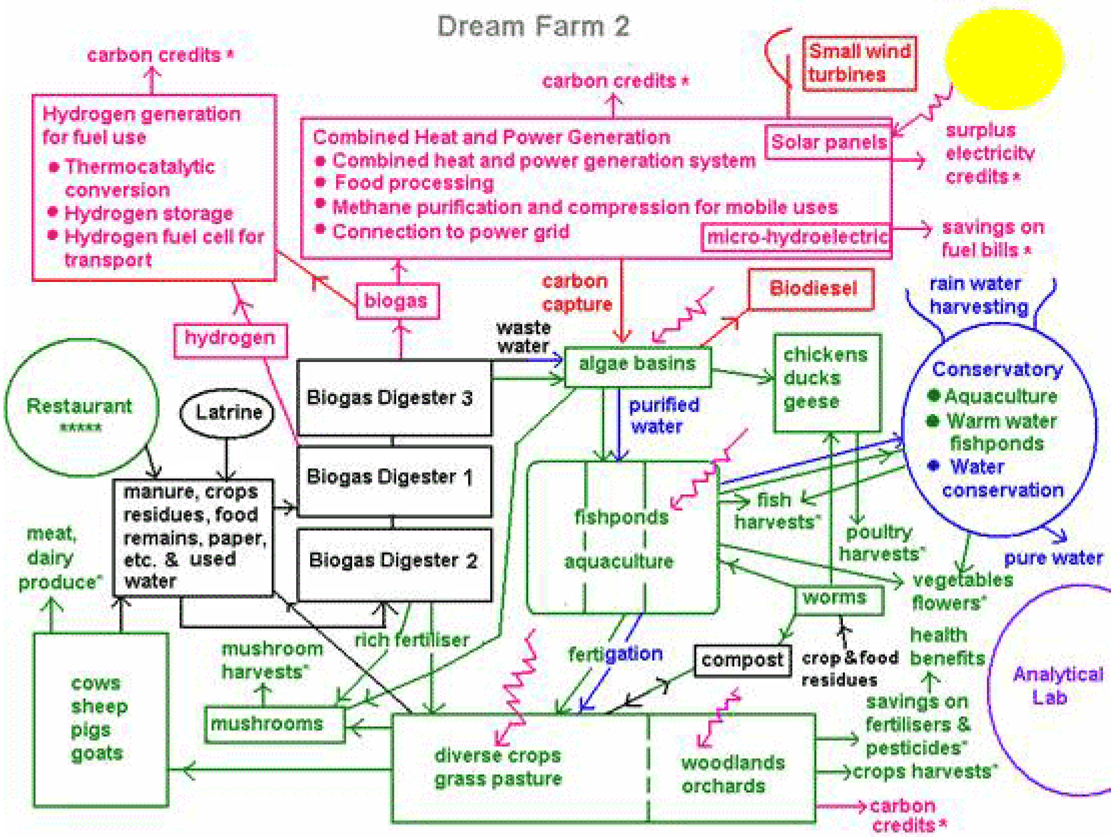

Figure 10: Dream farm 2, conceptualised by George Chan at ZERI.

Conclusion

In Australia, 50% of municipal waste is collected and recycled to some degree. In Germany, Denmark and Sweden this rate is between 87-100% (World Bank, 2018). In 2017, China implemented it's 'National Sword' policy, greatly reducing the amount of imported recycled waste and lowering the contamination thresholds (Towie, 2018).

With the previous attitude of it being someone else's problem, Australia has had its hand forced and now has to deal with more of its own rubbish. Thanks to companies like Veolia and Cleanaway, waste management education, recycling compliance has increased (Department of Environment and Energy, 2018),

European leaders that have set near zero waste targets are adopting circular economic strategies and investing in new technologies to meet these goals (European Environmental Bureau, 2018), but Australia is lagging far behind in this arena. Australia is a geographically dispersed country, which poses challenges when it comes to food miles and recycling, however the coordination and infrastructure for recycling agricultural waste is less complex than other materials. Regional bio-waste facilities on or off farm could be established like that of Circular Food, taking in waste and converting it to an organic fertilizer. The old paradigm of burning or letting vegetative matter rot is out, dated.

Farmers can transition their farms to an IFWMS, with training and some technical assistance. Fledgling industries, like duckweed and mushroom producers, and compost creators may currently guard their Intellectual Property (IP), but through open sourcing and the Blue Economy, this technology is being made available for the betterment of our food supply and future of the planet.

Adopting circular economic principles and practices is not only cost saving, but regenerative, and will become an absolute necessity as the population increases and resources become scarcer. Consumers are already demanding:

- Reduced food miles
- Sustainably sourced foods
- Plant based protein

- Nutrient dense produce
- Environmentally friendly products

Some governments are beginning to mandate these points, and early adopters and those willing to make the transition into a circular economy now, will have the first mover advantage in their industry.

Recommendations

- A national waste policy review, with a focussed national recycling program for agricultural and food waste. Education to be increased at all levels - from school to farm and industry groups.
- Government recognition at all levels; adoption and promotion of circular economic system practices, with renewed and accelerated goals to meet Scandinavian countries.
- Farmers to adopt waste stream/system integration to on farm nutrient cycling centres. Government to put policies into place to allow subsidised and low interest loans to establish nutrient cycling waste management infrastructure.
- Farmers to focus on whole system design, extension to the current "Smart Farms" program, and provide free agronomical consulting to transition farms into circular systems.
- Government, Council and Natural Resource Management support, funding and low interest loans to build infrastructure to support closed loop practices.
- Agriculture Tech entrepreneurs to improve platforms that allow farmers to share equipment and resources e.g. compost turners, waste materials.
- Government backed agriculture technology incubator funding and support, so Australia is not left behind.
- Farmers and industry to incorporate more regenerative practices, biomimicry of natural systems, and symbiotic nutrient cycling systems and increased R&D into plant based fertilizer.

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Plain English Compendium Summary

Project Title:	Name of project: Closing the loop, Circular economics within Agriculture
Nuffield Australia Project No.: Scholar: Organisation: Phone: Email:	1818 Steven Grist Cairns Microgreens & Exotics 1 Copland Road, Koah, QLD, 4881 0438 454 435 stevegrist@hotmail.com
Objectives	1. Investigate the technologies, options and limitations in implementing waste and nutrient cycling systems on farm. 2. Visit and research various working models. 3. Identify Opportunities for Australian farms.
Background	5.3 million tonnes of food waste is created in Australia each year. A small portion is composted or recycled into secondary uses, a large portion is lost in landfill becomes aerobic and contributes to Greenhouse Gas emissions in the atmosphere. Farmers and consumers can divert most of this waste into beneficial secondary uses such as composts and protein creation.
Research	Several operations in Australia, USA, NZ and Cuba were visited and investigated. These included composting, waste management, mycoremediation, bio intensive and agroforestry projects.
Outcomes	A number of new and innovative waste resource recovery options exist: 1. Farmers need to identify waste streams and learn ways in which to reintegrate them into current operations. 2. Consumers can play a more conscious and active role in waste management. 3. Government and industry need to support and incentivise these new technologies and techniques.
Implications	Adoption of Circular Economic or Agro cyclical practices which will valorise waste for smallhold farms. Incorporation of regenerative and whole system design on farm, coupled with smart waste management can reduce nutrient loss on farm, reduce Greenhouse Gases, and add other possible income streams to the farm.
Publications	Nuffield Australia National Conference, Brisbane, QLD. September 2019