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FOOD, WATER AND
WASTE PROGRAMME

GLOBAL FOOD WASTE MANAGEMENT: AN IMPLEMENTATION GUIDE FOR CITIES

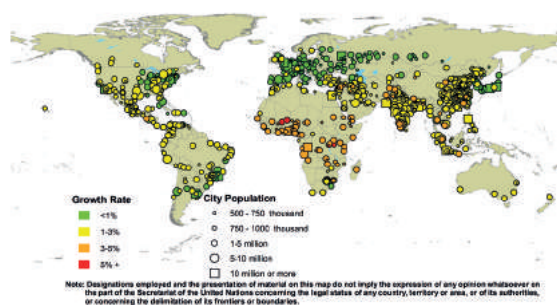
Full Report



GLOBAL FOOD WASTE MANAGEMENT: AN IMPLEMENTATION GUIDE FOR CITIES

FOREWORD

Globally, food waste has become an increasingly recognised environmental issue over the last decade. Not only has the issue of wasted food become an ethical one in a world where approximately 800 million people suffer from hunger, but the environmental impacts of producing food that is then discarded can no longer be overlooked. As population and urbanisation grows, more food is being produced and more food is being wasted. Moreover, food wasted in an urban context creates severe environmental and public health consequences that have a negative impact upon human well-being and the environment. For the first time in Human history, over 50% of the global population lives in cities and by 2050, this will rise to over 70%. This concentration of people is putting cities' infrastructure under tremendous pressure – the need to provide clean water, sewage treatment, public transport, maintain urban hygiene, build waste treatment facilities, provide education and health services, in cities growing constantly, is an enormous task; however, cities also provide unique opportunities for energy, resources and services efficiency, health services, technological innovation and sustainable development.



UN WORLD URBANIZATION PROSPECTS REPORT, 2014 UPDATE,
ANNUAL PREDICTED GROWTH RATE 2014-2030

¹ IPCC, 2007b

² Resource Savings and CO₂ Reduction Potential in waste management; Prognos, 2008. Climate Protection Potential in the Waste management sector; Umweltbundesamt, 2010.

³ <http://www.waste.ccacoalition.org/document/white-paper-waste-and-climate-change-iswa-key-issue-paper>

Food management is also a major source of greenhouse gas emissions and cities are key actors in the global mission to reduce the impact of climate change. The Paris Agreement commits signatories to “holding the increase in the global average temperature to well below 2 degrees above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5 degrees above pre-industrial levels.” Without the involvement of cities in this process, the goals become impossible to achieve.

Solid waste management is one of the key services every city government must provide with widely variable service levels, costs and environmental impacts. Solid waste generation is also increasing faster than any other environmental pollutant, including CO₂. As the world population becomes more urbanized and affluent, the increase of waste generation is putting enormous pressure on local governments, primarily in the rapidly growing cities of Africa, Latin America, Southeast Asia, China and India.

GHG emissions from solid waste management have also emerged as a major point of debate as, under current UNFCCC accounting methodologies, they are estimated to account for 3% of the overall global GHG emissions, primarily from methane from landfills.¹ However, recent studies demonstrate that current methodologies reflect only a limited recognition of the extent to which improved waste management systems can play in GHG reductions,² since most of the beneficial impacts from those actions are recorded in other parts of the overall inventory, or lost. Yet calculations undertaken by, for example, the International Solid Waste Association and presented to the Climate and Clean Air Coalition secretariat in 2009³, show that the waste sector can contribute reductions of some 15% to 20% of a city's emissions if all actions regarding waste management are fully considered. However, because the IPCC emissions accounting is undertaken by sectors, policy makers often overlook the contribution biodegradable waste can make to emission reductions.

This renders implementation of policies a difficult task and this report sets itself the task of ensuring those contributions are widely understood and recognised.

Cities have a responsibility to create solutions to climate change. Fortunately, they also have a real capacity – and will – to do so. Acting both locally and collaboratively, cities are making a meaningful global impact by implementing sustainable development practices. Each city is unique in its infrastructure, scope of control over municipal services, technical savvy and even progress in addressing climate change.

Competitive advantages allow individual cities to pursue a subset of strategies that will lead to meaningful emissions reductions at the local level. Cities can be nimble in implementing policy changes, but are also readily accountable to their citizens, local businesses, schools, and institutions for the success or failure of their actions. To this extent, cities are a test-bed for larger action: policies and programs that work - environmentally, economically and politically - have powerful potential to enact change globally. Cities with common profiles can network, collaborate on solutions and disseminate best practices that bring actions to scale in other similar cities.

When cities decide to undertake policies together, they can have the impact of nation states. The 90+ cities that are members of the C40 Cities Climate Leadership Group are witness to this willingness to act upon these global challenges.

This report intends to be a guide to assist the decision-makers in cities that recognise the challenges of food waste management and wish to find sustainable and effective solutions.

Cities and nations are acting in various ways to reduce and treat food waste. These include actions focused on donating schemes for food that would otherwise go to waste- especially left-over

food from points of sale to consumers that are now collected at the end of the day and given to collection centres where charities redistribute them to the needy. Nations, like France and Italy, have made the donation by supermarkets of left-over food a legal obligation and have reduced taxes to stimulate this. Private and public initiatives have multiplied in major cities, like London, where charities such as FareShare have become major distributors of edible food left-overs.

A significant fraction of food waste is considered unavoidable, which include peelings and skins, bones and fats, oils and fresh food mistakenly left to rot. Separate collection of food waste makes treatment much more efficient whilst promoting reduction too. Several cases are quoted in chapter 4 of cities that have decided to separately collect these residues and send them to treatment. From major cities like Milan to smaller towns, the movement to separately collect food waste is growing. New York, Paris, Oslo, Copenhagen, Auckland, San Francisco, Mexico City, and many others, separately and regularly collect their food waste from millions of citizens, either on a voluntary or obligatory basis. These are usually the result of decisions taken at a city level but often due to an enabling national legislation which has stimulated this action. The recent European Union agreement revising the Waste Framework Directive, in which separate food waste collections will be obligatory from 2023, is an example of how a wider policy framework will impact decisions at a local level.

This report will look at how these cities have implemented these policies and to what degree they have succeeded, what policies need to be enacted and how best results are achieved- learning from experience and understanding best practices. Food waste treatment can create a series of positive outcomes including renewable energy production; natural soil improvers that can store carbon and increase soil humidity; reduced methane and other GHG emissions; air

quality improvement; reduced reliance on landfills; job creation; economic development; sustainable infrastructure investments; and reduced reliance on fossil fuels.

In chapters 5, 6 and 7 we will look at these solutions and their relative suitability in different urban scenarios. Whilst anaerobic digestion technologies are mature and well-tested, they are relatively complex and require careful management to ensure they achieve their targets in terms of outputs and performance. Training, maintenance, health and safety considerations, upgrading, are continually needed to ensure that a plant performs well over its programmed life span.

This report is also a call to action. It is published in Spring of 2018 and recognises that time to implement policies and investments to combat climate change is running out. It is vital to remember that the impacts of climate change are already underway, and already being experienced around the world. Global temperatures have already increased by 1 °C from pre-industrial levels. Atmospheric CO₂ levels are already above 400 parts per million (ppm), far exceeding the 350 ppm deemed to be “safe” for human civilization. These facts emphasise the incredible urgency with which we need to act if the ambitions agreed in Paris are to be met. Recent C40 research shows that, based on current trends of consumption and infrastructure development, within five years the world will have “locked-in” sufficient future emissions to exceed 2 degrees. A third of these emissions will be determined by cities, making them pivotal actors in any solution.

The overriding and deeply significant finding of the C40 Deadline 2020 report is that the next 10 years will determine whether or not the world’s megacities can deliver their part of the ambition of the Paris Agreement. Without action by cities, the Paris Agreement cannot realistically be delivered. To remain within a 1.5 degree temperature rise, average per capita emissions across C40 cities need to drop from over 5 tCO₂e per capita today to around 2.9 tCO₂e per capita by 2030. For wealthier, high emitting cities that means an immediate and steep decline. Some developing cities can maintain their current levels for up to a decade, and in a small number of cases there is some scope for emissions per person to rise slightly before they

eventually fall to zero. But every city needs to diverge considerably from its current business as usual pathway.

The business-as-usual path of C40 cities’ emissions needs to ‘bend’ from an increase of 35% by 2020, to peak at only a further 5% higher than current emissions. This “bending of the curve” is required now to ensure that in the coming decades the necessary reductions remain feasible, given that actions can take many years to mature and reach full scale.

The reduction and treatment of urban food waste is one of the most significant methods cities can use to reduce their carbon footprint. The interesting aspects of food waste treatment technologies are that they can be implemented within a short timeframe and that cities have most of the powers to do so.

National and city authorities can take action immediately to reduce and capture the resources available in food waste and turn these into compost, biogas, transport fuel, soil improvers, power and heating and cooling. By quantifying the local availability of food waste feedstocks, the intrinsic energy and carbon value in these, the opportunities to reduce food waste, and the technologies available to treat the wastes that are left, cities can initiate the process for turning a major pollutant into a useful resource. Access to finance, the adoption of policies and the consequential actions follow from the decision to collect and treat food waste. Continuous communication activities involving the local population are needed to ensure the population understands, participates in and actively promotes the new system. Stakeholder involvement is required throughout the process and even more so once it is implemented to ensure continuity and successful running of the programmes. As some cities have shown, punitive measures may also be needed to ensure compliance.

The C40 Cities Food, Water and Waste Programme and the World Biogas Association offer their collective assistance to cities coming to terms with food waste, its reduction and treatment. By making our expertise in this sector available to those willing to embrace the food waste challenge, we hope to speed up the process of change and to help cities achieve their climate change and urban sustainability goals.

The report intends to give the reader a wide ranging overview of how cities can deal with food waste. As such the report wants to help policy makers and their relative stakeholders in cities adopt best practices to reduce the negative impacts of untreated food waste and create positive impacts related to energy, soil quality and human health.

Divided into 7 chapters, the report looks at the impacts of food waste on the global commons; how to prevent and reduce food waste; experiences of cities that have implemented source segregated collection of food waste; treatment options for food waste ranging from low to high investment solutions; the products derived from food waste treatment and how to use them; we enter into some detail about anaerobic digestion and its role in sustainable management of food waste; finally, we look at the policies required to overcome economic and social barriers to implementing food waste treatment.

This is a comprehensive report, one designed to be a point of reference to policy makers and stakeholders for time to come. It is also a dynamic report- through the website archive linked to the report itself, new resources are continuously uploaded bringing vast amounts of information about the issues discussed here.

You, the reader, are invited to contribute to this archive with your experiences and knowledge.

The report is a collaborative effort led by the C40 Cities Food, Water & Waste Programme and the World Biogas Association, with inputs and information provided by a host of expert writers from the world over. We are particularly grateful for the help received from the Global Methane Initiative of the Environmental Protection Agency of the United States of America and the Eastern Resource Group consultancy, for decades a leader in ensuring methane from landfills is captured and used for energy production. Some input has been received from the United Nations Food and Agricultural Organisation. We thank also the Editorial Board of the report who have dedicated free time to give their views, comments and inputs over the six months of drafting. Finally we thank the countless numbers of friends, colleagues and parties that have contributed experiences to the study without which it would have been poorer. They are cited in the annex and quoted where relevant in the report itself. Above all, our thanks go to Dr. Sarika Jain of WBA and Kathrin Zeller of C40 who have been the key contributors for this report and to their respective contributing colleagues. Sponsorship to pay for this report has been received from numerous sources and we thank each of the sponsors for their precious support



David Newman,
President, World Biogas Association



Ricardo Cepeda-Márquez,
Technical Lead – Food, Waste & Water Programme
C40 Cities Climate Leadership Group

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FOOD, WATER AND
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AUTHORS

Dr Sarika Jain, David Newman: World Biogas Association

Ricardo Cepeda-Márquez, Kathrin Zeller, : Food, Water
and Waste Programme - C40 Cities Climate Leadership
Group

LIST OF CONTRIBUTORS

Anaerobic Digestion and Bioresources Association:

Ollie More, Emiliano Lewis, Jessica Allan

Eastern Research Group: Brian Guzzone, Brooke Robel,
Jeanette Alvis, John Carter

Italian Composting and Biogas Association: Dr Marco
Ricci, Dr Alberto Confalonieri

City of Copenhagen: Dr Line Kai-Sørensen Brogaard

City of Oslo: Johnny Stuen

Seoul National University: Dr Jae Young Kim and Dr Ju
Munsol

Auckland Council: Ian Stupple, Parul Sood

Cajica, Colombia: Mr Josue Frias Cruz

Editorial Board

Ricardo Cepeda-Márquez

Johnny Stuen

Brian Guzzone

Juha Antti Kalevi Seppala

Dr. Mario A. Rosato

Ollie More

Håkan Rylander

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Acknowledgments:

Bioenergy Australia: Dr Bernadette McCabe

Methanum: Dr. Luis Felipe Colturato

Food and Agriculture Organisation: Emilie Wieben

Environmental Protection Agency: Christopher Voell, Thomas
Frankiewicz

Scania: Tanya Neech

Italian Biogas Council: Dr Fabrizio Sibilla

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1. SOURCES AND IMPACT OF FOOD WASTE

1.1. Introduction

This chapter explores the sources of food waste and the extent to which the environment, global economy and society are bearing the burden of food wasted and lost.

The lifecycle of the food we eat begins in the farms where it is grown and harvested or the sea, rivers and lakes it is fished from. It continues through handling and storage stages and, often, processing prior to distribution and consumption. Throughout the food cycle, losses and wastage occurs, at farms, processing plants, distribution centres, storage houses, supermarkets, restaurants and households.

The magnitude of the problem and lost opportunity is highlighted by the following three facts:

- **A third of the food produced for human consumption globally, about 1.6 billion tonnes per year, is lost or wasted ¹.**
- **The cost of food waste globally is estimated at around USD 2.6 trillion – of which USD 1 trillion is incurred from greenhouse gas (GHG) emissions, water scarcity, biodiversity loss, increased conflicts and loss of livelihood due to issues such as soil erosion, nutrient loss, reduced yields, wind erosion and pesticide exposure ².**
- **Food waste accounts for 4.4 giga-tonnes (Gt) of CO₂ eq. per year, which represents 8% of global anthropogenic GHG emissions ³. In comparison, the overall emissions from China, USA and India are 12.45, 6.34 and 3.00 Gt of CO₂ eq. per year ⁴.**

Avoiding food waste along its lifecycle is therefore imperative for all those managing food production, distribution and sales. However, as set out below, a significant fraction of food waste, especially at the household stage, still occurs. The correct management of these materials at the end of their lifecycle is essential in order to avoid the environmental and societal impacts caused by untreated, decomposing food.

By shifting from a linear to a circular management system, utilising food ‘waste’ as a ‘resource’, for example via composting or anaerobic digestion (AD), a multitude of

benefits can be delivered; renewable energy generation, reduced GHG emissions, reduced dependence on fossil fuels, improved soil fertility, food security, energy security, better health and sanitation, protection of water bodies, more self-sufficient and resilient communities and sustainable industrialisation, in addition to potential economic benefits from reduced expenditure and additional revenue streams from sale of electricity, heat, biomethane, vehicle fuel, digestate/compost or other high value products ⁵.

These benefits are described in greater detail in Chapter 5 and touched on in this chapter.

1.2. Definition of food waste

The terms food, inedible food, food loss and food waste need to be contextualised both geographically and within the food chain. For the purpose of this report, 'food' is defined as any substance, whether processed, semi processed or raw, that is intended for human consumption as well as the 'inedible parts' associated with food that are not intended to be consumed by humans ⁶. For example, pineapple is a food; its skin is inedible.

'Food loss' refers to food that unintentionally undergoes deterioration in quality or quantity as a result of food spills, spoils, bruising, wilting or other such damage as a result of infrastructure limitations at the production, storage, processing and distribution stages of the food lifecycle. In this report, 'food waste' means any food and inedible parts of food, removed from the food supply chain that can be recovered or disposed. This includes food waste that is to be composted, spread to land, treated through anaerobic digestion, combusted for bio-energy production, incinerated, disposed to sewer, sent to landfill, dumped in open dumps, or discarded to sea ⁷. The

rationale behind this choice of food waste definition is that from a resource efficiency perspective, any parts of food that are not consumed are still rich in carbon, water and nutrients. By collecting and recycling this food waste, nutrients and water can be recovered and recirculated, and renewable energy from the carbon harvested to substitute fossil fuels. It may be noted that by using this definition, inedible parts of food, such as fruit and vegetable skins, egg shells, are a part of food waste.

'Avoidable food waste' is defined as food or drink that was, at some point prior to disposal, edible (e.g. slices of bread, apples, meat) while 'unavoidable food waste' is waste arising from food and drink preparation that is not, and has not been, edible under normal circumstances (e.g. meat bones, egg shells, pineapple skin) ⁸.

Within the context of cities, food waste will primarily be characterised by where it is produced – not on the farm or in the fishery, but in households, catering facilities, processing plants (e.g. canneries, abattoirs, and bakeries), storage and distribution operations, markets and shops, restaurants, bars and cafés.



¹ Food and Agriculture Organisation of the United Nations (2011) *Global Food Losses and Food Waste – Extent, Causes and Prevention* <http://www.fao.org/docrep/014/mb060e/mb060e00.pdf>

² Food and Agriculture Organisation of the United Nations (2015) *Food Wastage Footprint & Climate Change* <http://www.fao.org/3/a-bb144e.pdf>

³ Food and Agriculture Organisation of the United Nations (2015) *Food Wastage Footprint & Climate Change* <http://www.fao.org/3/a-bb144e.pdf>

⁴ The World Bank Data Bank based on European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). *Emission Database for Global Atmospheric Research (EDGAR)*, EDGARv4.2 FT2012 <https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE>

⁵ Ellen MacArthur Foundation (2013) *Towards the Circular Economy Vol 2* https://www.ellenmacarthurfoundation.org/assets/downloads/publications/TCE_Report-2013.pdf

⁶ The Food Loss and Waste Accounting and Reporting Standard http://flwprotocol.org/wp-content/uploads/2017/05/FLW_Standard_Exec_Summary_final_2016.pdf

⁷ EU FUSIONS (2016) *Food waste definition* <https://www.eu-fusions.org/index.php/about-food-waste/280-food-waste-definition>

⁸ WRAP (2009) *Household food and drink waste in the UK* http://www.wrap.org.uk/sites/files/wrap/Household_food_and_drink_waste_in_the_UK_-_report.pdf

1.3. Impacts of food waste

In addition to the squandering of resources (including energy, carbon, water and nutrients) needed to produce food that is not consumed, poorly managed food waste adversely affects our climate due to the GHGs that are emitted upon its decomposition, contaminates watercourses from nutrient and leachate runoff and can be a vector for diseases and a health hazard.

This section gives an overview of the breadth and scale of the impacts that food waste inflicts upon society and the environment and how its collection and recycling can mitigate some of these. It describes the impacts, identifies the relevant international commitments in place to address these impacts, and explains some of the potential mitigation measures needed to achieve this, with particular regards to:

- GHG emissions and climate change;
- Water footprint;
- Nutrient loss;
- Sanitation;
- Ecological impacts; and
- Economic impacts.



1.3.1. GHG emissions and Climate Change

Background to impact

Carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) are greenhouse gases that contribute to global warming and climate change, and are emitted at all stages of the food life cycle, including:

- Change in land use from forests (for example) to agriculture causing release of carbon that was stored in the cleared biomass;
- Emissions from livestock and from manures and slurries;
- From burning fossil fuels to produce energy for:
- Operating farm machinery;
- Producing and using of mineral fertilisers;
- Heating farm buildings and greenhouses;
- Processing food (e.g. pasteurisation); and
- Refrigerating and transporting of food.
- When wasted food is disposed of in landfill sites or dumpsites, it decomposes and releases further emissions to the atmosphere.

CO₂, CH₄ AND N₂O
ARE GREENHOUSE GASES
THAT CONTRIBUTE TO GLOBAL
WARMING

International Commitments

In December 2015, 195 parties signed and 171 nations have ratified at the date of writing (so the Agreement is in force), the United Nations Framework Convention on Climate Change (UNFCCC) “Paris Agreement”, aiming to limit global warming to 1.5 – 2 degrees Celsius above pre-industrial levels by 2100, committing to collective action towards a low carbon economy. At the heart of this agreement are the publicly available plans

of each signatory’s post-2020 climate actions known as their Intended Nationally Determined Contributions (INDCs) ⁹. Each of the signatories is now working on their INDCs. Food waste accounts for 4.4 Gt of CO₂ eq. GHG emissions on an annual basis - 8% of all anthropogenic GHG emissions ¹⁰. By identifying and delivering actions on reducing and treating food waste, countries can achieve and increase their INDCs.

Mitigation

As explained further in Chapter 2, the prevention of waste along the food chain brings the greatest benefits to society and the environment through the reduced cost and impacts of food produced. Measures for the prevention of food waste can be implemented to prevent avoidable losses within urban contexts, whilst several climate change mitigation benefits will occur by managing unavoidable food waste once it is discarded, i.e. in collecting and treating it correctly.

Food waste treatment through composting or Anaerobic Digestion (AD) can prevent:

- **Methane emissions from rotting food in landfills and open dumps. 50% of all waste is still not collected in low income countries and up to 60% of these volumes are made up of food and organic waste .**
- **Carbon dioxide emissions from substituting fossil fuels traditionally used for energy production with biogas-based energy from AD which is renewable and produced from recovering food waste ¹¹.**
- **Emissions of black carbon and carbon dioxide from substituting traditional solid domestic fuel in households such as firewood, charcoal, dung cakes, etc. with biogas. This mitigates climate change and also improves indoor air quality.**
- **Carbon dioxide emissions from the energy used in the production of mineral fertilisers by substituting it with biofertiliser (compost or digestate) produced after treatment of food waste.**

It is estimated that 580 kg CO₂ eq. can be saved per each tonne of food waste diverted from landfill to an anaerobic digester when the resulting biogas is used to replace natural gas ¹².

Given the GHG emissions mitigation benefits of food waste collection and treatment, it is one of the few steps that every country and city should include in their INDCs and plan for their future.

⁹ United Nations Framework Convention on Climate Change http://unfccc.int/paris_agreement/items/9485.php

¹⁰ FAO (2015) Food Wastage Footprint and Climate Change <http://www.fao.org/3/a-bb144e.pdf>

¹¹ The World Bank (2012) What a waste – A Global review of solid waste management https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf

¹² Ellen MacArthur Foundation (2013) Towards the Circular Economy https://www.ellenmacarthurfoundation.org/assets/downloads/publications/TCE_Report-2013.pdf

1.3.2. Water footprint

Background to impact

Water is essential to plant and animal life and therefore for the production of food for human consumption. In places where rainfall is not adequate or seasonal, water is extracted from groundwater aquifers and surface water bodies for irrigation. The production of food that is wasted and the uncontrolled disposal of food waste has an impact on surface water as well as groundwater bodies.

Impacts on water supply and quality can arise as follows:

- **Wastage of food results in the waste of water extracted from the ground or surface water bodies for irrigation. It is estimated that the blue water footprint for the agricultural production of food that ends up being wasted is approximately 250 km³ which is three times the volume of Lake Geneva ¹³.**
- **Use and subsequent runoff of fertilisers and pesticides has an adverse impact on the water quality of ground and surface water bodies.**
- **Leachate from dumpsites and landfills pollutes the groundwater as well as surface water.**
- **Where poorly regulated, untreated wastewater from food processing industries pollutes the surface water bodies.**

International Commitments

The United Nations (UN) Sustainable Development Goal (SDG) 6 aims to substantially increase water-use efficiency across all sectors and ensure sustainable withdrawal and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity, by 2030. Also, by 2030, the international community is committed to improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse of water globally ¹⁴.

Mitigation

Preventing food waste can reduce the pressure on water bodies while collecting and treating the food waste that still occurs can reduce its impact on the quality of surface and groundwater.

**FOR MILLENNIA HUMANS HAVE LIVED IN RURAL
ENVIRONMENTS WHERE THE RECYCLING OF
FOOD AND HUMAN WASTE TO SOIL HAS BEEN A
CONTINUAL PRACTICE.**

¹³ FAO (2013) Food wastage footprint – Impacts on natural resources <http://www.fao.org/docrep/018/i3347e/i3347e.pdf>

¹⁴ United Nations Sustainable Development Goal 6 <https://sustainabledevelopment.un.org/sdg6>

- When wastewater from sources such as food processing industries is collected and anaerobically digested, carbon is captured in the form of biogas. This reduces the biological and chemical oxygen demand of the wastewater and also reduces the pathogens in it, thus, reducing the impact on water bodies.
- Proper collection and management of food waste reduces instances of leachate formation, accumulation and free flow such as in landfills and open dumps. This prevents contamination of ground water.
- With correct application of digestate to soil in the form of biofertiliser, farmers can manage their soil and reduce contamination of water bodies from leaching of synthetic fertilisers.

GROWING POPULATION AND CONSUMPTION ARE PUTTING INCREASING PRESSURE ON THE ALREADY LIMITED AGRICULTURAL LAND SUPPLIES TO PRODUCE EVEN MORE FOOD.

1.3.3. Nutrient loss

Background to impact

Plants are primarily made of carbon and water, and need nitrogen (N), phosphorus (P) and potassium (K), amongst other nutrients, for their growth. Plants photosynthesize carbon from the atmosphere while the NPK are obtained from soil, and from organic and inorganic fertilisers applied by farmers. Decades of unsustainable agricultural practices have resulted in depletion of these nutrients, as well as of organic matter in the soil.

With a growing population and its increasing wealth and consumption, there is increasing pressure on the already limited agricultural land supplies to produce even more food. Waste of food further exacerbates the problem of food security. For millennia human beings have lived in generally rural environments

where the recycling of food and agricultural waste and human excreta to soil has been a continual practice. Further, only in the last century have soils been subjected globally to intensive agricultural practices and use of synthetic fertilisers. As humanity has urbanised (in year 2014 54% of humans lived in urban areas and this will increase to at least 66% by 2050 ¹⁵) the natural recycling of food and agricultural waste and human excreta on farmland has declined, as these wastes are produced increasingly in cities, and not returned to farmlands. The breakdown in this cycle can be partially addressed by recycling these wastes from urban contexts back to farmland, through the use of digestate and compost. Cities therefore have a role to play in promoting sustainable food production through better food waste management.

¹⁵ United Nations (2014) World urbanization prospects <https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf>

A few key data give us an understanding of the value of soils.

- 95% of all food consumed by humans is grown in soil ¹⁶.
- 1.4 billion hectares (30% of all agricultural land) is used for the production of food that is never eaten as it is wasted ¹⁷.
- 2.6 billion people depend directly on agriculture, but 52 per cent of the land used for agriculture is moderately or severely affected by soil degradation ¹⁸.
- Globally, up to 2 billion hectares of land is degraded, with agricultural activities and deforestation being one of the primary causes of land degradation ¹⁹.
- The world's soils have lost 133 billion tonnes of carbon since the dawn of agriculture ²⁰. A part of this carbon, which is lost from the soils, ends up in the atmosphere in the form of GHGs such as carbon dioxide and methane, reducing the quality of air we breathe and also causing our climate to change.
- Phosphorus, which is widely used in agriculture to promote growth and is essential for maturity of plants, is depleting and concentrated in only a few countries (most of the world's reserves are owned or controlled by Morocco, China and the US) ²¹.

International Commitments

As a part of the UN SDGs 2 and 15, countries have committed to²²:

- **By 2030, end world hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round.**
- **By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality¹⁶.**
- **By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.**

¹⁶ FAO (2015) Healthy soils are the basis for healthy food production <http://www.fao.org/soils-2015/news/news-detail/en/c/277682/>

¹⁷ FAO (2013) Food waste footprint: Impacts on natural resources <http://www.fao.org/docrep/018/i3347e/i3347e.pdf>

¹⁸ United Nations Sustainable Development Goal 15 <http://www.un.org/sustainabledevelopment/biodiversity/>

¹⁹ United Nations Convention to Combat Desertification (2017) <http://www2.unccd.int/news-events/over-110-countries-join-global-campaign-save-productive-land>

²⁰ EcoWatch (2017) World's soils have lost 133bn tonnes of carbon since the dawn of agriculture <https://www.ecowatch.com/soil-carbon-loss-2478725457.html>

²¹ Cordell D, Drangert J and White S (2009) The story of phosphorus: Global food security and food for thought, *Global Environmental Change*, 19, 292-305.

²² United Nations Sustainable Development Goal 2 <http://www.un.org/sustainabledevelopment/hunger/>

THROUGH THE SDG, COUNTRIES HAVE COMMITTED TO END WORLD HUNGER, ENSURE SUSTAINABLE FOOD PRODUCTION AND COMBAT DESERTIFICATION.

Mitigation

Prevention of food waste has the effect of reducing the pressure on land for higher yields. This in turn gives agricultural land a chance to replenish, reducing its degradation.

Collecting food waste, digesting it and applying the digestate or compost to agricultural land can have multiple benefits:

- It slows down degradation of land by returning organic carbon to soil, increasing yields and reducing the need for inorganic fertilisers to grow crops and obtain higher yields.
- Returning the food waste to agricultural land in the form of digestate and compost prevents loss of nutrients (nitrogen, phosphorus and potassium) to landfills, keeping them in circulation for reuse. This is particularly important for phosphorus, the remaining reserves of which are geographically concentrated and in continual decline.
- Nutrient recycling also prevents run-off nutrients to surface water bodies, which causes eutrophication and growth of algal blooms, which in turn impact aquatic life and the livelihood of people who depend on it.

1.3.4. Sanitation

Background to impact

Globally, about 50% of waste is sent to landfills while 13 to 33% of waste is still being openly dumped in lower and middle-income countries ²³. The food and other organic waste in the landfills and dump sites can lead to parasitic and gastrointestinal diseases in the populations living and working near the site, including women and children ²⁴. Organic waste in dumpsites attracts vermin, flies, birds and other carriers of communicable diseases and those that prey on them, further increasing the health risk via transfer to the food chain ²⁵. Grazing animals whose meat and milk are consumed by humans can be found in open dumps across the globe.

International Commitments

As a part of SDG 3, UN Member States have committed to substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.

Mitigation

Source segregated collection and treatment of food waste prevents it from being available to disease spreading rodents, mitigating the spread of diseases. Anaerobically digesting the food waste also reduces the pathogens in the waste, further preventing spread of diseases and odours, and promoting sanitation and hygiene.

²³ The World Bank (2012) What a waste – A Global review of solid waste management https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf

²⁴ UNEP ISWA (2015) Global Waste Management Outlook Waste <http://www.iswa.org/nc/home/news/news-detail/article/press-release-global-waste-management-outlook-gwmo/109/>

²⁵ ISWA (2015) The Tragic Case of Dumpsites https://www.iswa.org/fileadmin/galleries/Task_Forces/THE_TRAGIC_CASE_OF_DUMPSITES.pdf

1.3.5. Ecological impacts

Background to impact

Increased food production to support the growing global population has resulted in widespread ecological damage from:

- **Change of land use from forests, prairies, peat, marshes, etc., to agriculture;**
- **Loss of biodiversity of species, including mammals, birds, fish, and amphibians; and**
- **Over exploitation of marine life.**

The impacts of this damage from food production at the global scale have been felt in the form of loss of biodiversity, soil quality, marine population, and many other such indicators.

International Commitments

UN SDG 15 aims to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss. It aims to integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts by 2020. In addition, SDG 14 aims to prevent and significantly reduce marine pollution of all kinds, in particular from land based activities, including marine debris and nutrient pollution by 2025.

Mitigation

Circumstantial evidence from areas where food waste is separately collected suggests that collection allows for the easier measurement of such waste and enables the development of more effective, targeted policies and prevention measures.

Ecological impacts of food waste can be mitigated in the following ways:

- Use of biogas as a domestic fuel in households dependent on solid fuels such as firewood, charcoal, dung cakes, etc., reduces the pressure on local woods and forests and other natural resources.
- Proper collection and management of food waste prevents free flowing leachate formation from untreated food waste openly dumped. The liquid and solid by products of composting and anaerobic digestion are applied to farmland as organic fertiliser preventing nutrient pollution: the contamination of ground water and surface water bodies, their eutrophication and formation of algal bloom.

1.3.6. Economic impacts

The total annual economic, environmental and social costs of food waste to the global economy are in the order of USD 2.6 trillion ²⁶, the figures attributed to each of these aspects are shown in the table below.

TABLE 1 : GLOBAL COSTS OF FOOD WASTE

ASPECT	COST (US DOLLARS)
Economic	1 trillion
Environmental	700 billion
Social	900 billion
Total	2.6 trillion

Source: FAO (2014) Food wastage footprint (2014)

Further research is needed to understand how these macro estimates can be assessed at the local level of individual cities. For example, food waste which is not separately collected and disposed of in landfill, generates a cost to the city relative to transport and gate-fees, not including any environmental or social costs. This may vary from USD 150 per tonne in Europe to near zero in emerging economies where landfill or open dumping is not charged for.

Cities may account for the cost of GHG they emit. GHG accounting for untreated food waste sent to landfills, the impacts on health of the local population living near those sites, the cost of pollution to water bodies and soil, are possible to quantify with detailed analysis, but are very location specific - an analysis in emerging economies with poor quality landfill management practices will be completely different to cities where, for example, landfill gas is extracted from sites.

The separate collection and treatment of food waste from urban food cycles has a cost and, as we shall see in Chapters 3, 4 and 5, this represents a significant barrier to implementation of such practices. Only by correctly analysing the true cost of uncontrolled disposal is it possible to put the cost of separate collection and treatment into context and measure holistically. The environmental and economic costs of untreated food waste may be analysis cities would wish to undertake before evaluating the costs of collection and treatment, in order to have a comparison. Finally, it is necessary to understand the income generated from the treatment of food waste in urban contexts through the sale of compost, organic soil amendment or biogas to produce electricity, heat, transport fuel and soil nutrients.

²⁶FAO (2014) Food wastage footprint – Full-cost accounting <http://www.fao.org/3/a-i3991e.pdf>

1.4.Sources of food waste

In order to prevent food waste, understanding where, when and why it is being generated is absolutely essential. In this section, we briefly analyse the primary sources of avoidable food waste.

Food is lost and wasted at various stages of its life cycle: production, processing, distribution, retail and consumption. While in developing countries food loss takes place primarily in the production, processing and distribution stages, due to lack of infrastructure, food waste in developed countries primarily occurs in the retail and consumption stages due to consumption patterns and expectations. The average per capita food waste by consumers in Europe, North America and Oceania is 95-115 kg per year while that in Sub-Saharan Africa and South and South-Eastern Asia is only 6-11 kg per year. An extensive study commissioned by the FAO in 2011 can be seen in these graphics in abbreviated form.

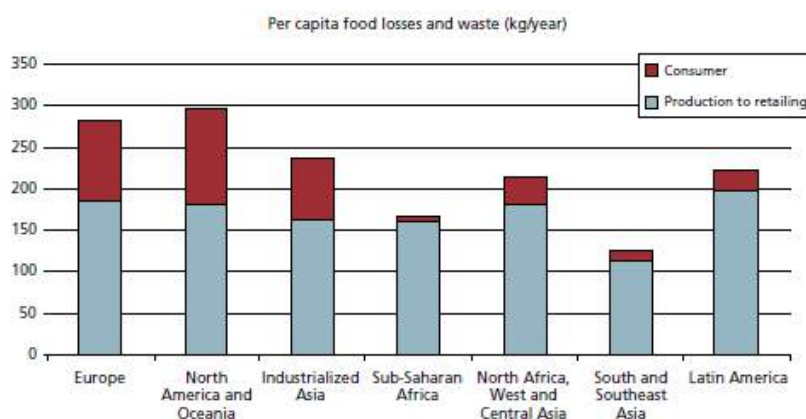
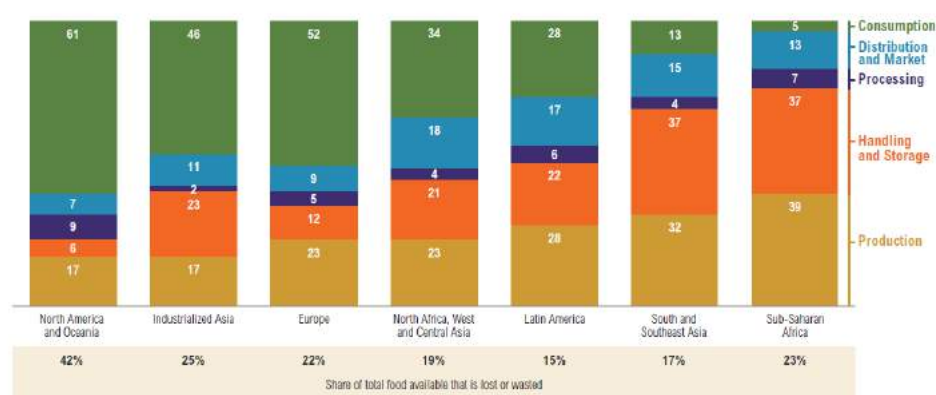


Figure 1: Food Loss in different regions

1.4.1. Developing countries

In developing countries, the proportion of food waste is much smaller than food loss. Food loss here primarily takes place in the agricultural production, post-harvest handling and storage and processing stages, for example, due to premature harvesting, poor storage facilities and lack of infrastructure, lack of processing

facilities, inadequate market systems. Food waste, which is the focus of this report, in developing countries is composed primarily of the inedible parts of food, such as peels, shells, pulp, etc. These may be what is left over after consumption by people or a by-product or waste after processing by the food and drink industry.

1.4.2. Industrialised countries

In industrialised countries, there are increased wastes and losses in the distribution and consumption stages. On average, in the EU, around 180 kg of food is wasted per person per year. Food that may still be suitable for human consumption is discarded for various reasons.

The main drivers and sources of waste are shown below ^{27,28,29}:

Manufacturing:

- Over-production resulting from pressure to meet contractual requirements,
- Appearance quality standard for produce,
- Damaged products,
- Cheap disposal alternatives,
- Inedible parts of produce.

Wholesale and retail:

- Temperature changes leading to spoilage,
- Aesthetic standards expected by the consumers and retailers,
- Packaging defects making produce not fit for sale,
- Over supply due to consumer choices,
- Overstocking due to poor planning and excess surplus.

Food services:

- Lack of flexibility in portion sizes,
- Insufficient planning in forecasting and ordering ingredients,
- Consumer attitudes towards taking leftovers home,
- Refused food due not meeting customer preferences.

Households:

- Buying too much due to poor planning,
- Bad storage resulting from lack of awareness,
- Confusion over freshness and safety labels,
- Discarding edible parts of produce like bread crusts or apple peels,
- Discarding leftovers,
- Large portion sizes.

²⁷ FAO (2011) Global food losses and food waste – Extent, causes and prevention <http://www.fao.org/docrep/014/mb060e/mb060e00.pdf>

²⁸ European Environment Agency (2016) What are the sources of food waste in Europe <https://www.eea.europa.eu/media/infographics/wasting-food-1/view>

²⁹ European Commission (2011) Preparatory Study on Food Waste Across EU 27 http://ec.europa.eu/environment/eussd/pdf/bio_foodwaste_report.pdf

SDG 12.3 AIMS TO CUT THE GLOBAL FOOD WASTE IN HALF AT THE RETAIL AND CONSUMER LEVELS BY 2030.

The primary focus of this report is the prevention, collection and treatment of this food waste within the context of cities.

Across the globe, food waste campaigners have brought the need to prevent food waste and treat unavoidable food waste correctly to the attention of the public and thus to policy makers.

As a result, there are a number of relevant initiatives underway on multiple fronts:

- With the recent surge in decentralised renewable energy production in developing countries, significant research and innovations are being targeted towards better infrastructure to prevent food loss.
- *Not-for-profit* organizations like ‘FeedBack’ are lobbying for transparency in the food supply chain ³⁰.
- Software applications like ‘Too Good To Go’ are targeted towards redistribution of cooked meals ³¹.
- There are a growing number of Food Banks now functioning in a number of countries and cities to redirect surplus food to those who need it most via community groups and not for profit organisations such as the Global Food Banking Network ³² and the Robin Hood Army ³³.
- The Consumer Goods Forum has called upon all retailers and food producers to act on simplifying date labels to reduce food waste by 2020.
- Cities have initiated separate collection of food waste, mainly in the more developed countries. Milan, Copenhagen, Paris, New York, San Francisco, London, Stockholm, Oslo, Auckland, Minneapolis, Cajica, and many others, are examples of where separate food waste collections are successfully implemented.
- France and Italy have introduced legislation that obliges retailers to donate edible food that has reached its sell-by date to charities that then distribute the food to those in need.
- Anaerobic digestion of separately collected food waste is increasing in the developed economies. More countries are looking to capture the energy and environmental advantages of the technology.

³⁰ FeedBack <https://feedbackglobal.org/> Accessed on 02/01/2018

³¹ Too Good To Go <http://toogoodtogo.co.uk/> Accessed on 02/01/2018

³² The Global Food Banking Network <https://www.foodbanking.org/> Accessed on 02/01/2018

³³ The Robin Hood Army <http://robinhoodarmy.com/> Accessed on 02/01/2018

While these trends are encouraging, there remains much to be done. Chapter 2 will elaborate upon the food waste prevention strategies, Chapter 3 on food waste collection while chapters 4, 5 and 6 will focus on the processes available for food waste treatment.

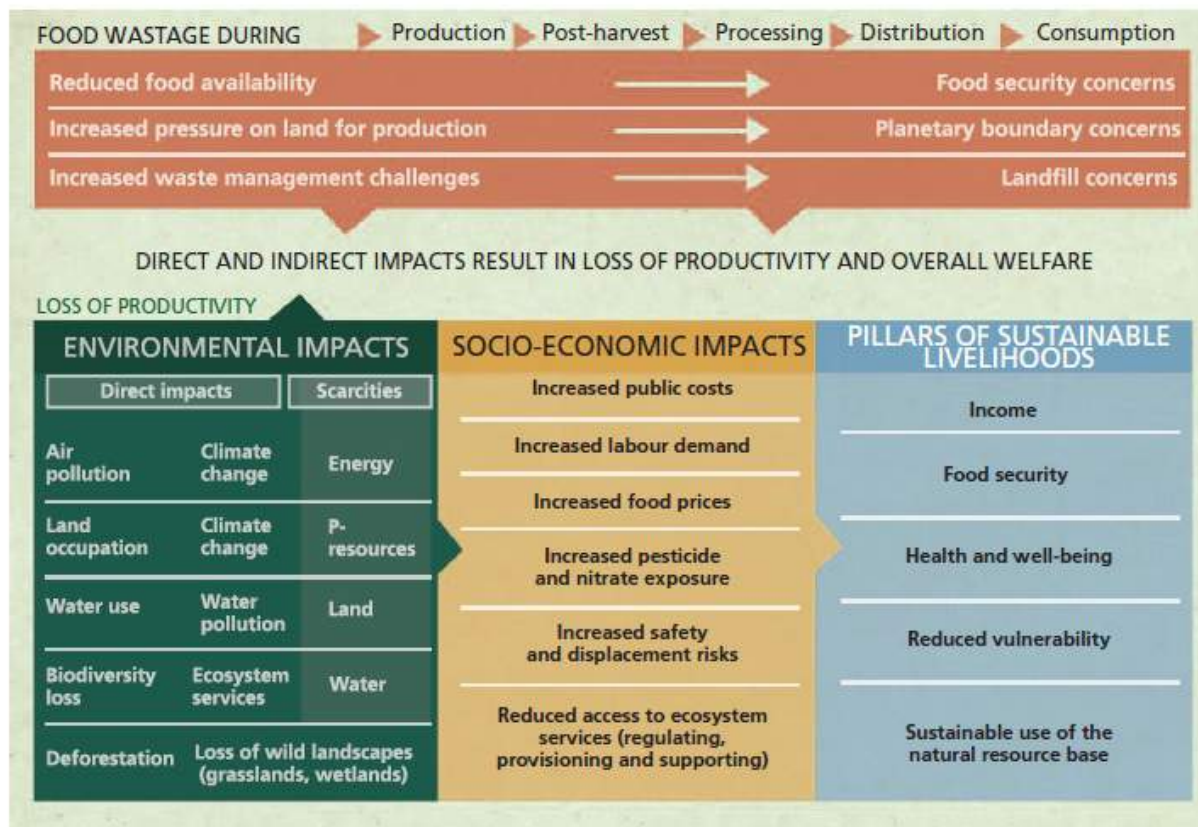


Figure 2: Full landscape of impacts of food waste

2. FOOD WASTE PREVENTION

2.1. Introduction

This chapter explores some of the ways in which cities and governments can facilitate a reduction in the generation of food waste in urban areas. The focus, both of this chapter and the report, is food that is wasted in manufacturing, the wholesale and retail sector, food services and households as a result of various causes, including lack of information, planning, coordination, awareness and not having accounted for the impacts of food waste.

The UN SDG 12 - “Ensuring sustainable consumption and production patterns” - includes a specific food waste reduction target: “by 2030, to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses”¹.

The scale and impact of food waste calls for immediate action from governments, businesses and individuals. The first step in this direction is the prevention of food waste.

This chapter explores:

- The steps in food waste management;
- How governments can support the prevention of food waste generation by raising awareness amongst citizens and industries within its jurisdiction;
- How businesses can reduce the food waste generated and improve their bottom lines by implementing available technology and best practices;
- How governments and businesses can engage with and support community organisations;
- How governments can employ regulatory measures to prevent food waste; and
- Examples of best practices and initiatives in food waste prevention from all around the world.

SDG 12: TO REDUCE GLOBAL FOOD WASTE AT THE RETAIL AND CONSUMER LEVELS IN HALF BY 2030

¹ United Nations Sustainable Development Goals <http://www.un.org/sustainabledevelopment/sustainable-consumption-production/>

2.2. Food and drink material hierarchy

The concept of a waste hierarchy, first proposed into legislation by the Netherlands MP Ad Lansink in 1979 and adopted into the *European Waste Framework Directive* in 2008, is often a reference point for nations in forming their own waste legislation. The hierarchy sets out the treatment and disposal preferences for waste, with the pinnacle being prevention. In the UK, for example, Government guidelines enshrine in law an

obligation to apply the hierarchy to those who produce and deal with waste ².

The diagram of the hierarchy shown below was produced by the United Nations Environment Programme (UNEP) and the FAO and shows an inverted pyramid with prevention of food and drink waste as the preferred action ³.

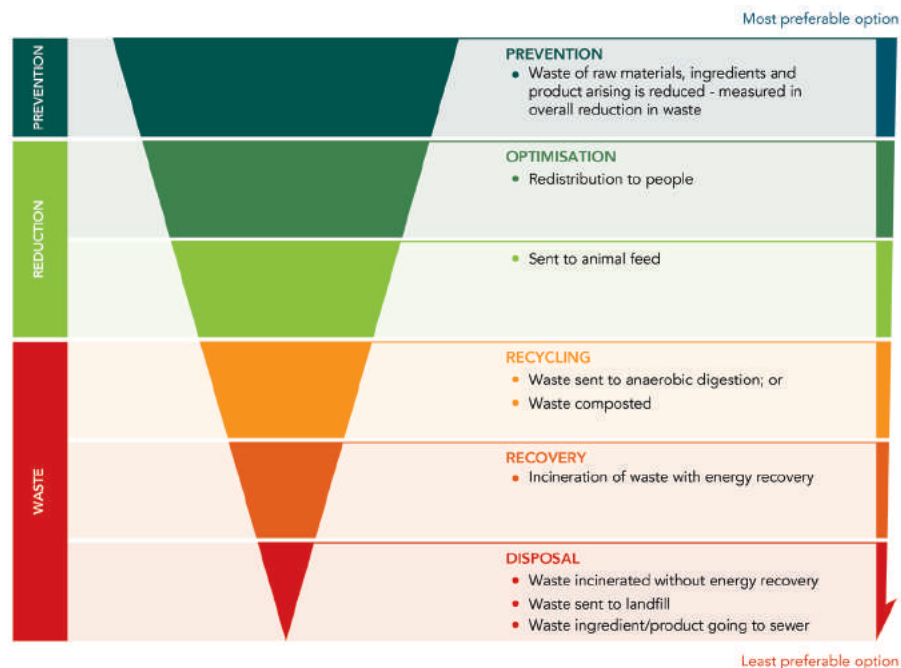


Figure 3: Food and Drink Material Hierarchy

The food and drink material hierarchy sets out guidance on the preferred methods of dealing with food waste so as to minimise its impact on the environment and the society. On the top of the hierarchy is prevention of waste. While every effort should be made to prevent the generation of food waste, any that is still generated should be redistributed to people if possible, if not then to animals. Once it has been deemed that the food cannot be consumed, then it should be treated through composting or anaerobic digestion (AD), as energy and nutrients can be recovered and available for reuse (see Chapter 4 and 5 for further information). Incineration with energy recovery is the least preferred recovery method for food waste. Methods of disposal by which all nutrients and energy is lost, including incineration without energy recovery, landfilling or disposal in sewers, are least preferred.

² Department for Environment Food and Rural Affairs (2011). Guidance on applying the Waste Hierarchy https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69403/pb13530-waste-hierarchy-guidance.pdf

³ UNEP (2014) Prevention and reduction of food and drink waste in businesses and households - Guidance for governments, local authorities, businesses and other organisations, Version 1.0. http://www.fao.org/fileadmin/user_upload/save-food/PDF/Guidance-content.pdf

Prevention

- **FOOD WASTE PREVENTION:** Prevention of food waste sits on the top of the material hierarchy. Any food or drink material wasted is a loss of the resources that have gone into producing it (nutrients, soil, energy, water, biodiversity, labour), a burden on the solid waste management system used to dispose of it or a burden on the environment, if it is not managed suitably. Hence, every effort should be made to prevent waste generation by optimising resource utilisation.

Optimisation

- **REDISTRIBUTION TO PEOPLE:** If there is food that has been produced but cannot be utilised or sold by the producer, then it should be redistributed to those who can use it. This step is possible for food and drink materials that are edible and still safe for human consumption and improves resource utilisation. There is some energy spent on transport and redistribution, but this is a small investment for a larger scale benefit from the prevention of wastage.
- **SENT TO ANIMAL FEED:** This step is applicable for the part of food waste that is inedible for humans, such as juice pulp, spent brewer's grains and whey permeate, but edible by livestock. The key to redistribution to livestock is food safety and animal health. Different countries have taken different views on this, for example recycled food waste in Japan is sold as a premium product, "eco-feed", for livestock consumption; there is a certification scheme in place to ensure safety standards are maintained and there are ambitious targets for its uptake ⁴. In contrast, in the USA feeding food waste to animals is heavily regulated under federal law, with some states going further and banning the feeding of vegetable waste to pigs ⁵. The EU also bans reusing food waste for animal feed, enshrined in the *Animal By-Products Regulations*, which first entered into force in 2002 (Reg. 1774/2002).

⁴ Sugiura K, Yamatani S, Watahara M and Onodera T (2009) Ecofeed, animal feed produced from recycled food waste, *Veterinaria Italiana*, 45 (3), 397-404 http://www.izs.it/vet_italiana/2009/45_3/397.pdf

⁵ Harvard Food Law and Policy Clinic and the Food recovery Project University of Arkansas, School of Law (2016) Leftovers for livestock: A legal guide for using food scraps as animal feed https://www.chlpi.org/wp-content/uploads/2013/12/Leftovers-for-Livestock_A-Legal-Guide_August-2016.pdf

Recycling

- **ANAEROBIC DIGESTION:** anaerobic digestion (AD) is a process in which food waste breaks down in a series of biological reactions, resulting in the release of biogas. Biogas is rich in methane and can be used in energy production, while the left-over organic material is rich in nutrients and can be used as a soil conditioner for further production of food and further refined by composting with garden waste. AD constitutes energy and nutrient recycling, contributes towards mitigating climate change by renewable energy generation and prevention of emissions gases and odours from landfills. The full benefits of AD are discussed in detail later in this report.
- **COMPOSTING:** Composting of food waste results in recovery of nutrients that have gone into its production. Often, the organic material left-over from anaerobic digestion is composted and then applied to land. Composting can provide a more easily managed soil improver.

Recovery

- **INCINERATION WITH ENERGY RECOVERY:** Incineration of food waste is suboptimal from both the nutrient and energy point of view. The nutrients in food waste are lost to the ashes. Some energy is recovered but due to the high water content of food waste, the proportion of recovery is quite low, which is why it is difficult to consider it a form of recycling.

Disposal

- **LANDFILLS, INCINERATION WITHOUT ENERGY RECOVERY, DISPOSAL TO SEWER:** These are the least favoured options as these forms of disposal results in complete loss of energy and nutrients and have a detrimental effect on the climate, water bodies and sanitation and hygiene, if not managed properly. There are good practices within these such as landfill gas capture, energy recovery through municipal waste water treatment plants and maintaining hygiene via incineration, however these measures are the last resort before the food waste is categorised as unmanaged.

The report reflects the structure of this hierarchy with this chapter, Chapter 2, exploring food waste prevention and redistribution to people. Chapter 3 looks at collection methods and best practices from around the world. Chapter 4 discusses the various options available for recycling and recovery of food waste, including AD, composting and incineration. The report then delves deeper into AD, with Chapter 5 as an overview of the technology. Chapter 6 looks at the products of AD and how they can be used, while; Chapter 7 looks at the barriers to implementation of AD and gives policy recommendations to enable adoption.

2.3. Quantification and characterisation of food waste

The first step in the prevention of food waste is to quantify it. Quantification not only gives an insight into the sources of food waste which can be used to implement targeted preventive measures but also provides a baseline to measure the effectiveness of any campaign.

Among examples of instruments to measure food waste is *The Food Waste and Loss Protocol*, which is a multi-stakeholder partnership that has developed the global *Food Loss and Waste Accounting and Reporting Standard* (FLW Standard). This gives a framework for quantification of food and associated inedible parts removed from the food supply chain ⁶. The framework may be used by countries, cities, companies and others to develop food waste and loss inventories and management.

The FLW standard provides guidance on how to define food loss and waste for the context, system boundaries, units of measurement, types of data sources and, quantification methods as well as evaluation of trade-offs between accuracy, completeness, relevance and cost, evaluating accuracy of results and their reporting.

Countries, cities, sectors, industries, businesses and households may develop their own standards and methods that are customised to their context. Some of these could be direct measurements, mass energy balances, statistical analysis, questionnaires, food waste diaries, interviews or a combination of the above ⁷.

CITIES AND GOVERNMENTS MAY START WITH ASKING THESE VERY SIMPLE QUESTIONS:

- ✓ What do we know about household waste in our jurisdiction?
- ✓ What major industries are producing edible and inedible food waste in our jurisdiction?
- ✓ How are commercial and industrial establishments in our jurisdiction disposing of their food waste?
- ✓ What is the volume of food waste being generated in our jurisdiction? What proportion of this food waste is avoidable?
- ✓ What does it cost our government/authority to dispose of this waste?
- ✓ How much can we as policy-makers invest in waste prevention in order to ultimately avoid expenditure in disposal and related environmental and health costs?
- ✓ Are there any current food waste prevention programmes or policies in place in our jurisdiction? If yes, how can we make them stronger and more effective?
- ✓ Is our government aware of the global state-of-the-art practices and technologies available in this field? How can we modify and adopt those for our population and circumstances?

⁶ Food Loss + Waste Protocol (2016) Food Loss and Waste Accounting and Reporting Standard http://flwprotocol.org/wp-content/uploads/2017/05/FLW_Standard_final_2016.pdf

⁷ EU Fusions (2014) Report on review of (food) waste reporting methodology and practice

Having quantified the sources and volumes of food waste being generated in the jurisdiction, there are many regulatory and awareness initiatives that can be undertaken to prevent it.

2.4. Raising awareness and communication policies

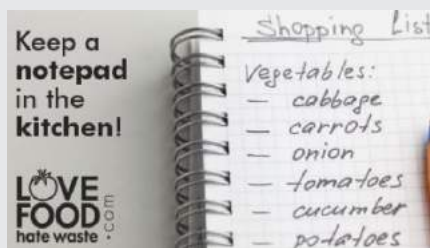
Cultural and geographical contexts require tailored communication instruments, which will change over time and respond to changes in consumption patterns and social behaviour. For example, the growth of pre-prepared, ready-to-eat food delivered to households, often managed through web apps, has led to a dramatic change in the ways people produce waste. The growth of households with one inhabitant in inner cities has accelerated this trend. Packaging waste increases whilst food waste falls as people cook less at home. Indeed, in advanced economies, the idea of building new dwellings without kitchens has been proposed ⁸.

Changes in how people live clearly impacts on the waste they produce and therefore the prevention and management techniques that will be effective or needed. Once a jurisdiction has identified food waste as being an issue which requires attention, has monitored food waste sources and volumes, has explored collection and treatment possibilities, and has decided upon an

implementation strategy, raising awareness among its stakeholders (e.g. public, enterprises) is required. Educational campaigns may involve web-based instruments, the delivery of printed materials, public meetings with citizens, information seminars with local businesses and door-to-door interviews with citizens, as well as the requirement of reporting and constant monitoring. Indeed, by requiring reporting from businesses, there will be greater awareness of the amount and cost of the food waste produced and therefore they will be more willing and incentivised to respond to the challenge of prevention. Such is especially true for catering businesses, retailers and markets selling food. Wasted food is usually wasted money for these businesses, a waste they are often not fully aware of. One example is the UK food chain Pizza Hut which has a zero landfill policy for food waste and has invested in monitoring and reducing its food waste ⁹.

Below are some examples of communication and educational actions.

- **HOUSEHOLDS** - Educational campaigns, such as *Love Food Hate Waste* ¹⁰ in the UK, *Stop Wasting Food Movement* ¹¹ in Denmark, and *Think.Eat.Save* ¹² a global partnership between UNEP, FAO and Messe Düsseldorf in support of the UN Secretary-General's Zero Hunger Challenge, are aimed at raising awareness about the problem of food waste. These campaigns offer practical advice and solutions to the public on how to reduce food waste through a variety of communication media such as guidelines, recipes, engaging with the community via events, radio adverts, articles on the web and newspapers, dedicated websites, etc. The UK *Love Food Hate Waste* campaign saw a reduction in avoidable food waste of 14% in the first 6 months of its launch, saving money for consumers on the cost of buying food, local authorities on disposal of food waste as well as being environmentally beneficial ¹³. Similar campaigns have been undertaken in France - *Antigaspi* ¹⁴, Singapore – *Save Food Cut Waste* ¹⁵, and many others all around the world.
- **SCHOOLS** – Education and awareness are central to driving change in behaviour towards food waste. Educating children about food waste and its impacts can start in schools as a part of the science/environment/society curriculum. School lunches are a wonderful opportunity for schools to reinforce what the children learn in the curriculum.
- **EDUCATION OF WOMEN** – In cultures where women still play a central role in households and are for the most part responsible for cooking and planning the meals, it is important to specifically educate them in food and food waste management.
- **ADVOCACY CAMPAIGNS** – Campaigns such as 'Feeding the 5000' run by *FeedBack* ¹⁶ raise public awareness on the issue of food waste, while also advocating for better regulations and business practices to reduce generation of food waste.



⁸ Tara Slade (2016). Could You Live In A Home Without A Kitchen? <http://popupcity.net/could-you-live-in-a-home-without-a-kitchen/>

⁹ Pizza Hut (2017) Corporate Social Responsibility <https://www.pizzahut.co.uk/restaurants/about/csr/>

¹⁰ Love Food Hate Waste <http://www.wrap.org.uk/content/love-food-hate-waste>

¹¹ Stop Wasting Food <http://stopwastingfoodmovement.org/>

¹² Think.Eat.Save Reduce your footprint <http://thinkeatsave.org/>

¹³ The impact of Love Food Hate Waste http://www.wrap.org.uk/sites/files/wrap/West%20London%20LFHW%20Impact%20case%20study_0.pdf

¹⁴ Ministry of Agriculture and Food <http://agriculture.gouv.fr/antigaspi>

¹⁵ Save Food Cut Waste <http://www.savefoodcutwaste.com/>

¹⁶ Feeding the 5000 <https://feedbackglobal.org/campaigns/feeding-the-5000/>

2.5.Engagement and reporting

The management of food wastes is easier if the amounts and quality of food waste produced are regularly monitored and accounted for. Engagement to ensure the dissemination of best practices and experiences helps spread the understanding of how to prevent waste occurring.

- **LARGE FOOD WASTE GENERATORS** - Businesses that generate large quantities of food waste, such as food processing facilities, wholesale, retailers, food services, etc., may be required to report the origin, volume and disposal methods of such waste. This informs policy-makers about the sources and volume of food waste, but also enables the business to calculate the cost of their waste, thus encouraging its reduction. Such legislation has been implemented in Japan resulting in a 17% decrease in generation of food waste from the food industry over a period of 5 years (2008-2012) ¹⁷.



Figure 4: Edible food waste per capita (2010-2015)

- **FOOD SUPPLY CHAIN** – Voluntary or mandatory reporting requirements on the food discarded by producers and warehouses, unsold food items in supermarkets, surveys from households can raise awareness amongst these sectors on their food waste. Such a program, ForMat was implemented in Norway for 6 years and resulted in a 12% decrease in edible food waste measured as kg per head of population ¹⁸.

- **ENGAGEMENT** – Engaging with trade associations, industry publications, conferences and tradeshow to disseminate sectoral knowledge, best practices and performance standards can help reduce generation of food waste by developing strategies that work for that specific sector, which may be food services like restaurants, food and drink industries like dairies and distilleries, institutions like schools, hospitals or any other sector generating food waste.
- **RECOGNITION AND REWARD** – Recognising the efforts of institutions and industries towards food waste prevention motivates and challenges them to reduce their food waste and build better public relations by recognising high achievers. Such a challenge and recognition programme ‘*The Food Recovery Challenge*’ is run annually by the US Environmental Protection Agency ¹⁹.

¹⁷ Organisation for Economic Cooperation and Development (2014) Preventing food waste: Case studies of Japan and the United Kingdom [http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/CA/APM/WP\(2014\)25/FINAL&docLanguage=En](http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/CA/APM/WP(2014)25/FINAL&docLanguage=En)

¹⁸ Ostfoldforskning (2016) Food Waste in Norway 2010 – 2015 https://ec.europa.eu/food/sites/food/files/safety/docs/fw_1lib_format-rapport-2016-eng.pdf

¹⁹ Food Recovery Challenge <https://www.epa.gov/sustainable-management-food/food-recovery-challenge-frc>

2.6. Organisation-level initiatives

For commercial establishments in the food industry, food waste can be prevented by implementing a range of voluntary or regulatory initiatives and using available technology. Some examples of successful initiatives are listed below.

- **FOOD RETAILER COMMITMENT** – Partnerships between supermarkets and food banks and other community organisations, such as that operated by Tesco via a UK based food redistribution charity *FareShare FoodCloud*²⁰, can not only prevent food waste but also provide nourishment to the vulnerable parts of the society. *FareShare FoodCloud* received and redistributed 13,552 tonnes of food from the food industry and stores supporting 6,723 charities and community groups, providing 28.6 million meals in 2016/17 in the UK²¹.



- **ENDING QUANTITY-BASED DISCOUNTS** – Quantity-based discounts such as ‘buy one get one free’ encourage people to buy food in quantities larger than they immediately need, leading to food waste. In Denmark, supermarket chain *REMA 1000* has discontinued such quantity-based discounts, and has replaced them with offering the same price discount on each unit²².
- **COMMERCIAL KITCHEN SOLUTIONS** – Software solutions designed specifically to manage food waste in commercial kitchens may be integrated into the operations of the enterprise to reduce wastage and save money. The implementation of *Winnow Solutions* at Sofitel Bangkok Sukhumvit has reported a reduction of food waste by 50% and a saving of \$60,000 per year²³.
- **ENCOURAGE DOGGY BAGS** – While the concept of taking left-over food home from a restaurant or house party is common in countries like the USA, in others like Italy and France, it is still not widely culturally acceptable or adopted. Since the food services industry accounts for 14% of the food waste in Europe²⁴, changes in attitude towards packing left-overs can make a big contribution towards the prevention of food waste.

²⁰ Tesco Community Food Connection <https://www.tesco.com/community-food-connection/>

²¹ FareShare (2017) FareShare report and financial statements <http://fareshare.org.uk/wp-content/uploads/2017/10/FareShare-annual-report-and-financial-statements-2016-2017.pdf>

²² EU Fusions (2016) Denmark – Country report on national food waste policy <https://www.eu-fusions.org/phocadownload/country-report/DENMARK%2023.02.16.pdf>

²³ Winnow Solutions website <http://info.winnowsolutions.com/sofitelfoodwaste-2>

²⁴ European Environment Agency (2016) What are the sources of food waste in Europe <https://www.eea.europa.eu/media/infographics/wasting-food-1/view>

2.7. Regulatory initiatives

The EU (at the time of writing early in 2018) is in the process of adopting changes to the *Waste Framework Directive* in a series of policy revisions known as the *Circular Economy Package*. Included in the Directive are actions required of member nations to implement waste prevention policies and to report back to the European Commission on their efficacy. Further, an obligation to separately collect food waste by 2023 and an aspirational target to reduce food waste within the EU by 2030 by 50%, have been adopted.

Such regulatory changes indicate decisive action from governments to tackle food waste. Regulatory requirements can work either by enabling action or incentivising it or by streamlining current processes. Other regulatory options have been listed below.

- **GOOD SAMARITAN LAW** – In order to facilitate redistribution of surplus food, and to address the legal obstacle, governments can pass “Good Samaritan” laws which limit the liability of donors in case redistributed food unexpectedly turns out to be somehow harmful to the consumer unless there has been gross negligence ²⁵. The law enables donors and foodbanks to serve more people and reduce more food waste.
- **TAX CREDITS AND TAX DEDUCTIONS FOR FOOD REDISTRIBUTION** – Multiple European countries including France, Germany, Greece, Italy and Poland give tax and fiscal incentives for donation of food as a goodwill gesture and to encourage donations. For example, in Italy, value added tax (VAT) is not imposed on food that is donated. Similarly, in France and in Spain, a proportion (35-50%) of the value of donated food can be deducted from the taxable revenue of the donor enterprise ²⁶.
- **FOOD DATE LABELLING** – While some date labels on food bought from grocery stores refer to food safety (for example, ‘use by’) others are targeted towards food quality (for example, ‘best if used by’ and ‘display until’). The meanings of these labels are often unclear to the consumers and leads to wastage of food that is still edible and safe to consume. There has been a call for action by the Consumer Goods Forum to standardise food labels worldwide by 2020 ²⁷. This includes using only one date label on a product and educating the consumers on its meaning via in-store displays, web service and public service announcements. Should this happen, the standardisation of labels is likely to have a widespread impact of reduction of food waste generated by households, supermarkets, and any other establishment selling packaged food.

²⁵ Bill Emerson Good Samaritan Food Donation Act <https://www.law.cornell.edu/uscode/text/42/1791>

²⁶ European Economic and Social Committee (2014) Comparative study on EU Member States’ legislation and practices on food donation http://www.eesc.europa.eu/resources/docs/executive-summary_comparative-study-on-eu-member-states-legislation-and-practices-on-food-donation.pdf

²⁷ The Consumer Goods Forum (2017) Call to action to standardise food date labels worldwide by 2020 <https://champs123blog.files.wordpress.com/2017/09/champions-123-call-to-action-to-standardize-food-date-labels-worldwide-by-2020.pdf>

■ SUPERMARKET FOOD WASTE RECOVERY

REQUIREMENT – Regulatory requirements, such as banning the destruction of edible food by addition of water or bleach unless it poses a real food safety risk, may be enacted to encourage redistribution and energy/nutrient recovery from the food ²⁸.

■ BANNING OF ORGANIC WASTE TO LANDFILLS –

the EU Landfill Directive obliges the member states to reduce the amount of biodegradable waste going to landfill to 35% of 1995 levels by 2020 ²⁹.

Some EU member states have gone further and banned any food waste to landfill (such as Germany, Austria and Sweden). Along similar lines, commercial establishments generating organic waste in excess of a predetermined threshold may be required to recycle it, if such a facility exists within a certain distance. This encourages businesses to reduce their food waste in the first instance. Such laws have been enforced in some states in USA, such as Massachusetts and Connecticut, and also in the City of Vancouver, Canada.

■ PAY-AS-YOU-THROW (PAYT) – ‘Pay as you throw’

(PAYT) schemes charge the producers of food waste for the disposal of the waste they generate based on the waste’s weight/volume. Seoul (South Korea) ³⁰ has reported a 10% reduction in food waste generation after implementation of such a collection method. PAYT schemes have a direct impact on the profit or expenditure of the business or household and are an effective tool for food waste prevention, as well as contributing towards the funding of collection/treatment. This tool, however, needs strict monitoring to prevent illegal dumping or fly tipping. This policy mechanism will be explored in detail in Chapter 7.

2.8. Research

Finding new ways of reducing food waste is a topic that must be a priority for every government, business and individual and ongoing research is required. An example of the impact of research is provided by a project undertaken by the Japanese Ministry of Economy, Trade and Industry and the Japan Weather Association – the project utilised weather forecasting information, social media such as Twitter, and other data to reduce food loss and waste in the supply chain, and successfully prevented food waste by cutting food loss inventory of soup for cold noodles by 20% over the year before. The project is being widened to include more food groups ³¹.

**THE EU LANDFILL DIRECTIVE
OBLIGES MEMBER STATES
TO REDUCE BIODEGRADABLE
WASTE GOING TO LANDFILL
TO 35% BY 2020, COMPARED
TO 1995**

²⁸ NRDC (2015) France moves toward a national policy against food waste <https://www.nrdc.org/sites/default/files/france-food-waste-policy-report.pdf>

²⁹ European Commission (2016) Biodegradable waste <http://ec.europa.eu/environment/waste/compost/index.htm>

³⁰ Waste Management World (2017) High Tech Bins Cut Food Waste in Seoul by 10%. <https://waste-management-world.com/a/video-high-tech-bins-cut-food-waste-in-seoul-by>

³¹ Ministry of Economic, Trade and Industry (2017) Successful Achievement of Zero Food Loss by Forecasting Demand Based on Weather Information and Other Data http://www.meti.go.jp/english/press/2017/0605_003.html

2.9. Food waste prepared and treated to be used as animal feed

The food waste hierarchy suggests that the next best option for food waste, if it cannot be prevented and is not suitable for human consumption, is to use it as animal feed. Depending on the proximity of food waste generators to local farms or zoos, it may be viable to recover discarded food as feed for livestock, poultry, or other animals.

Food waste's high nutrient content makes it a good potential option for animal feed. Most analyses reveal food waste to have high protein and fat content, both in excess of 20%. The bulk of research completed with food waste has used wet waste for animal feed; however, recent projects have used various processes (with the food waste being extruded, dehydrated, pelleted, ensiled, etc.) and products in animal feeding experiments. The ability to further process and dewater food waste would allow preservation, storage, and easier use commercially ³².

There are numerous by- or co-products of industries currently fed to animals, examples being brewers and distillers grains, beet pulp,

citrus pulp, soy hulls, and cottonseed, to name a few. These have been fed to animals for many years, are consistent in nutrient content, and are often available regionally, if not nationally.

Disposing of food waste to technologies such as incineration or landfill usually incurs a cost to the food waste producer. However, food surpluses sold for animal feed usually achieve an income. This is an added benefit of sending food waste to animal feed, when allowed.

The issues with animal feeding relate primarily to animal health concerns, moisture content, and nutrient variability. Food waste is relatively inconsistent in quality, is usually high in moisture content, and only available locally. Some food scraps, such as coffee or foods with high salt content, can be harmful to animals, and regulations pertaining to the types of food waste that can be used vary from place to place ³³.

Below are some examples to show how the use of food waste in animal feed is variable between different locations.

Rotterdam actions on Food Waste Prevention

Rotterdam is no exception with respect to the worldwide trends of foodwaste in cities. Roughly 14% of the food entering the city is wasted. That is slightly above the national average of 12%. In fact, recent research about material flows estimated that the city of Rotterdam currently wastes 38,400 tonnes of food annually. The vast majority of this waste comes from households (28,220 tonnes), and to a lesser extent from catering industry (7,520 tonnes) and retail (2,660 tonnes). As such, the foodwaste represents one of the largest residual flows of the city. However, most organic waste is not collected or disposed of separately and therefore ends up in the incinerator as residual waste. A small part is collected as organic waste and is processed to make biogas and compost.

³² Michael L. Westendorf, Iowa State University Press (2000) *Food Waste to Animal Feed* <http://onlinelibrary.wiley.com/doi/10.1002/9780470290217.fmatter/pdf>

³³ U.S. EPA (2014) *Food Waste Management Scoping Study* https://www.epa.gov/sites/production/files/2016-01/documents/msw_task11-2_foodwastemanagementscopingstudy_508_fnl_2.pdf

There are various solutions to close the leakages of the current linear system in the various flows of the agri-food sector in Rotterdam. The proposed measures aimed at reducing food waste can together reduce up to 50% of the current volumes of food waste.

Rotterdam is home to a number of social initiatives and

enterprises focused on preventing foodwaste. Some initiatives like 'voedselbanken' (or food banks) that distribute discarded food from larger supermarkets to Rotterdammers with a low income, or festivals where large amounts of discarded food is prepared and eaten by and for Rotterdammers, are listed below.

TABLE 2 : ROTTERDAM FOOD WASTE AVOIDANCE INITIATIVES

ROTTERDAM BASED INITIATIVES WORKING TO PREVENT FOOD WASTE	ROTTERDAM BASED ENTREPRENEURS & START-UPS WORKING WITH FOODWASTE	FOODWASTE FESTIVALS, PLATFORMS & NETWORKS
<ul style="list-style-type: none"> ■ Isaac en de Schittering : One of many Rotterdam Food Banks ■ BroodNodig: campaigning against bread waste ■ ResQ: app in which restaurants offer leftover dishes at discount. 	<ul style="list-style-type: none"> ■ BEWA : composting & digestion of food waste ■ Eat Art Collective: foodwaste collective ■ Freggies: snacks from foodwaste ■ RotterZwam : grow mushrooms on coffee grounds ■ Coffeebased: make bioplastics from coffee grounds ■ FruitLEather: make leather from fruit waste ■ Ugly Food Rescuers Club: zero waste catering & foodwaste collective ■ GroenCollect – Logistic start up that collects (food)waste with EV's 	<ul style="list-style-type: none"> ■ ERGroeit, Rotterdam ■ Milieucentrum, Rotterdam ■ Zero Waste, Rotterdam ■ Food Cluster, Rotterdam ■ Youth Food Movement ■ Slow Food Movement ■ Blue Food Festival: recurring well visited festival in BlueCity ■ Zero Food Waste, Rotterdam: working on a food waste distribution centre ■ Damn Food Waste 2015: over 3,000 visitors ensured that more than 1,000 kilos of food was saved.

UK

In the UK there are around 2.2 Mt of food or food by-products from food manufacturing used as animal feed ³⁴ and there is regulation and standards in place to ensure food safety and animal health is protected.

Vietnam

The most popular method of reusing food waste in Vietnam is feeding it to livestock, particularly to pigs in smallholder farms in peri-urban areas. Household kitchens, restaurant kitchens, markets, hotels, food shops, and food processing plants produce a huge amount of avoidable uneaten food that contains cellulose, hemicellulose, lignin, protein compounds and nutrients that are beneficial to pigs. Pigs can therefore play an important role in food waste management, as they can eat and digest different food types and are considered food waste collectors ³⁵.

Egypt

The same is true in Egypt where the *Zabaleen* community collects food waste from households to feed pigs. The Zabaleen are Coptic Christians and therefore eat pork, but this is at times a conflictual issue in a mainly Muslim nation ³⁶. This highlights that culture and religious beliefs and practices should be taken into account when considering food waste use in animal feed. The reluctance of farmers to feed these food wastes directly to their pigs for fear of transmission of disease can be overcome by cooking the food waste before feeding it to the animals, producing what is colloquially known as “swill” (cooked food waste fed to pigs) ³⁷. The application of heating and fermentation technologies rids the food waste of disease.

Treating and recycling food waste as animal feed can deliver a triple benefit of increasing pig farmers’ incomes, managing food waste, and also reducing disease and environmental pollution ³⁸.

Swill was banned in the EU in 2002 after the UK foot-and-mouth disease epidemic (which is thought to have been started by the illegal feeding of uncooked food waste to pigs), but it is actively promoted in nations such as Japan, South Korea, Taiwan, and Thailand. As mentioned, heat treatment deactivates viruses such as foot-and-mouth and classical swine fever, and renders food waste safe for animal feed.

³⁴ Parry, A., P. Bleazard and K. Okawa (2015), “Preventing Food Waste: Case Studies of Japan and the United Kingdom”, OECD Food, Agriculture and Fisheries Papers, No. 76, OECD Publishing, Paris <http://www.oecd-ilibrary.org/docserver/download/5js4w29cf0f7-en.pdf?expires=1513935777&id=id&accname=guest&checksum=A97DF7C1E1C177225645278365FD8DE7->

³⁵ CIRAD, INRA (2015). Food Waste recycling into animal feeding in Vietnam. https://umr-selmet.cirad.fr/content/download/4053/29641/version/2/file/NIAS_REPORT_FW2FEED_VN.pdf

³⁶ Layla Eplett (2013) Second Helpings: Recycling Cairo’s Food Waste <https://blogs.scientificamerican.com/guest-blog/second-helpings-recycling-cairos-food-waste/>

³⁷ Erasmus zu Ermgassen (2015). Regulate, rather than prohibit, the use of food waste as feed: learning from East Asian experiences. https://www.feedipedia.org/sites/default/files/public/BH_024_food_waste.pdf

³⁸ CIRAD, INRA (2015). Food Waste recycling into animal feeding in Vietnam. https://umr-selmet.cirad.fr/content/download/4053/29641/version/2/file/NIAS_REPORT_FW2FEED_VN.pdf

Japan and South Korea

As of 2015, Japan and South Korea respectively recycled 35.9% and 42.5% of their food waste as animal feed. In these countries, the industry is tightly regulated: the heat treatment of food waste is carried out by registered “Ecofeed” manufacturers, who are required by food safety law to heat treat food waste containing meats for a minimum of 30 minutes at 70°C or 3 minutes at 80°C. In Japan and South Korea, swill is seen as a strategic resource: it is a cheap, domestic alternative to the more expensive, volatile international market for grain- and soybean-based feeds ³⁹.

While food waste as animal feed has been historically used for pigs, it can, of course, be fed to other species. A number of studies have trialled food waste diets for poultry, fish, insects, and ruminants (cattle, goat and sheep)⁴⁰.

2.10. Conclusion

Governments, businesses and people have a gamut of awareness, reporting and regulatory options to encourage food waste prevention and avoid its harmful effects on the environment, economy and people. The chapter has listed a few select measures that can be implemented to avoid food waste.

Each country and city with its unique population, geography, economics and culture; each business with its unique feedstock, scale, logistics and financial model; and each person/family with their unique circumstances and preference; need to take action to make food waste prevention an integral part of their regulations, strategies, operations and lives.

While all efforts are being made to reduce food waste, the unavoidable fraction of food waste as well as the inedible fractions need to be collected and treated in order to contain their impact on the environment and people. These aspects will be discussed in the following chapters.

³⁹ Erasmus zu Ermgassen (2015). *Regulate, rather than prohibit, the use of food waste as feed: learning from East Asian experiences*. https://www.feedipedia.org/sites/default/files/public/BH_024_food_waste.pdf

⁴⁰ Erasmus zu Ermgassen (2015). *Regulate, rather than prohibit, the use of food waste as feed: learning from East Asian experiences*. https://www.feedipedia.org/sites/default/files/public/BH_024_food_waste.pdf

3. FOOD WASTE COLLECTION

3.1 Introduction

This chapter explores the methods used to bring food waste from households and businesses into treatment plants. We provide a series of examples of collection systems adopted in cities around the world and attempt to show how these have succeeded and where they have encountered difficulties. We also look at the policies that have enabled the implementation of collection systems and the barriers they overcame, including the experience of their citizens.

Separate collection of organic waste is important for the recovery of nutrients and energy. There are, however, differences in the collection schemes of cities: while some cities have separate collection of food waste, others collect a wider range of organic material, such as garden waste, together with food waste. While some cities collect food waste from businesses only, others collect from households as well. While some cities have made food waste collections mandatory, others have used differential waste management taxes to aid the collection. This is also reflected

in the treatment of this material: while some cities treat the collected food waste via wet or dry anaerobic digestion, others compost it. While some cities use the biogas from collected food waste to produce electricity, others convert the biogas to biomethane to be used in waste collection and other vehicles. There are therefore a series of different models that can be studied with reference to the specific circumstances of a city wanting to implement food waste collections.

The collection systems, the frequency, the treatment process, the policies to support them, as well as the use of energy are all based on operational local conditions such as existing infrastructure, climate, demographics, population density, and type of housing, as well as the political landscape, existing regulatory processes, the consensus of the local population, the national commitments, and the available funding.

Following are some examples from cities that have implemented food waste collections.

3.2 Auckland, New Zealand ¹

The city of Auckland is highly urbanised, with food waste accounting for 40% of the waste stream. In 2012, Auckland Council established two goals:

- **Reducing kerbside non-recyclable waste collection by 30% by 2018 from 2012 baseline; and**
- **To achieve zero waste by 2040 by turning its waste into resources.**

In order to achieve these targets, separate kerbside collection of food waste was identified as a key step.

A pilot was rolled out to 2,000 households to get a good estimate of participation rates, volume of collection, contamination levels, resident behaviour, customer satisfaction, barriers, and benefits, and to identify best practices.

Before rolling out the trial, a postcard was sent out informing residents. This was followed by door-to-door visits by waste advisors.

The trial ran for four months in which a 23 litre (L) kerbside bin and a 6L caddy for kitchen, and compostable bags were delivered to the residents along with how-to information booklets, collections calendar and date of first collection.



Example Images: photographs of bins and educational information provided to residents (left) and door-to-door visits (Photographs courtesy of Auckland Council)



Example images: leaflet explaining what can and cannot be placed in the organics bin

¹ The case study is based on information provided by Auckland Council to C40 Cities.

Once the collections began, waste advisors undertook follow-up visits to resolve any issues such as undelivered bins and rubbish taken out on the wrong day. In addition, they conducted audits of the waste and left feedback tags on the bins explaining whether separation had been done correctly or if contamination had been found in the separated food waste (shown in the images below).

Example images:
example feedback tags
for bins



Periodic quantitative and qualitative surveys were also conducted during the trial period and it was found that residents were receptive to separate food waste collection with an approval rating of 93%.

Further trials in different areas and types of housing have been planned, leading to full service roll out to 490,000 citizens by 2021.

Feedstock collected

Only food waste is collected. The food waste collection volume is expected to go up to 50,000 tonnes per annum from 2,500 tonnes per annum in 2018.

Collection process

Food waste is collected on a weekly basis using dedicated vehicles for separate collections. These are side loading, semi-automatic vehicles that involve no interactions with the rear of the truck, a danger spot for the collectors.

Treatment process

The chosen method of treatment by Auckland Council is composting. It is currently a

combination of aerated static pile and Gore-Tex cover system. A new in-vessel composting technology is expected to be in place by 2021.

Available financial information

The Council is in a procurement process but has estimated the cost per household receiving the service at approximately \$67NZD per year by 2021.

Barriers

The main barrier for implementation of separate food waste collection is that Auckland has very low landfill disposal costs (including the waste levy and Emissions Trading Scheme), which are significantly less than food waste processing.

Conclusion

The separate food waste collection programme is a great example of gradually growing the collection infrastructure. The one-to-one interaction of waste advisors with the residents make the collections easy for them, while the residents indirectly gain from participating in a public good service like recycling or collection food waste.

3.3 Cajica, Colombia ^{2,3}

In Cajica, Colombia, Empresa de Servicios Públicos de Cajicá (EPC) and IBICOL have been running a door-to-door source-segregated organic waste collections programme since 2008. The collection programme now serves 25,000 houses and 88,000 inhabitants. This is one of the very few examples of food waste collection in Latin America that have endured over a long time period.

Feedstock collected

About 480 tonnes of organic matter is collected from homes and schools per month.

Collection process

Residents collect organic waste in a plastic bucket with holes at the bottom to drain liquid produced by accumulated waste. The collected liquid can be drained in the household drain. The bucket is pre-applied with Bokashi EM (Effective Microorganisms)⁴, a rice/wheat bran based material which has been fermented with a mix of microbial cultures and then dried. Bokashi EM aids in the composting of the organic matter and reducing odours and is supplied to the residents free of charge. The waste is collected once a week and transported to a composting site.



Example images: photographs illustrating the collection process in Cajica (Courtesy of Cajica municipality)

Treatment process

The composting process takes place at an IBICOL facility. EM compost is made from the kitchen waste by crushing and spraying with Activated EM (AEM). The mixture is set in piles and kept for further fermentation. These piles are turned over according to the temperature (must be more than 60°C and less than 70°C) and after approximately 50 days, the compost is ready to use for growing vegetables. AEM must be applied every time the pile is turned over.

Citizen engagement

The successful implementation of segregated collection and composting can be attributed to the upfront emphasis placed on the education of students and the residents by the local officials. The students, as well as local officials, were involved in training residents on correct segregation, the composting process and the environmental pollution the system was addressing. The following measures were taken during the implementation process:

- **Involvement of educational sector as well as community;**
- **Call for active participation of residents;**
- **Setting up of infrastructure; and**
- **Application of biotechnology (EM technology).**

Some initial resistance was faced from the residents which was overcome by education and involvement.

Conclusion

Cajica is an example of a town in an economically developing country which has successfully implemented source segregated food waste collections for nearly 10 years now. The infrastructure and investment required is minimal. The education and involvement of residents has been identified as a key element. The project has been reported to have been carried out in 24 cities in Colombia. It has reduced illegal dumping, raised public awareness about recycling and encouraged home growing of food.

² Case study based on information provided by Mr Josue Frias Cruz, former Manager of the "Empresa de Servicios Publicos"/ ESP and Ibicol, and responsible of the development and implementation of the program.

³ EMRO EM for Sustainable Society, Cajica City, Colombia <https://emrojapan.com/case/detail/17> (No date, accessed on 20/02/2018)

3.4 Copenhagen, Denmark ⁵

At the time of writing, Copenhagen is in the process of finalising the implementation of separate food waste collection. The city started implementing the collection of food waste from all households in September 2017 and will be fully implemented in spring 2018. It is a mandatory scheme, but villas (single family houses) have the opportunity to cancel their participation. Around 300,000 households are included in the scheme (280,000 in multi-family houses and 20,000 villas). This covers the population of around 600,000 inhabitants.

Private waste collection companies are hired by the municipality through a tender process for the different districts of the city. These companies collect waste from households and businesses. If businesses produce waste in amounts similar to the generation from a household then their waste can be included in municipal collection.

Feedstock collected

The volumes are expected to increase each month since the sorting and collection only started from September 2017. 10,000 tonnes are expected to be collected in 2018 when the collection is fully implemented.

Collected waste includes food waste, raw and cooked, rice, pasta and breakfast products, meat, fish, bones, bread and cakes, fruit and vegetables, gravy and fat, cold cuts, eggs and eggshells, nuts and nutshells, coffee grounds and coffee filters, tea leaves and tea filters, used paper towels, and cut flowers.

Collection process

Private collection companies hired by the municipality through a tender call collect the waste from multi-family houses as well as from villas. The biowaste is collected once per week from multi-family houses. From villas it is collected every second week, but during summer it is collected once per week to avoid smell and insects. Villas can share one bin for biowaste between two households.



BAGS OF BIOPLASTICS



KITCHEN BIN (15L)

Example Images: bags and kitchen bins for collection of biowaste in the City of Copenhagen

⁵ The case study is based on information provided by Dr Line Kai-Sørensen Brogaard, City of Copenhagen

Treatment Process

The biowaste is treated via anaerobic digestion (AD). Larger items, misplaced waste and bags are separated from the waste during pre-treatment. The biowaste is pre-treated to create a bio pulp that can be pumped into a biogas reactor tank. The AD plant treats organic waste from several cities as well as industrial waste from food producing industries. The AD plant also receives waste from the fishing industry, slaughterhouses, breweries as well as manure from mink, cow and chicken farms. The biogas produced, 7,500,000 m³ per year, is used for production of electricity sent to the grid and district heating for the local village of 450 houses. In the future, when a new AD plant is built closer to Copenhagen, the gas will be used for heavy duty goods vehicles. Digestate is used by local farmers as fertiliser for the fields.



Example Images: AD plant provided by City of Copenhagen

Available financial information

Local farmers own the AD plant and therefore they financed the plant when it was built. The collection and treatment of biowaste is funded via the taxes paid for waste management. There were increased costs due to the investment in food waste collection bins and a revised collection programme. Copenhagen believed that their waste management tax would decrease over the coming years, but it has decreased by less than was foreseen. However, inhabitants will still benefit from a decrease in the waste tax in coming years. The cost of the collection and treatment of biowaste is lower than the cost of incineration.

Policies

The initiative to collect and recycle organic waste is part of the 'Resource and Waste Management Plan 2018' for the City of Copenhagen⁶. The recycling target of the City of Copenhagen is 45% by 2018 and introducing source separation of organic waste is an important step to meeting this target. It is not allowed to send biowaste to landfill since this was banned in 1997.

Barriers

The only barriers that have been experienced are operational, such as lack of space in back yards and kitchens in apartments for separate containers for biowaste (a 15L bin).

Citizen engagement

Most inhabitants reacted positively about sorting biowaste, but a few concerns were raised such as:

- **People were concerned about the distance of transportation of the waste. It was calculated and communicated that the CO₂ emission from the transportation equates to only 7% of the total CO₂ benefit from the production and use of the biogas.**
- **People were concerned about which is better; incineration or AD. Regarding CO₂ and the effect on climate change, the impact and savings of CO₂ is similar. However, nutrients can be recycled when sending the biowaste to AD, which is not possible if the waste is incinerated.**

Conclusion

Copenhagen is an example of a recently implemented food waste collection project. It has begun by integrating its food waste treatment into a treatment plant that already existed and was digesting manure and food waste from other cities and industries. The city plans to build a new AD facility that is closer, and utilise biogas as biomethane for heavy duty transportation.

⁶ Resource and Waste Management Plan 2018 http://kk.sites.itera.dk/apps/kk_pub2/index.asp?mode=detalje&id=1184

3.5 Hartberg, Austria ⁷

Hartberg is a countryside town in Austria. Food waste from Styria and Burgenland is collected. Catering and other businesses are served by a private waste management company, *Saubermacher*, as well as other waste collectors who deliver it to the biogas plant which is about 2km away from Hartberg's town centre.

Feedstock collected

On an annual basis, about 5,450 tonnes of food waste are collected from catering services, 530 tonnes from beverage production industry, as well variable waste from fruit and vegetable waste, waste from butchery and slaughterhouses, dairy farms, milk, grease removal separators, and grass and green waste.

Collection process

Food waste is collected in 120L brown bins which can be sealed and have a shutter on top of the lid. Weight of the collected food waste bin varies between 80 and 100kg. About 50,000 bins are collected annually and transported for treatment in trucks with a carrying capacity of 40 bins. The frequency of collections varies from once every two weeks for small generators to twice a week for large generators. The generators of food waste pay per collected bin. The bins are collected and transported to the biogas plant where they are emptied and washed with hot water from the inside and outside and then returned back to customers, usually once a week. It should be noted that a bin is not specific to a customer and may be returned to other customers when collecting full bins.

**HARTBERG IS COLLECTING APPROXIMATELY
5,450 TONNES OF FOOD WASTE FROM CATERING
SERVICES AND 530 TONNES FROM BEVERAGE
PRODUCTION INDUSTRY PER YEAR**

Treatment process

The collected food waste is treated via AD. The food waste is emptied from the bins into a storage tank from where it is transported to a metal separator and then shredded into particles of less than 1cm. Other impurities are then removed and the food waste is pasteurised according to Austrian regulations. The hot water from washing the bins is added during the digestion process. The food waste is then digested and the biogas is used for heat and electricity generation via a CHP unit. The digestate is used by farmers as soil amendment for their crops.

⁷ Case study based on information provided in Bin2Grid (2016) Good Practice on segregated collection of food waste http://www.bin2grid.eu/documents/73603/136534/D2.1_Good+practice+on+segregated+collection+of+food+waste.pdf/

Available financial information

The cost of bins is about €30 and they are designed for a lifetime of 10 years. The gate fee for treating waste being charged by the biogas plant is about €10 per tonne for beverage waste and €25-€60 per tonne for food waste. The cost of collection comes to €150-250 per tonne. The fee charged to customers and revenue generated from the sale or use of energy is not known. The biogas plant employs three people for discharging

bins, logistics, maintenance and administration. In addition, farmers are paid €14 per tonne for accepting digestate to be applied to farmland.

An initial investment of about €2 million was made in the building of the biogas plant, with a few additional investments during subsequent upgrades. The annual operation and maintenance cost is about 2% of the investment cost.

Conclusion

The town of Hartberg is a fantastic example of the collection and digestion of food waste from commercial enterprises and industries on a small scale. It is different from most other kerbside collections which collect the waste in garbage trucks and leave the bin behind, as it is the property of the household or business. The collection of the bin, washing, delivery and circulation between customers is a unique process of implementation of food waste collection. The simplicity of implementation of this type of food waste collection and treatment enables quick deployment and reduced investment in infrastructure.

3.6 Milan, Italy^{8,9,10}

The city of Milan was one of the pioneers in separate food waste collection from households. The city extended separate collection of residential food waste in 2012, which was previously available only to businesses and organisations such as restaurants, hotels, schools and supermarkets. After an initial period of 1.5 years, the service was extended to all households in the city. The collections are made by a Public Company – AMSA (A2A Group).

Feedstock collected

Food waste from 100% of households and commercial activities is collected, which equates to around 1.4 million residents. About 140,000 tonnes of food waste is collected annually from residents, businesses, industries and markets.

Collection process

Food waste is collected separately from green waste. Collection is at the kerbside for all waste (i.e.

household and commercial). Households are equipped with a 10L vented kitchen-caddy plus a starter kit of compostable bioplastic liners. Multiple-occupancy buildings (i.e. high-rise) are equipped with one or more 240L wheely-bins depending on the number of households per building. Food waste is collected twice a week. Residual waste is collected twice a week in transparent bags. The waste is collected by AMSA with methane or biodiesel powered trucks.

⁸ The case study is based on information provided by the Italian Composting and Biogas Association

⁹ Bin2Grid (2016) Good Practice on segregated collection of food waste http://www.bin2grid.eu/documents/73603/136534/D2.1_Good+practice+on+segregated+collection+of+food+waste.pdf/

¹⁰ Milano Recycle City (2015) Food waste recycling: the case study of Milan https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

Commercial premises are equipped with 120/240L wheely-bins and collection frequencies rise from two per week up to six per week. Market booths producing biowaste are equipped with watertight, biodegradable plastic bags and a bag-holder; the biowaste is collected daily, at the end of the market. Figure 5 below shows the growth in the recycling rate of biowaste from 5.3% in 2011 to 18.1% 2014 ¹¹.

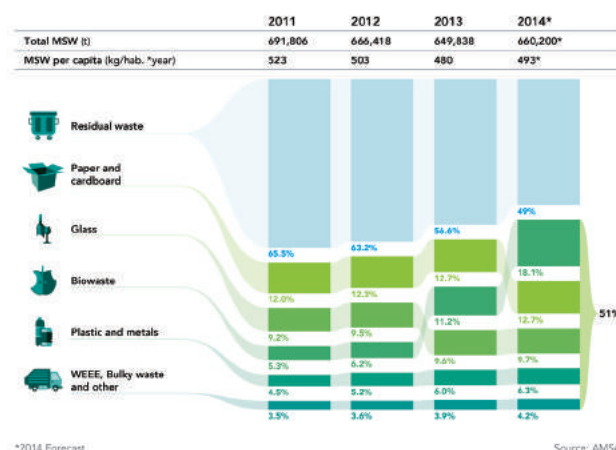


Figure 5: recycling rates of different waste fractions

Treatment process

Food waste is discharged in a transfer station and transported to an integrated AD and composting facility by large-capacity trucks of 30 tonnes. The facility is located in Montello near Bergamo and was built in 1997. The residual, non-recyclable waste is sent to incineration with energy recovery.

Every year, the plant processes under thermophilic conditions 285,000 tonnes of biowaste into biogas for the generation of electricity, for which the installed capacity of the plant is about 9 MW_{el}, and another 300,000 tonnes a year of biogas which is converted into biomethane that is fed into the national gas grid. During the pre-treatment process, bags are shredded, metallic contaminants are removed and recycled, while plastic contaminants are sent for energy recovery.

Available financial information

The project was financed by Municipality of Milan which spent about €4.5 million for the purchase of 45 vehicles and other equipment required for the collection process. Citizens were provided with delivery bins and baskets, 25 free certified compostable bin liners and instruction leaflet on how to recycle.

The payback was planned via a waste management fee, which comprises of a fixed component (~70%) based on the size of housing and a variable part (~30%) based on the number of inhabitants. Based on the size and location, the price of collection can vary between €150-300 per tonne of collected waste. The gate fee charged by the biogas plant varies between €50 and €80 per tonne of waste depending on the biogas potential of the waste. The produced compost/digestate is sold to farmers at €20-50 per tonne depending on its quality.

¹¹ Milano Recycle City (2015) Food waste recycling: the case study of Milan https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

It is worth noting that due to a considerable reduction in waste sent to incineration, at a higher price than the food waste being sent to AD, AMSA was able to reduce its disposal costs and this helped to cover much of the extra cost of the investment in new collection infrastructure.

Policies

The collection of food waste is driven by EU Waste Framework Directive and the EU Landfill Directive which have been transposed into legislative decrees targeting 65% municipal waste recycling by 2012 and landfilling of biowaste below 81kg per inhabitant per year by 27 March 2018.

In addition, several decrees over the last decade have set incentives for electricity produced from renewable sources and in December 2013 the first decree providing incentives for biomethane production came into effect to provide financial incentives for generation and utilisation of biogas. Separate food waste collection is mandatory in the City of Milan. To maximise the efficiency of separate food waste collection, a mechanism of fines has been implemented to help reduce contamination and maximize recycling. A dedicated crew of inspectors perform visual check on sample buildings an hour before collection, penalising households that put impurities into food waste collections, such as plastics. In areas with lower quality than average, additional awareness activities are implemented.

Barriers

One of the major challenges faced during the implementation of separate household food waste collection in Milan was the preparation, coordination and delivery of vented kitchen bins, compostable bags, and information, as well as wheely bins to over half a million households in a highly densely built city. This challenge was overcome by mapping the housing and planning procurement, delivery and contingency.

Citizen engagement

One of the mainstays of the separate food waste collection in Milan was the extensive communication with the residents, which started with raising awareness of property managers of multi-family buildings. It was followed up with a letter to inhabitants sharing details about the service. In addition, calendars, leaflets in multiple languages, a smartphone app, newspaper, radio and television advertisements and a toll-free phone line were used for engagement.

Face-to-face education and awareness raising was undertaken during the delivery of the free delivery of vented kitchen bins, compostable liners and communication materials. In addition, numerous compost giveaway events have been held to demonstrate the circular nature of food waste collection and recycling.

Whilst citizens undertaking food waste collection in Milan have adopted the system quickly and with overwhelming approval, some have voiced concerns around the development of the biogas installation at Montello. These are often politically motivated groups but also genuinely concerned citizens worried about emissions and increased frequency of traffic to the plant. The biogas plant works continuously with local citizen groups and organizes frequent visits to the plant to raise transparency and show the operation of the plant.

Conclusion

The case study of the city of Milan shows that it is possible to implement separate food waste collection and digestion in a large, densely populated city. The proportion of non-compostable waste contaminating the food waste is consistently under 5%, with a positive reduction trend. One of the primary reasons for its success has been the engagement of the community and its education.

3.7 Minneapolis, USA ¹²

The City of Minneapolis initiated an organics collection pilot in 2008, then expanded coverage in 2009 and 2010. These initial pilots were critical to determining the level of participation in a free opt-in programme (e.g. sign up), assessing the effectiveness of the city's outreach methods (e.g. mailings, neighbourhood events), and developing efficient collection routes based on the number of stops and weight of the organics ¹³.

In 2012, the city requisitioned a study to evaluate options for moving the organics programme forward. In 2014 followed the establishment of several organics collection drop-off sites around the city to engage early adopters and educate the broader public. The low-cost drop-off sites comprised 96 gallon rolling carts in parking lots with combination locks; residents that signed up to use the carts received the lock code via e-mail ¹⁴. That same year, the Hennepin County Board approved a measure for Minneapolis to begin collecting food scraps city-wide in 2015.

More than 45,000 households—equating to 43 percent of the eligible single-family households and small apartment buildings—have enrolled in the organics programme since its city-wide expansion ¹⁵.

Feedstock collected

Food scraps, food soiled and non-recyclable paper products, and certified compostable plastics are accepted. Other acceptable waste includes coffee grounds, filter and tea bags, tissues, cotton swabs and balls, wood chopsticks, popsicle sticks and tooth picks, floral trimmings and house plants, animal and human hair and nail clippings, small amounts of grease and oil. Yard waste is collected separately and is not accepted along with food waste ¹⁶.

Treatment process

The collected food waste is sent to a commercial composting facility where it is mixed with garden waste and composted for six to nine months and then applied in gardens, landscaping projects or erosion control projects ¹⁷.

Available financial information

Organics collection is free for residents that receive Minneapolis Solid Waste & Recycling services.

¹² This case study was authored by Brooke Robel, Brian Guzzone and John Carter at ERG (Eastern Research Group, Inc)

¹³ Kish K (2017) Recycling coordinator of City of Minneapolis, Minnesota

¹⁴ *ibid*

¹⁵ Roper, E. (2017) Minneapolis curbside composting yields high interest, less organic waste than expected. *Star Tribune*. 14 July 2017. www.startribune.com/minneapolis-curbside-composting-yields-high-interest-less-organic-waste-than-expected/434569713/

¹⁶ Minneapolismn (2017) Organics <http://www.ci.minneapolis.mn.us/solid-waste/organics/acceptable-organics> Accessed on 09/02/2018

¹⁷ Minneapolismn (2018) Residential organics recycling <http://www.ci.minneapolis.mn.us/solid-waste/organics/organics-faq> Accessed on 09/02/2018

Policies

In 2015, the City Council approved goals calling for recycling and/or composting for 50% of city-wide commercial and residential waste by 2020, then increasing to 80% by 2030 ¹⁸.

Citizen engagement

Minneapolis has utilised many of the traditional outreach mechanisms (e.g. welcome kits, direct mail, websites, and social media) since the city-wide programme began in 2015, but more recent 2016-2017 efforts by interns going door-to-door and talking directly with residents yielded a 36% sign-up rate among residents reached via door-knocking ¹⁹.

Conclusion

The City of Minneapolis is a great example of gradual introduction of source segregated food waste collection. It started the process with a pilot programme which informed key decisions for the full scale implementation. The full scale implementation was started as drop offs to engage with public and then gradually as the public awareness increased, moved to kerbside collections. This gives ample time for raising public awareness and making investment required in infrastructure. Minneapolis does not recover energy from its food waste but is able to accept a wider range of organics in addition to food waste such as food soiled, non-recyclable paper, wooden 'popsicle' sticks and cotton balls by choosing composting as the treatment technology.

3.8 New York City, USA ²⁰

New York City (NYC) has been targeting organics since the late 1980s with its first law requiring the Department of Sanitation of New York (DSNY) to collect and compost leaves and seasonal yard waste. In 2006, DSNY released its 'Comprehensive Solid Waste Management Plan' that emphasised the need to address the organic portion of the city's waste stream and also created a Compost Facility Siting Task Force ²¹.

Subsequent laws sought to strengthen seasonal yard waste collection efforts and requisitioned a food waste composting study. In accordance with a 2013 NYC law to establish voluntary organics collection, DSNY initiated its organics pilot programme to collect yard waste and food scraps, then spent several years — from 2014 to 2016 — expanding the programme district-by-district. By late 2017, 30 of 59 districts had this service. Households with one to nine units were auto-enrolled in the programme and larger multiple unit buildings completed online applications.

Feedstock collected

New York City collects food scraps such as fruit, vegetable, meat, bones, dairy and prepared food waste as well as food soiled paper such as napkins, tea bags, plates and coffee filters and leaf and yard waste such as plants, trimmings, twigs and grass ²².

¹⁸ Minneapolis (2015) City sets recycling goals. City of Minneapolis, MN. Published 19 June 2015. <http://www.ci.minneapolis.mn.us/news/WCMS1P-143012>

¹⁹ Kish K (2017) Recycling coordinator of City of Minneapolis, Minnesota ²⁰ This case study was authored by Brooke Robel, Brian Guzzone and John Carter at ERG (Eastern Research Group, Inc)

²⁰ This case study was authored by Brooke Robel, Brian Guzzone and John Carter at ERG (Eastern Research Group, Inc)

²¹ Anderson, B. (2017) From Curb to Compost: How the City of New York is Building an Organics Collection Program to Serve 8.5 Million People. Waste 360 Webinar presentation. 16 November 2017.

²² Department of Sanitation (2017) Organics curbside collection <http://dsny.wpengine.com/wp-content/uploads/2018/01/organics-collection-brochure-OCB2017.pdf>

Collection process

More than 750,000 households (representing approximately 3.3 million residents) are currently served by the organics collection programme, as well as about 750 schools and more than 100 institutions ²³. There are also more than 100 food scrap drop-off sites throughout the city. NYC ultimately strives for city-wide access by the end of 2018, and earmarked nearly US\$30 million to distribute

bins, educate residents, and collect/transport materials for *composting* ²⁴. Some of the variables to consider when providing organics collection in the largest U.S. city include: housing and population density (single-family households and multi-family high-rise buildings) diversion/capture rates, day-to-day operations (e.g., single- or dual-hopper rear-loading trucks, route length/distance, labour), and proximity to processing facilities ²⁵.

When it comes to collection frequency, NYC has three modes:

- **Once a week on residents' "recycling day" with a single-hopper truck;**
- **Twice a week on residents' "trash day" using a dual-hopper truck; and**
- **Three times a week for high-rise buildings using a single-hopper truck.**

Treatment process

The collected waste is largely composted. The city also runs the NYC Compost Project via which it teaches composting to its citizens and gives away compost for community gardens, parks, street trees, and similar uses.

Policies

Under the NYC commercial organics rules, segregation of food waste is mandatory for businesses that meet the below criteria:

- **Food service establishments with a floor area of at least 15,000 square feet;**
- **Food service establishments that are part of a chain of 100 or more locations in the city of New York; and**
- **Retail food stores with a floor area of at least 25,000 square feet.**

Larger food waste generators are targeted under regulations and the burden of proving compliance is placed on them while giving them a choice of hiring a private carter for transportation, haul their own waste or process it onsite.

In addition to the environmental benefits of diverting organic materials from landfills, implementing a cart-based food waste collection system is also expected to reduce the city's rodent problem since most trash was previously placed at the curb in bags ²⁶. With aggressive initiatives like the city-wide organics programme in 2018 and enhanced single-stream recycling in 2020, NYC strives to achieve a goal of zero waste to landfills by 2030.

Conclusion

NYC is a great example for a step-by-step and variable implementation of organics collection for highly densely populated city with separate systems in place for households, schools and commercial establishments.

²³ Anderson, B. (2017) *From Curb to Compost: How the City of New York is Building an Organics Collection Program to Serve 8.5 Million People*. Waste 360 Webinar presentation. 16 November 2017.

²⁴ Rueb, E. (2017) *How New York Is Turning Food Waste Into Compost and Gas*. The New York Times. 2 June 2017. www.nytimes.com/2017/06/02/nyregion/compost-organic-recycling-new-york-city.html

²⁵ Anderson, B. (2017) *From Curb to Compost: How the City of New York is Building an Organics Collection Program to Serve 8.5 Million People*. Waste 360 Webinar presentation. 16 November 2017.

²⁶ Yepsen, R. (2015) *BioCycle nationwide survey: Residential food waste collection in the US*. BioCycle, 56(1): 53. 15 January 2015. www.biocycle.net/2015/01/15/residential-food-waste-collection-in-the-u-s-2/

3.9 Oslo, Norway ^{27,28,29,30,31}

In 2006, the City Council in Oslo decided to establish source segregated collection of food and plastic waste from residual waste of households. It was agreed that this should be sorted into different coloured plastic bags to be sorted at central sorting plants based on the colour.

After some years of planning and building, the first sorting plant was opened in October 2009. After that, several treatment plants were changed and build, and in summer 2013 the biological treatment plant at Romerike went into operation. Since then, this plant has delivered both compressed and liquefied biogas, delivered mainly to buses and waste trucks in Oslo.

Feedstock collected

Food waste is collected from 660,000 inhabitants of Oslo ³² with collection rate of about 25kg food waste per person. It is collected on a weekly basis from the residents, along with other waste. Small amounts of soiled kitchen paper may be added provided they don't contain any soap.

Collection process

The City of Oslo has implemented a collection process which is a combination of door side collection by the city and delivery of waste to kerbside collection points or recycling stations by residents.

The collection system is based on colour coded plastic bags. The residents dispose food waste in a green bag and clear plastic packaging in a blue bag. These green and blue bags are available for free in supermarkets. Residual waste is collected in normal shopping bags and paper and cardboard in a separate container.

All bags are discarded into the same waste container from which the city collects them. The coloured bags are sent to optical sorting plants from where food waste to an anaerobic digester, plastic is sent for recycling and the residual waste to incinerators with energy recovery.

Garden waste, clothes, electronic waste, hazardous waste are taken to collection points or recycling stations by residents.



Images: photograph showing colour-coded bags at the sorting centre (City of Oslo)

²⁷ This case study is based primarily based on information provided by Johnny Stuen, Waste-to-Energy Agency, City of Oslo

²⁸ City of Oslo factsheet: Biological treatment of food waste https://www.oslo.kommune.no/getfile.php/134907/Innhold/Avfall%20og%20gjenvinning/Behandlingsanlegg%20for%20avfall/Fact_sheet-Biological_treatment_of_food_waste.pdf

²⁹ City of Oslo factsheet: Biogas and Biofertilizer https://www.oslo.kommune.no/getfile.php/134904/Innhold/Avfall%20og%20gjenvinning/Behandlingsanlegg%20for%20avfall/Fact_sheet-Biogas_and_biofertilizer.pdf

³⁰ Oslo Council, The Source Sorting System in Oslo <https://www.oslo.kommune.no/avfall-og-gjenvinning/kildesorteringssystemet-i-oslo/>

³¹ City of Oslo (2017) European Green Capital Award 2019 Application City of Oslo (2017) European Green Capital Award 2019 Application http://ec.europa.eu/environment/europeangreencapital/wp-content/uploads/2017/06/Indicator_7_Waste_Production_and_Management.pdf

³² Jentoft H (2017) Circular bioresources: treatment of food waste, garden waste and sludge from wastewater, Oslo, Norway http://www.eurocities2017.eu/files/uploads/files/Oslo_Circular%20economy%20case%20study.pdf

Treatment process

The food waste from the sorting centres is sent to the Romerike biogas plant. Here the bags are opened, contaminants like metal, plastic, packaging and other large unwanted materials are removed, and the waste ground to a smaller size. The waste undergoes thermal hydrolysis followed by flashing to kill pathogens, fungi and plant and make the digestion easier and faster.

The waste then undergoes AD under mesophilic conditions (38°C), producing biogas and digestate. The biogas is upgraded

to compressed biogas (CBG) and then liquid biogas (LBG). The digestate is treated to produce two different products: a firm digestate with high total solids content of 25%, and a liquid bio concentrate with total solids approx. 15%.

In 2013, the Romerike plant produced 1.164 million Nm³ biogas from food waste from households and businesses in Oslo and other municipalities. The biogas was sufficient to fuel 135 buses and the biofertiliser enough for 100 medium-sized farms.

*Image: Biogas plant
(City of Oslo)*



*Image: biogas-powered buses
(City of Oslo)*



*Image: waste collection
vehicles
(City of Oslo)*



THE CITY OF OSLO AIMS TO INCREASE FOOD WASTE RECYCLING TO **60% BY 2025**

Available financial information

The waste handling is fully financed on a non-profit basis via the pay-as-you-throw system. The household charges for collection of all waste begin at Euro 443 per year for 140L bin and vary with bin size.

Citizen engagement

To engage with citizens to raise awareness about the benefits of recycling, how the source sorting system works and the importance of their actions, the City of Oslo undertook communication campaigns and distribution of brochures, advertising campaigns in the media and public spaces, door-to-door campaigns and engaged celebrities to promote source separation of waste.

Policies

Since 1984, the management of household waste is regulated under a separate city regulation which specifies the rights and duties of both the City and the citizens. This regulation gives the City the right to sanction citizens who are failing to source separate at a satisfactory rate, even after several visits and information campaigns. So far, no sanctions have been imposed.

The City of Oslo has changed its procurement policy, favouring non-fossil transportation, and developed a climate and energy strategy for the city. In this strategy, developing electric personal transportation and short distance transportation are important actions, and at the same time cooperating with private transportation companies, to develop a biogas cluster in Oslo for heavy transportation. This is still in the planning stage.

Conclusion

The source segregated waste collection system of the City of Oslo ensures that no biodegradable waste is sent to landfill, which was prohibited in 2009. About 44% of food waste was collected and recycled. The City of Oslo aims to increase this to 60% by 2025 while reducing the food waste generation by 30%.

The highlights of the source segregated collection system in Oslo is its simplicity to implement, colour coded plastic bag collection system supported by the sophisticated optical sorting plants and its focus on production of vehicle fuel for waste collection vehicles and public transport. In addition, the clearly defined targets and the annual residual waste analysis are driving action and steering the City in the direction of increased recycling.

3.10 Seoul, South Korea ^{33, 34}

The city of Seoul in South Korea has one of the most complex and sophisticated systems in place for the collection and disposal of food waste.

Collection process

Seoul is densely populated with multi-unit building as well as single family houses which comprise about 70% of the city. In the past, there was a flat rate fee for food waste disposal system in multi-unit buildings while a volume-based fee was charged to the single-family houses. But after running a two-year pilot programme starting 2011, the city has now moved to a 'volume-based system' which is implemented with slight variations in different districts. The system is a combination of volume-based waste bags, waste containers, weight-based Radio Frequency Identification (RFID) for households and trucks and payment certificates as shown in the figure 6³⁵.



Figure 6: Volume based food waste disposal system

Treatment process

The collected food waste is compacted and then sent to treatment facilities. Food waste is converted into animal feed, composted, anaerobically digested or supplied in its original form to farmers for use on land. The liquid fraction of food waste is sent for treatment to public waste water treatment facilities as shown in Figure 7 ³⁶.



Figure 7: Flowchart of food waste collection and disposal

³³ Case study is based on information provided by Dr Jae Yung Kim and Dr Ju Munsol of Seoul National University.

³⁴ *Seoul Solution (2016) Minimising food waste: Zero food waste Seoul 2018* <https://seoulsolution.kr/en/content/minimizing-food-waste-zero-food-waste-seoul-2018>

³⁵ *Seoul Solution* (2016) *Minimising food waste: Zero food waste Seoul 2018* <https://seoulsolution.kr/en/content/minimizing-food-waste-zero-food-waste-seoul-2018>

³⁶ Seoul Solution (2016) Minimising food waste: Zero food waste Seoul 2018 <https://seoulsolution.kr/en/content/minimizing-food-waste-zero-food-waste-seoul-2018>

Policies

Korea joined the London Convention in December 1992 which committed to preventing marine pollution by dumping of wastes into the sea. The initial efforts towards food waste reduction started from there, and were further strengthened by a ban on direct landfilling of food waste in 2005. Further in 2013, food waste water was banned from being released into the sea. These policies forced a change in the disposal and treatment of food waste in South Korea.

Available financial information

The cost of disposal is shared by the municipalities and citizens via the Pay-As-You-Throw system.

Conclusion

The collection of food waste resulted in a 10-14% reduction in its generation, while also reducing marine pollution and pressure on landfills. Food waste is considered a social issue and both citizens and local governments pay for its disposal.

3.11 Conclusion

In this chapter we have given examples from nine cities and towns of different sizes, population configurations and geographical locations. There are several aspects the cases have in common:

- Collection programmes were implemented gradually, after trials, and extended across the wider population once it was shown the system functions;
- Cities utilised various treatment options including composting, AD or returning food waste to animal feed;
- Cities often use compostable bags for collection to reduce contamination of food waste, especially where composting is the chosen treatment method;
- Food waste is often collected separately from garden waste and especially so if AD is the chosen treatment option.

There are varied methods of collection and treatment of food waste available and being implemented across the globe for resource and energy recovery. Learning from these will enable other authorities to implement collection systems most suitable to their own circumstances, population and geography, as well as to model systems within budgetary limitations.

The following chapter explores the treatment options available for food waste whether collected separately or mixed in with green or inorganic waste.

4. FOOD WASTE TREATMENT TECHNOLOGIES

Having covered the different available food waste collection systems and models in Chapter 3, this chapter presents an overview of the technologies available for the treatment of collected food waste.

The first part of the chapter gives an overview of the technologies available. Section 4.1 outlines the technologies, in alphabetical order, that treat source-separated food waste. Section 4.2 outlines the technologies that treat food waste mixed with other wastes as part of residual waste collections. For each technology the following aspects are briefly outlined: the wastes that are treated, the process, the output products, the appropriate scale for the technology, and the advantages

and disadvantages. Policy-makers need to understand the various treatment technologies in order to make informed choices.

It will be clear that those technologies treating separated food waste provide a number of benefits that those treating mixed wastes cannot, including maximising energy recovery, fertiliser production and improved soil health, resulting in economic and environmental benefits.

Section 4.3 provides a summary table which shows how the food waste treatment technologies compare to one another with respect to several parameters.

4.1 Technologies that treat separately-collected food waste

This section sets out a range of technologies that can treat separate food waste. It describes the source of wastes used, the process and the products.

A) Anaerobic Digestion

Anaerobic digestion (AD) will be discussed in detail in Chapters 5 and 6. As those chapters will describe, AD provides a number of benefits over many other treatment technologies.



These benefits include:

- By separately collecting food waste, raising awareness of the cost and quantity of food waste and therefore reducing the quantity of food waste produced;
- Reducing the health impacts of poor waste management;
- Recovering energy - AD recovers 60% more energy than direct combustion¹;
- Producing a nutrient-rich fertiliser;
- Helping replenish soils through the addition of organic matter – the Food and Agriculture Organisation of the

United Nations has calculated that, due to soil degradation, the world's soils can only support 60 more harvests ²;

- Creating local jobs through the effective use of local resources;
- Reducing greenhouse gas emissions by up to 2 tonnes of carbon dioxide equivalent per tonne of food waste treated for electricity production with no heat recovery, compared to open landfilling ³; and
- Overall, moving from a wasteful, linear economy to a sustainable, circular economy.

B) Composting

Composting is an aerobic process that decomposes organic material into a nutrient-rich soil conditioner. Types of composting include backyard or onsite composting, vermicomposting, aerated windrow composting, aerated static pile composting and in-vessel composting (IVC). Both IVC and windrow composting are described in this section as appropriate methods for treating urban food waste, which will often include animal by-products requiring high temperature treatment. IVC is practised throughout Europe whilst we find windrow composting widely implemented in the USA and developing countries.

IN VESSEL COMPOSTING

Source of waste

IVC is often used to treat food and garden waste mixtures, but can also be applied to sewage sludge, farm waste (manure, crop residues), and agro-industrial by-products⁴.

Process

In-vessel composting uses a drum, silo, concrete-lined trench or chamber, or similar structure to contain the biowaste at a controlled temperature, moisture and oxygen level. It is well-suited to larger volumes of waste like those managed by local governments, institutional facilities or food processing facilities, especially for wet foodwaste. For the scope of this report, the focus is upon the treatment of food and garden waste typically collected in cities.

¹Valorgas (2014) Valorisation of food waste to biogas, Pg. 33 http://www.valorgas.soton.ac.uk/Pub_docs/VALORGAS_241334_Final_Publishable_Summary_140110.pdf

²Food and Agriculture Organisation of the United Nations (2015) international Year of Soil Conference 2015 <http://www.fao.org/soils-2015/events/detail/en/c/338738/>

³WBA calculation, based on data collected from the International Energy Agency, Biograce, UK Waste Resources Action Programme, US Environmental Protection Agency, EU Valorgas programme

⁴Waste and Resources Action Programme (WRAP). In vessel composting (IVC). <http://www.wrap.org.uk/content/vessel-composting-ivc>.

In the first stage of the process, the mixed garden and food waste is delivered to an enclosed reception area. It is then shredded to a uniform size and loaded into what is known as the first 'barrier', which will be a bay/tunnel or chamber depending on the system used. After the first stage (which can take between one and three weeks), the material is transferred to the second 'barrier', where the composting process continues, usually for a similar duration. Processing in two stages ensures that all parts of the composting mass reaches the required temperature and biodegrades. The oxygen level, moisture and temperature are carefully monitored and controlled during both composting stages to ensure the material is fully sanitised – specifically that the material reaches a defined temperature for a certain period, usually up to 70°C for one or two days. Once the sanitisation process is complete the compost is left to mature in an open windrow or an enclosed area for approximately 10-14 weeks to ensure stabilisation.

The composted material is then screened to eliminate contaminants and produce a range of product grades suitable for various end uses, such as soil conditioning. Often the leftover aggregates that are too large for product grades are fed back into the processing system to break down fully.

Products

Composting is a natural, controlled and accelerated process of biodegradation where heat is created by the biodegrading mass itself and its temperature may rise to 70°C. These temperatures are needed to accelerate the biodegradation process and are created by the natural fermentation of the biomass itself.

The compost product contains many of the minerals needed to maintain soil health: N, P, K, as well as organic carbon contained in organic matter. Loss of organic matter in soils in many parts of the world is reducing the ability of the world's soils to retain water and maintain microbial activity beneficial to crops. The replenishment of soil organic matter through the use of compost is a response to this concern. Compost may have a dry matter content of 60%⁵ and organic carbon as high as 25% of dry matter ⁶.

The quality of the final product depends upon a variety of factors, including the inputs and the process used.

Scale

Composting can be operated at all scales. It can be undertaken at single garden scale to large-scale industrial composting of hundreds of thousands of tonnes per year.

⁵WRAP (2016) Digestate and compost use in agriculture http://www.wrap.org.uk/sites/files/wrap/Digestate_compost_good_practice_guide_reference_version.pdf

⁶Centemero M., Caimi V. (2001) Impieghi del compost: settori di maggior rilevanza, modalità d'uso, scenari attuali di mercato. Atti Corso Compost: produzione ed utilizza, Ed. CIC Rimini - settembre 2001 http://www.compost.it/materiali/cic_bc.pdf

Advantages

- Produces high organic matter compost for a range of plant growing markets – including agriculture and horticulture – helping to restore soils;
- Restores the carbon storage and sequestration capacity of soils;
- Stabilises and sanitises food waste;
- Allows food waste to be collected alongside other organic wastes such as garden waste, reducing the cost of collections; and
- Is a relatively simple, predictable and naturally-occurring process.

Disadvantages

- Does not recover energy, thus reducing the emissions-saving potential;
- Careful management of contaminants and odour are required; and
- The market value and use of compost will depend upon the quality of the input

WINDROW COMPOSTING

Source of waste

Windrow composting is most suitable for processing of garden waste, such as grass cuttings, leaves and cutting from pruning but can be used for source segregated organics such as food waste where allowed. While in some countries such as Australia⁷ and USA⁸, it is used to treat food waste, in others such as UK and EU, it is prohibited to process food waste using this method due to health and sanitation concerns.

Process

In windrow composting waste is shredded and laid in windrow. A windrow is an elongated pile of waste, typically 2-3 meters high and 3-5 meters wide and pyramid shape. Length of the row depends on the volume of the feedstock and the orientation of the plot of land. The material is periodically turned or aerated manually, or using special equipment like a bucket loader, tractor or a windrow turner.

There are two phases in the composting process: Active and Curing. During the active phase, the biological degradation of waste raises the temperature to at least 55 °C. To kill weeds and pathogens, the temperature of waste needs to be kept higher than 55°C for at least 3 days. This phase can take anything from 8 to 12 weeks in hot climate such as that of Australia⁹ to 8 to 9 months in cooler climate such as that of Vermont in USA¹⁰.

The curing process starts when the temperature of the compost reaches about 32 – 37° C and usually takes 1 to 3 months. During this phase, the compost is generally kept aerobic by passive oxygen supply and does not require turning or aeration.



⁷Sustainability Victoria (2009) Guide to best practice for organics recovery <http://www.sustainability.vic.gov.au>

⁸Vermont Agency of Natural Resources (not dated) Turned Windrow Composting: Sizing your compost pad <http://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/Documents/ANR%20Sizing%20Your%20Composting%20Pad.pdf> Accessed on 23/03/2018

⁹Sustainability Victoria (2009) Guide to best practice for organics recovery <http://www.sustainability.vic.gov.au>

¹⁰Vermont Agency of Natural Resources (not dated) Turned Windrow Composting: Sizing your compost pad <http://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/Documents/ANR%20Sizing%20Your%20Composting%20Pad.pdf> Accessed on 23/03/2018

Upon completion of process, like IVC, the composted material is screened and ready to be used. The larger than specified aggregated maybe returned as feedstock for a second round of composting. Contaminants such as plastic residues, are eliminated.

Products

The screened composted material may be used as soil conditioner, mulch, blended products, and woody parts potentially for pyrolysis, combustion or refuse derived fuel manufacture or returned to the beginning of the process as a bulking product, especially when wet food waste is being treated.

Scale

Like IVC, windrow composting can be implemented at any scale, from single garden to large industries and organic fraction of municipal solid waste of a municipality.

Advantages:

- Is a relatively simple, predictable and naturally-occurring process;
- Requiring little machinery and upfront cost is low;
- Subject to availability of land, large amounts of waste can be processed
- Produces high organic matter compost for a range of plant growing markets – including agriculture and horticulture – helping to restore soils;
- Restores the carbon storage and sequestration capacity of soils;

Disadvantages:

- Cannot be used in some countries, such as UK, to treat wastes that contain catering and animals wastes due to Animal By-Products Regulations¹¹;
- There are no emission controls;
- Waste is susceptible to environmental changes such as storms and changes in temperature causing disruptions to the process and other problems such as over heating or charring of waste and water runoff;
- The process is susceptible to odour emissions;
- Active management of vectors such as vermin, birds and insects is required;
- Does not recover energy, thus reducing the emissions-saving potential;
- The usability of compost will depend on the quality of the input.

¹¹WRAP (2016) Open Windrow Composting <http://www.wrapcymru.org.uk/collecting-and-reprocessing/organic-waste/composting/open-windrow-composting>

C) Liquefaction

Liquefaction – the conversion of food waste into a liquid effluent - can be accomplished by multiple methods. Mechanical and biological liquefaction are outlined below. Hydrothermal liquefaction is not discussed here as to date it has not been widely adopted.

Source of waste

Household and business food waste.

Process

Mechanical systems are driven by an electric motor and use mechanical grinders to shred food waste. At a household scale, they are incorporated into kitchen sink drainage, and the food waste is ground into small pieces before being mixed with water and washed into the drainage system, to be treated with the rest of the waste water and sewage. The grinding mechanism has no knives or blades. Instead, impellers mounted on a spinning plate use centrifugal force to continuously force food waste particles against a stationary grind ring. The grind ring breaks down the food waste into very fine particles (less than 2mm) – virtually liquefying them¹².

Microorganisms or nutrients can be added to the material to accelerate the process– this is then described as biological liquefaction and is a more complex but more effective process¹³.

Products

Liquid grey water drained into the waste water network.

Scale

Household scale – fitted into kitchen sinks. Food waste disposers are typically rated between 0.4–0.5 kW¹⁴. Biological liquefaction would generally be for larger scales.

Advantages

- At a household scale, it is incorporated into the existing kitchen sink drainage, therefore it saves upon the need to separately collect food waste;
- Simple and easy to use; and
- Where treated at a waste water treatment works with AD, allows many of the benefits of AD to be realised.

Disadvantages

- Waste water systems may not be designed to treat waste foodstuffs in addition to existing sewage loads;
- Requires an energy input;
- In older cities, the drainage systems will often have difficulty managing extra loads that cause blockage and grease build-ups; and
- It is simply used as a means to dispose of food waste rather than a means to produce a quality product.

¹²The Association of Manufacturers of Domestic Appliances (not dated) How food waste disposers work <https://www.food-waste-disposer.org.uk/how-they-work> Accessed on 08/03/2018

¹³Griffith-Onnen I, Patten Z and Wong J (2013) on-site systems for processing food waste <http://www.mass.gov/eea/agencies/massdep/recycle/reduce/massdep-food-waste-final-report.pdf>

¹⁴The Association of Manufacturers of Domestic Appliances (not dated) How food waste disposers work <https://www.food-waste-disposer.org.uk/how-they-work> Accessed on 08/03/2018

D) Rendering

Rendering is a process that converts waste animal tissue and by-products into saleable commodities such as high-quality fat and protein products. These can then be used in the production of animal feed (e.g. pet food), soap, paints and varnishes, cosmetics, explosives, toothpaste, pharmaceuticals, leather, textiles, lubricants, biofuels and other valuable products.

Rendering can be carried out on an industrial, farm or kitchen scale. In the UK there are around 2 Mt of animal by-products sent to rendering plants¹⁵. Rendering is an energy-intensive process and has a limited application – it can only be used to treat certain feedstocks, namely animal tissue.

1.75m

TONNES OF ANIMAL
BY-PRODUCTS ARE
PROCESSED ON
26 DEDICATED
RENDERING PLANTS
IN THE UK.

Source of waste

The most common animal sources are beef, pork, sheep and poultry. The majority of tissue processed comes from slaughterhouses in the form of fatty tissue, blood, bones and offal, as well as entire carcasses, but rendering companies also get their materials from meat and poultry plants, restaurant grease, butcher shop trimmings, the foodservice industry, farms and expired meat from grocery stores.

Process

The rendering process is relatively simple. Animal products not used as food for people are ground so they are uniform in size and then heated to a time and temperature combination necessary to thoroughly cook the material. Fat separates from the protein naturally due to the heat, is centrifuged and ready for use. Protein is ground again to make a consistent protein meal¹⁶.

Rendering uses heat and pressure to sterilise and stabilise animal material. Sterilisation kills harmful microorganisms thus eliminating disease risk. Stabilisation prevents any further decomposition of by-products and makes them suitable for storage and reprocessing for other uses. A key step is removing water. Only a proportion of the feedstock is turned into material, the rest is lost as water which is treated for safe return to the environment.

¹⁵Parry, A., P. Bleazard and K. Okawa (2015), "Preventing Food Waste: Case Studies of Japan and the United Kingdom", OECD Food, Agriculture and Fisheries Papers, No. 76, OECD Publishing, Paris. <https://www.oecd-ilibrary.org/docserver/5js4w29cf0f7-en.pdf?expires=1525784803&id=id&accname=guest&checksum=097503A68F4EA992CADBEC498B54F03>

¹⁶National Renderers Association. <http://www.nationalrenderers.org/about/faqs/#what-is-rendering>.

IN THE US AND CANADA, THE RENDERING INDUSTRY CONSISTS OF MORE THAN THREE DOZEN FIRMS OPERATING MORE THAN 200 PLANTS.

Products

Rendering produces fat (tallow), high-protein meat or grease¹⁷, and the products that can then be created from these.

Scale

In Australia, batch dry cooking is the most widely used type of rendering. Batch cooking systems are well suited to small-scale operations since a single cooker can handle 3,500-5,500 tonnes of raw material per year.

On the larger scale, continuous dry rendering systems are used, where capacity ranges from 25,000-100,000 tonnes per year, depending on the size of the heat transfer area of the cooker and the water content of the raw material.

In the US and Canada, the rendering industry consists of more than three dozen firms operating more than 200 plants. This number includes plants that are integrated with meat processing companies to process the captive by-products generated by these firms, and independent renderers that are not directly owned by meat processing companies but instead collect and process by-products from many different sources.

In the UK, 26 dedicated rendering plants process around 1.75m tonnes of animal by-products per year, meaning each plant processes an average of 70,000 tonnes per year.

Advantages

- Produces highly valued protein supplements for livestock, poultry, and pet foods; and
- Amid increases and volatility in the price of conventional feed and concerns about the environmental impact of grain- and soybean-based feeds, rendering food waste provides a very good substitute for conventional animal feed.

Disadvantages

- Requires close regulation and stringent legislation on what types of food waste are used;
- Requires an energy input;
- If the food waste contains animal by-products and is not effectively heat-treated, it can transmit diseases such as foot-and-mouth disease and African swine fever; and
- Rendering poses biosecurity concerns due to the transportation of livestock mortalities to multiple locations en-route to the rendering plant.

¹⁷EFPPA. Which By-Products are Rendered? <http://efpra.eu/which-byproducts-rendered/>.

4.2 Technologies that treat non-separated food waste (i.e. organic waste mixed in with inorganic waste)

In the instances where organic wastes are not collected separately from other household and business wastes, there are several treatment technologies which can be used. They are included in this report to provide a full overview of the available options for processing organic wastes. The merits and drawbacks of the different technologies are also briefly explored for some technologies, both in relation to each other and to the technologies which treat separated food waste (as set out above).

A) Gasification

Gasification is a process that converts organic materials (e.g. biomass, food wastes) or combinations of organics and inorganics into a combustible gas called syngas, by reacting the material at high temperatures ($>700^{\circ}\text{C}$) with a controlled amount of oxygen and/or steam. It is therefore a technology that involves thermochemical conversion, like incineration or pyrolysis. The syngas is usually comprised of carbon monoxide (CO), hydrogen (H_2) and CO_2 . Gasification as a technology has been slow to develop, with few waste gasifiers operating globally, especially at the scales required to deal with MSW.

Source of waste

Mixed household and business waste, ideally which is non-recyclable.

Process

Thermal gasification takes place in a reactor called a gasifier. Before entering the gasifier, the waste has to be prepared for the gasification process, which involves breaking it down to a suitable size and drying it to suitably low moisture content. The waste should be also free from other undesirable materials, such as stones or metals, which could cause operational problems¹⁸.

Gasification is an intermediate step between pyrolysis and combustion. It is a two-step, endothermic process. During the first step the volatile components of the fuel are vaporized at temperatures below 600°C by a set of complex reactions. No oxygen or other reactive agent is needed in this phase of the process. Hydrocarbon gases, hydrogen (H_2), CO, CO_2 , tar and water vapour are included in the volatile vapours. Char (fixed carbon) and ash are the by-products of the process which are not vaporized. In the second step, char is gasified through the reactions with oxygen, steam, CO_2 and/or hydrogen. In some gasification processes, some of the unburned char is combusted to release the heat needed for the endothermic gasification reactions.

¹⁸IEA Task 33. Thermal Gasification of Biomass. http://task33.ieabioenergy.com/content/thermal_gasification.

Products

The main products of gasification are syngas, and by-products such as char and tars. The composition of the syngas and the level of undesirable components (tars, dust, ash content) produced during the thermal biomass gasification process are dependent on many factors such as feedstock characteristics (composition, water content, granulometry), reactor type and

operating parameters (temperature, pressure, oxygen fuel ratio, fluidizing agent).

Gaseous products formed during the gasification may be further used for heating or electricity production, or ideally further processed into high-value chemicals. The main gas components are CO, H₂, CO₂, H₂O, methane (CH₄) and other hydrocarbons.

Scale

Can operate at 100 tonnes per day and over, e.g. Covanta Tulsa Renewable Energy LLC in Tulsa, USA¹⁹.

Advantages:

- May be implemented for treatment of : an average of just 100 tonnes/day in comparison to larger amounts for incineration with energy recovery ²⁰; and
- According to the World Energy Council, both gasification and pyrolysis are more efficient and score better in environmental impacts than incineration with energy recovery ²¹. However, with the lower number of operational plants developed to date than incineration, there is debate over whether these efficiencies can be achieved in practice.

Disadvantages:

- Lack of nutrient recovery: like incineration, gasification of mixed waste which includes food waste also wastes the nutrient value of the food waste, which could be converted to fertiliser through composting or AD. Whereas

gasification recovers the energy content of the waste, AD both recovers the energy content and the nutrient content of the waste;

- Lower efficiency compared to AD in terms of GHG emission reductions ²²;
- Higher capital costs than incineration ²³;
- When the moisture content of the waste being treated is high, the energy recovered is low and potentially negative, thus increasing the cost of treatment further.
- The mechanical treatment ahead of gasification, sensitivity to feedstock properties, low heating value of waste fuel, costly flue gas clean-up systems, difficulty of syngas clean-up and poor performance at small scale have been a great challenge during gasification of MSW ²⁴; and
- Operates more effectively with homogeneous feedstocks, reducing the flexibility of the plant in comparison to incineration.

¹⁹ Solid Waste of North America (2013) 2013 SWANA Waste-to-Energy Excellence Award Nomination https://swana.org/Portals/0/Awards/2013/WTE_Bronze.pdf

²⁰ World Energy Council (2016) World Energy Resources - Waste to Energy. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf.

²¹ World Energy Council (2016) World Energy Resources - Waste to Energy. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf.

²² World Energy Council (2016) World Energy Resources - Waste to Energy https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf

²³ World Energy Council (2016) World Energy Resources - Waste to Energy https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf

²⁴ World Energy Council (2016) World Energy Resources - Waste to Energy https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf

B) Incineration with energy recovery

Incineration is the controlled combustion at extremely high temperatures of mixed solid waste to reduce the volume of the waste. The process is highly exothermic (it releases heat) and the objective is the safe disposal of the waste.

Source of waste

Mixed solid waste, including food waste, from municipal, commercial and industrial sources, ideally non-recyclable.

Process

Incineration is a thermochemical conversion technology, like pyrolysis and gasification. Originally, incinerators were designed to reduce the volume of MSW to be disposed of and to destroy pathogens/hazardous substances. Waste incineration where energy is either not recovered or done so inefficiently is classed as disposal and is at the bottom of the waste hierarchy, and is therefore less desirable in terms of overall environmental performance than recycling or recovery options²⁵.

Waste incinerators have been a technology used for more than a century. Since those days, however, these waste burning facilities have evolved to include energy extraction from the combustion process. Their permitted emission standards have been significantly restricted over time to avoid emission of persistent organic pollutants (POPs) from burning hazardous materials such as polyvinyl chloride. Modern incineration plants have complex air pollutant emission reduction systems. Where energy is recovered from the combustion process, usually in the form of electricity and heat, the process

is generally referred to as 'energy from waste' (EfW), waste to energy (WtE) or 'energy recovery'. EfW technologies are generally seen as a form of disposal in the waste hierarchy. In many cities, incineration facilities are well located to provide district heating to local communities, which improves

the economics of any scheme and helps with public acceptance of the waste facility. Sweden, Denmark, Germany and Japan are examples of countries which send more than 90% of their residual waste to incineration or energy recovery and produce both electricity and district heating from them.

In many countries there is a large amount of potentially combustible residual waste still disposed of in landfill that could be utilised in incineration with energy recovery and therefore there is potential room for growth in both forms of recycling (including AD) and incineration with energy recovery – at the expense of landfilling²⁶. However, this is country-dependent and those countries that first built large EfW capacities have seen the increase of recycling result in the reduction of the amount of waste to be burnt, leading to a market in the import of waste to feed these plants in Germany, Denmark, Sweden, Norway, the Netherlands and Austria.



²⁵DEFRA (2014). *Energy from waste: A guide to the debate*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/284612/pb14130-energy-waste-201402.pdf.

²⁶DEFRA (2014). *Energy from waste: A guide to the debate*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/284612/pb14130-energy-waste-201402.pdf

Some of the controversies around EfW technologies are that, since they require very large capital investments that need to be amortized over long periods of time, they often lock cities to keep generating high amounts of waste for decades to feed the incinerator and can hinder efforts to increase recycling or reduce the amount of non-recyclable plastics in the waste-stream. Additionally, as most of the materials that can be burned are carbon-based (plastics, wood, food and green waste) it means that carbon that was already stored in those materials will be released into the atmosphere in the form of CO₂, worsening global warming.

Some estimates put the carbon intensity of EfW, that is, the amount of CO₂ released per ton combusted, on the same level as burning coal²⁷.

Products

The products of waste combustion are generally electricity and heat. Ash is also produced, from which it is possible to extract some recyclable materials as well as waste for landfilling.

Scale

Usually over 100,000 tonnes per year.

Advantages:

- An advantage of incineration and energy recovery is that food and other waste streams are not required to be separated at source. This saves on collection costs. However, incineration with energy recovery could also be used in conjunction with separate food waste, garden waste and dry recyclable collections, providing a more efficient approach that maximises recycling rates and recovers energy from non-recyclable residual waste; and
- Depending on the treatment options for the bottom ash formed by the inorganic constituents of the waste, ferrous and non-ferrous metals can be recovered and the remaining ash can be further enhanced to be used for road construction and buildings²⁸.

Disadvantages:

- Sending food waste to incineration with energy recovery is not an efficient use of the resource compared to AD or composting. One study has estimated AD to be capable of recovering 60% more energy than EfW²⁹;
- Lack of nutrient recovery: Incineration with energy recovery using mixed waste which includes food waste does not capture the nutrient value of the food waste, which

could be converted to fertiliser through composting or AD. Whereas incineration with energy recovery recovers part of the energy content of the waste, AD both recovers the energy content (and heat) and the nutrient content of the waste;

- Incineration with energy recovery facilities usually require higher tonnages to be cost effective³⁰, compared with much smaller amounts for composting or AD;
- The capital cost of installation is high, although savings can be made against the cost of separate collection of food waste and other recyclables;
- Not a good option to treat food waste due to the high moisture content. Thermochemical conversions such as incineration operate best when they treat dry materials³¹. Certainly where food waste constitutes high percentages of total waste, as in developing economies, there are few energy recovery gains to be made from burning high volumes of very wet food waste; and
- Incineration releases carbon to the atmosphere in the form of CO₂. The impacts from this carbon release are worse in the locations where there is less source segregation.

²⁷U.S. EPA Clean Energy web page, "How Does Electricity Affect the Environment," <http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html>

²⁸World Energy Council (2016) World Energy Resources - Waste to Energy. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf.

²⁹Valorgas (2014) Valorisation of food waste to biogas, Pg. 33 http://www.valorgas.soton.ac.uk/Pub_docs/VALORGAS_241334_Final_Publishable_Summary_140110.pdf

³⁰World Energy Council (2016) World Energy Resources - Waste to Energy. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf

³¹World Energy Council (2016) World Energy Resources - Waste to Energy. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf.

C) Landfill without gas collection

A sanitary landfill is a site for the disposal of solid waste materials. Sanitary landfills are designed to protect the environment from contaminants, which may be present in the waste stream³². Historically, waste material has been thrown into pits and left in piles in landfill sites, but more recent practice dictates the waste is buried. Over the course of history, landfills have been the most common method of organised waste disposal and remain so in many places around the world.

Source of waste

Landfills take all types of waste material. Some landfills are designed to take MSW, others to take industrial waste (commercial and institutional waste) and others to take hazardous waste (defined as hazardous for reasons of health or safety risks or pollution risks).

Process

A well-designed landfill site will follow the following steps when waste arrives at the site³³. First, the waste is weighed on the delivery vehicle as it enters the site. It is taken to the working area and tipped out. The waste is then spread and compacted using a bulldozer or landfill compactor. Daily cover of soil or clay is moved to the working area at the end of each day, and that too is spread and compacted. The final cover material is delivered, spread and compacted after the working area has reached the desired waste depth.

Products

No product – sanitary landfills are simply used as a way of disposing of and storing waste.

Scale

Landfilling of waste is a common method of waste disposal across the world. Landfill sites

can vary in size from very small sites taking less than 1,000 tonnes per year to huge sites that can take over a million tonnes per year, such as the one in Xinfeng, Guangzhou, China which encompasses 227 acres, and the one in Bordo Poniente, Mexico City, Mexico, which encompasses 927 acres³⁴.

As of 2015, in Peru, there were 10 sanitary landfills, which process the solid waste of close to 30mn residents. Another 20 dumping sites receive approximately 3,500 tonnes/day of waste³⁵. In Australia, landfill sites are classified as ‘very small’ if they take less than 1,000 tonnes per year, as ‘small’ if they take between 1,000 and 20,000 tonnes per year, ‘medium’ if they take between 20,000 and 100,000 tonnes per year, and ‘large’ if they receive more than 100,000 tonnes per year. The majority of Australia’s landfills are small or very small, receiving less than 20,000 tonnes of waste per year³⁶. At one end of the scale are small, shallow sites with minimal control on the type or quantity of waste entering and no gas collection or leachate management. At the other are large, deep sites with multiple liners where the waste is monitored, compacted and covered, gas is collected for flaring or energy use and leachate is collected and treated to prevent groundwater pollution³⁷.

³²U.S. EPA. What is a landfill? <https://www.epa.gov/landfills/basic-information-about-landfills#whatis>.

³³European Commission (2001) Waste management options and climate change http://ec.europa.eu/environment/waste/studies/pdf/climate_change.pdf

³⁴World Atlas (2017) Largest landfills, waste sites, and trash dumps in the world <https://www.worldatlas.com/articles/largest-landfills-waste-sites-and-trash-dumps-in-the-world.html>

³⁵Peru Solid Waste NAMA (2014) Program for supporting up-scaled mitigation action in Peru's solid waste sector https://www.nefco.org/sites/nefco.org/files/pdf-files/7_peru_solid_waste_nama_concept_note.pdf

Advantages

- Sanitary landfills are cheaper than other food waste treatment/disposal technologies³⁸ both in terms of capital cost and operating cost; and,
- Can take mixed waste: waste does not have to be separated at source.

Disadvantages

- Create lasting detrimental impacts to the environment;
- Require large areas of land and so in populated areas create an issue of space and odours;
- Lead to the release of greenhouse gas emissions to the atmosphere, contributing to climate change, and, if any leakage from the landfill site occurs, this could contaminate the hydrosphere³⁹;
- Can also be extremely dangerous if not designed properly – unstable landfills can lead to disasters such as landslides, such as the one that killed around 300 people in Manila, Philippines in 2000⁴⁰; and,
- Often catch fire emitting toxic substances into the environment.
- Management and maintenance costs can become high over time, also requiring long maintenance post-closure

D) Landfill with gas collection⁴¹

Landfilling continues to be the primary option for disposal of much of the MSW generated throughout the world. When designed, constructed and operated properly, a sanitary landfill can offer an effective method for disposing of waste remaining after recovery of valuable materials (e.g. recyclables, organic waste). A sanitary landfill should be designed and operated to maximise safeguards to the environment and public health, and at a minimum include protections for groundwater (e.g. leachate collection and treatment) and landfill gas (LFG) capture and recovery (flaring or utilisation or both) to reduce air pollution and global warming. A sanitary landfill performs like an anaerobic digester wherein organic waste is disposed and decomposes in the absence of oxygen resulting in the generation of landfill gas (LFG), a gas mixture primarily composed of Methane, CO₂ and water vapour. Maximising the recovery of LFG requires installation of equipment to collect as much of the gas as possible to prevent escape to the atmosphere.

Process

The installation of a gas collection and control system (GCCS) involves placing piping within the waste disposal area connected to a blower or vacuum system that draws the LFG into a central location for combustion by a flare and/or energy recovery. The collection piping can be horizontal, vertical, or a combination of both types. The piping within the waste connects to wellheads which are then connected to lateral piping that carries the LFG to the central header⁴².

³⁶WMAA and Blue Environment (2013) Analysis of landfill survey data <https://www.environment.gov.au/system/files/resources/91763f0e-f453-48d0-b33e-22f905450c99/files/landfill-survey-data.pdf>

³⁷European Commission (2001) Waste management options and climate change http://ec.europa.eu/environment/waste/studies/pdf/climate_change.pdf

³⁸Peru Solid Waste NAMA (2014) Program for supporting up-scaled mitigation action in Peru's solid waste sector https://www.nefco.org/sites/nefco.org/files/pdf-files/7_peru_solid_waste_nama_concept_note.pdf

³⁹CIRAD, INRA (2015). Food Waste recycling into animal feeding in Vietnam. https://umr-selmet.cirad.fr/content/download/4053/29641/version/2/file/NIAS_REPORT_FW2FEED_VN.pdf.

⁴⁰BBC (2000). 'Hundreds' dead in Manila dump collapse. <http://news.bbc.co.uk/1/hi/world/asia-pacific/830809.stm>.

⁴¹The overview, process and products parts of this section has been authored by Brian Guzzone at ERG (Eastern Research Group, Inc)

⁴²U.S. EPA, LMOP. LFG Energy Project Development Handbook. June 2017. <https://www.epa.gov/lmop/landfill-gas-energy-project-development-handbook>.

LFG that is simply flared does not require any treatment or conditioning, however LFG that will be used as an energy source does. The level of treatment and preparation depends upon the energy use technology and the site-specific LFG composition.

Products

LFG is typically about 45-50% CH₄, 45-50% CO₂, and less than 1% other compounds. The CH₄ component of the gas has value as an energy source, giving raw LFG a heating value of about 19 mega joules per cubic metre (MJ/m³)⁴³. In comparison, natural gas in the USA and UK has a heating value between 38-39 MJ/m³. Prepared LFG can be combusted in reciprocating internal combustion engines, other types of engines, gas turbines, micro turbines, utility boiler/steam turbines, and gas turbine/steam turbines to generate electricity; it can also be used in a variety of other technologies to generate heat including boilers, heaters, kilns, burners, and ovens. Some of the electricity-generating projects also create heat by capturing waste heat from the primary technology. These types of technologies require low to moderate levels of LFG treatment and preparation. LFG can also be cleaned to nearly pure methane for

injection into a natural gas pipeline for use in any number of applications, replacing natural gas one-for-one. This pipeline-quality gas can alternatively be used to create vehicle fuel on site as either compressed natural gas or liquefied natural gas, again replacing fossil natural gas resources. As of November 2017, there were 637 currently operating LFG energy recovery projects in the USA, using LFG from approximately 580 landfills⁴⁴. About 75% of these projects generate electricity, about 18% create heat directly, and the remaining 7% clean the LFG to pipeline-quality gas or create vehicle fuel on site⁴⁵. LFG capture projects have been operating for a few decades in all parts of the world including Argentina, Chile, Brazil, Colombia, El Salvador, Europe, Mexico, Poland, Ukraine, China and Republic of Korea⁴⁶.

Scale

All scales, although there are minimum requirements of stored biodegradable materials and moisture content to enable biogas production over time. Landfills comprised of dry waste (where foodwaste for example has been collecting separately and excluded from landfill delivery) will produce little or no biogas.

⁴³U.S. EPA, Landfill Methane Outreach Program (LMOP). LFG Energy Project Development Handbook. June 2017. <https://www.epa.gov/lmop/landfill-gas-energy-project-development-handbook>

⁴⁴U.S. EPA, LMOP. Landfill Gas Energy Project Data and Landfill Technical Data webpage. Accessed on 13/12/2017. <https://www.epa.gov/lmop/landfill-gas-energy-project-data-and-landfill-technical-data>.

⁴⁵U.S. EPA, LMOP. LFG Energy Project Data Files [November 2017]. "Aggregated file of currently operational projects (XLSX)". Accessed December 13, 2017. <https://www.epa.gov/lmop/landfill-gas-energy-project-data>.

⁴⁶Global Methane Initiative (2012). International Best Practices Guide for Landfill Gas Energy Projects. http://www.globalmethane.org/documents/toolsres_lfg_IBPGAppendixA.pdf. Accessed on 04/01/2018.



Advantages

- Relatively low cost to implement and does not require the cost of introducing separate collections;
- Energy is recovered via methane extraction and combustion; and,
- CH₄ has a lifetime of about 12 years in the atmosphere, its actual impact is nearly 90 times more powerful than CO₂ over a 20-year period. Therefore, destruction of CH₄ via flaring or anaerobic digestion, helps mitigate the potential climate effects of landfilled waste.

Disadvantages

- Does not support the reduction in food waste quantities that are associated with separate collections of food waste;
- Recovers less energy than anaerobic digestion operated in controlled conditions;
- Careful management is needed to prevent landfill gas leaks; and,
- Does not recover nutrients or help build organic matter in soils.
- LFG capture is never 100% efficient, meaning that some methane will still escape to the atmosphere, contributing to global warming and decreased air quality.

E) Mechanical Biological Treatment (MBT)

Mechanical biological treatment (MBT) describes a number of different processes dealing with the treatment of waste. It is the combination of both biological and physical processes, which can be arranged in a number of different ways. MBT is an established waste treatment technology in many European countries such as Germany, Italy, the UK, and Austria⁴⁷.

Source of food waste

Though MBT is capable of dealing with both mixed waste and source separated waste, it tends to be used for the former, for residual or “black bag” waste.

Process

The mechanical part, which is the physical stage of an MBT process, is normally at the front end of the process. The aim of the mechanical process to separate the drier fractions from the wet organic fraction through mechanical separation, leaving on the one hand mixed dry fractions such as plastics, paper and textiles, and on the other an organic-rich fraction or biodegradable fraction which is destined for biological treatment.

Mechanical separation processes can include any number of the following: size reduction or shredding of the waste, separation of ferrous and non-ferrous metals, heat or steam treatment and screening and/or size reduction of outputs. Not all of these processes are used in each MBT facility – what exactly is done will depend on individual aims and circumstances. The mechanical process can be both a dry and wet process depending on the role of the final product. Though the mechanical part is normally at the front end of the process, it can also play a key role at the back end of the process. For example, the plant can be designed to have mechanical screening to take out further contaminants and or reduce particle size at the end of the process, especially if the residues are going to be used for a purpose other than landfilling.

The biological processes of MBT include aerobic decomposition to AD, or a combination of the two. AD is outlined in more detail in Chapter 5. The key here is that AD of mixed MSW will not produce a material of appropriate quality without some form of mechanical treatment at the front end of the MBT plant.

⁴⁷Chartered Institute of Waste Management (CIWM). Mechanical Biological Treatment. <https://www.ciwm.co.uk/ciwm/knowledge/mechanical-biological-treatment.aspx>.

Products

The mechanical process recovers dry recyclables such as cardboard, plastics, paper and metals. The biological process, like AD, will produce biogas which can be used in different ways as well as compost, which, depending upon the quality and local regulations, may have a use or be classified as a waste. Contamination of all the recovered materials from MBT is a significant issue resulting in very low yields of reusable materials that often constitute no more than 8% of outputs, the rest being waste. The advantage of MBT is that it reduces the volume of waste through the evaporation process, takes out the putrescible (food waste) fraction, and leaves a drier fraction suitable for burning, also known as refuse derived fuel (RDF). Specialised MBT plants making RDF to specific standards for burning in cement kilns and EfW plants are now common.

For the purposes of this report, the output of MBT from food waste mixed with other wastes is a very low-quality, contaminated compost whose uses are limited mainly to cover of contaminated sites or daily cover of landfills.

The EU Fertiliser Regulations, being revised and awaiting entry into law as we write in early 2018, prohibits the use of mixed waste as a feedstock for fertilisers⁴⁸.

Scale

MBT plants can operate at large scale with inputs of more than 1,000 tonnes per day or at a smaller scale. MBT plants are not a final disposal operation, and require disposal options for their outputs – either landfills or incineration.

Advantages

- Allows recycling of material otherwise inefficiently combusted or landfilled;
- Does not require the cost associated with the separate collection of food waste; and
- Allows energy recovery from food waste via the anaerobically digested organic fraction.

Disadvantages

- Residue material is not of sufficiently high quality to be used in farming or horticulture, thus nutrient and organic matter is wasted;
- High cost of construction and operation;
- Energy intensive process to separate an organic fraction from recyclables and other material; and
- Digestion of organic material containing variable inorganic materials can be a complex process, with an ongoing risk of performance failures.
- Requires a final disposal route for the non-recyclable outputs, whether to incineration or landfill

⁴⁸European Parliament (2017). Review of the Fertilising Products Regulation. <http://www.europarl.europa.eu/legislative-train/theme-new-boost-for-jobs-growth-and-investment/file-review-of-the-fertilising-products-regulation>.

F) Pyrolysis.

Pyrolysis is the heating of an organic material in the absence of oxygen, resulting in the decomposition of organic material into gases and charcoal. It is therefore a technology that involves thermochemical conversion, like incineration, EfW and gasification. Compared to combustion, pyrolysis has a lower process temperature, lower emissions of air pollutants and the scale of pyrolysis is also more flexible than incineration plants⁴⁹.

Sources of waste

One of the great advantages of this process is that many types of raw materials can be used, including industrial and domestic residues. The pyrolysis process can use many waste types including MSW, waste plastics, medical waste, rubber and tyres, e-waste, biomass/wood and organic sludge. The fractions of MSW subjected to pyrolysis mainly consist of paper, cloth, plastics, food waste and yard waste.

Process

Pyrolysis allows the utilisation of all carbon-containing materials both organic and inorganic as opposed to commonly used biological methods of waste disposal.

Pyrolysis of MSW on an industrial scale is carried out in rotary kilns, because they provide sufficient heat transfer with relatively low energy consumption. In general, slow pyrolysis of organic waste (e.g., wood, food and garden waste, paper, natural textiles) is usually carried out at temperatures of about 400-500°C and heating rates of 5–20°C/minute under nitrogen flow. Fast pyrolysis is more complicated, but it is also used.

Products

Pyrolysis is a flexible technology that can generate a combination of solid, liquid and gaseous products in different proportions, by varying the operating parameters such as temperature or heating rate. It also provides an opportunity to transform materials of low-energy density into bio-fuels of high-energy density, and at the same time recover high value chemicals.

Scale

Can be designed to operate on as little as 10 tonnes per day⁵⁰

Advantages:

- Can potentially operate at smaller scale;
- No additional oxygen is required for the process (only heat), unlike EfW⁵¹; and
- Potentially more efficient than EfW. However, as outlined in the gasification section above, there is still debate the efficiency of both gasification and pyrolysis compared to EfW.

Disadvantages:

- Lack of nutrient recovery: like gasification and EfW, pyrolysis does not obtain the

nutrient value of food waste, which could be converted to fertiliser through AD. Whereas pyrolysis recovers the energy content of the waste, AD recovers both the energy content and the nutrient content of the waste;

- Lower carbon efficiency compared to AD in terms of GHG emissions⁵²;
- Higher capital costs than EfW due to the complexity of the process; and
- There are few operational full-scale facilities treating MSW so operational experiences are limited – lack of technology maturity.

The following chapters give an overview of the AD process and technology, the products of AD and how the technology can be implemented with the support of incentives, regulations and policies.

⁴⁹Thermal Science and Engineering Progress (2017) https://ac.els-cdn.com/S2451904917300690/1-s2.0-S2451904917300690-main.pdf?_tid=b8a5a210-df2b-11e7-a16c-00000aab0f01&acdnat=1513076645_08bfddb5b8fc7ad42624169120700043

⁵⁰World Energy Council (2016) World Energy Resources - Waste to Energy. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf.

⁵¹World Energy Council (2016) World Energy Resources - Waste to Energy. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf.

⁵²World Energy Council (2016) World Energy Resources - Waste to Energy. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf

5. ANAEROBIC DIGESTION

5.1. Introduction and overview

This chapter looks at how anaerobic digestion (AD) technologies can treat food and other wastes collected in cities and transform these streams into energy and soil nutrients. The chapter explains AD as a process and explores its benefits. The different stages of

the AD process are discussed, followed by information on the practicalities and financial costs of setting up and operating a biogas plant. The products of AD and their utilisation are discussed here briefly and then in greater detail in Chapter 6.

5.1.1. The process

AD is a series of biological processes in which micro-organisms digest plant and/or animal material in sealed containers, producing biogas, which is a mixture of methane, carbon dioxide and other gases. The organic material left over, known as digestate, is rich in organic matter and nutrients such as nitrogen, phosphate and potash. Biogas and digestate are therefore both important outputs of AD and their uses are explained below.

The difference between AD and composting is that anaerobic digestion occurs within containers in absence of oxygen, whereas composting, or aerobic digestion, requires oxygen.

5.1.2. The waste feedstocks suitable for AD

A wide range of organic matter, such as domestic and commercial food waste, municipal and industrial sewage, agricultural material and livestock manures, can be digested via AD. For this report, 'organic matter' means any material derived from

recently-living organisms. It should be noted that when organic materials are landfilled, their decomposition emits biogas in much the same way, and can be captured through landfill gas technologies. These are explained in Chapter 4.

Urban waste for AD may include¹:

- **Lipid wastes, including fats, oils and greases;**
- **Simple carbohydrate wastes, including bakery waste, brewery waste and sugar based solutions;**
- **Complex carbohydrate wastes, such as fruit and vegetable waste and organic fraction of municipal solid waste (MSW);**
- **Protein waste, such as waste from abattoirs and dairy processing facilities; and**
- **Other waste from commercial and industrial facilities.**

¹U.S. EPA (2014). *Food Waste to Energy: How Six Water Resource Recovery Facilities are Boosting Biogas Production and the Bottom Line*. https://www.epa.gov/sites/production/files/2016-07/documents/food_waste_to_energy_-_final.pdf.

5.1.3. Products and co-products of AD

The purpose of AD is usually to produce biogas and nutrients. Biogas contains methane and it is the combustion of the methane element which constitutes the energy component of biogas. This energy may be used in many different ways:

COMBUSTED DIRECTLY IN:

- Domestic stoves for cooking or used in gas lamps for lighting, after minor modifications^{2,3}.

COMBUSTED IN:

- Boilers to generate heat;
- Internal or external combustion engines to produce electricity;
- Combined heat and power (CHP) plants to produce both heat and electricity; and
- Tri-generation systems to provide cooling via absorption chillers in addition to heat and electricity.

UPGRADED INTO BIOMETHANE:

- To be used as vehicle fuel in gas-powered vehicles;
- To be used in place of natural gas in industrial, commercial and domestic uses; and
- Carbon dioxide may be extracted for commercial use, for example as a feedstock in greenhouses.

PROCESSED INTO HIGHER VALUE PRODUCTS SUCH AS BIO-PLASTICS OR BIO-CHEMICALS.

A co-product of the AD process is a material called 'digestate', containing water, nutrients and organic carbon suitable for soils. Digestate is the remaining part of the material fed into the digester once the gas is extracted. The digestate may be used as a bio-fertiliser

and applied to land ⁴ as 'whole digestate', composted, or separated into liquid and solid fractions before being applied to land. Elemental fertilisers may also be extracted from digestate for more targeted applications. These are considered in greater detail in Chapter 6.

^{2,3}Sasse L, Kellner C and Kimaro A (1991). *Improved Biogas Unit for Developing Countries*. http://www.susana.org/_resources/documents/default/2-535-sasse-1991-improved-biogas-unit-for-developing-countries.pdf

⁴World Biogas Association (2016). *The contribution of Anaerobic Digestion and Biogas towards achieving the UN Sustainable Development Goals*.

5.1.4. The benefits of AD

The AD of food waste has multiple benefits in the form of:

RENEWABLE ENERGY PRODUCTION:

- Production of baseload energy for sustained energy use;
- Production of energy that can be stored and used to meet peak load demand;
- Generation of electricity for on-site, local or injection into the electricity grid;
- Off-grid, localised energy production;
- Enhanced energy security from domestic sources;
- Reduced dependence on fossil-fuel energy;
- Generation of heat from CHP units within biogas plants;
- Generation of biomethane for vehicle fuel; and
- Generation of biomethane for on-site, local or injection into the natural gas distribution network.
- Generation of energy in combination with other forms of power generation, e.g. together with wind and solar power

CLIMATE CHANGE MITIGATION:

- Reduced greenhouse gas emissions and particulate emissions by substituting fossil fuels such as coal and oil as energy supplies to buildings, homes and industry;
- Reduced greenhouse gas emissions from vehicles by substitution of diesel and gasoline with biomethane as fuel;
- Reduction of uncontrolled methane emissions in dumps and landfills and generation of renewable energy from untreated food and other organic wastes;
- Capture of biogas from landfills avoiding methane emissions;

Substitution of synthetic and mineral fertilisers with digestate bio-fertiliser; and

- Reduction of deforestation by replacing solid-biomass-based domestic fuels with biogas.
- Using digestate to restore the carbon storage and sequestration capacity of soils

CONTRIBUTING TOWARDS A CIRCULAR ECONOMY:

- Improving the self-sufficiency and sustainability of industries by extracting the energy from their own effluents and using it for the self-generation of electricity and/or heat; and
- Recirculating nutrients and organic matter in organic wastes through AD and returning them to the soil in the form of digestate bio-fertiliser.

IMPROVING URBAN AIR QUALITY:

- Substituting biomethane for fossil fuel in vehicles; and
- Substituting biogas for solid fuel for domestic cooking and heating.
- Avoiding the uncontrolled release of methane from landfills, which then acts as an ozone precursor in the atmosphere, deteriorating air quality

CONTRIBUTING TOWARDS FOOD SECURITY:

- Restoring soils through the recycling of nutrients, organic matter and carbon;
- Increasing crop yields through use of nutrient-rich digestate bio-fertiliser; and
- Recirculating phosphorus, which is essential for the growth of plants.

These benefits of AD are closely linked to many of the UN Sustainable Development Goals, including 2, 3, 5, 6, 7, 9, 11, 13 and 15.

IMPROVING HEALTH AND SANITATION THROUGH BETTER SOLID WASTE MANAGEMENT:

- Treating and recycling organic wastes to reduce odours and the spread of diseases from uncontrolled dumping;
- Preventing spread of diseases through collection and proper management of organic waste;
- Improving sanitation and hygiene through decentralised and local treatment of organic and sewage waste;
- Protecting water bodies; and
- Reducing the carbon load of wastewater to reduce impact on water bodies.

ECONOMIC DEVELOPMENT AND JOB CREATION:

- Generating short-term construction employment and long-term equipment manufacturing and maintenance employment, as well as plant operations employment;
- Encouraging growth of new enterprises by providing reliable electricity that can be stored and used when needed, i.e. baseload energy;
- Generating employment in the waste sector by collecting food and other biogenic wastes separately and through sales of digestate; and
- Improving quality of life in marginal farming communities and reducing migration from these by improving crop yields and sanitation, lighting and heating.

In addition to contributing to the UN SDGs, AD of food waste has the following advantageous characteristics:

- **DIVERSE AND LOCAL FEEDSTOCK** – AD is a flexible process and can take multiple, locally available feedstocks in varying quantities, including household food waste, abattoir waste, brewery slops, fruit waste and palm oil mill effluents. It must be noted that some operational aspects of a biogas plant need to be adjusted for variation in feedstock to sustain the biological process and optimum gas production.
- **FLEXIBILITY OF SCALE** – AD has no minimum scale of implementation and its maximum scale is limited only by the amount of feedstock available within feasible distances. AD can provide anything from cooking gas for one family to baseload energy for a manufacturing facility, depending on the size of the plant and feedstock. It can be implemented to digest food waste of a family, community, restaurant, industry or city.
- **FLEXIBLE USE OF BIOGAS** – Biogas can be utilised in a way that is most beneficial for the generator. If the plant is built onto a distillery, biogas produced can be used to generate heat; if the plant is run on municipal food waste, then the biogas can be upgraded and used as fuel for collection vehicles or local public transport buses; if there is a need for electricity, the best use may be generation of electricity via a CHP engine.
- **MULTIPLE REVENUE STREAMS** – Each of the products and by-products of AD – electricity, heat, cooling, biomethane, carbon dioxide, digestate and elemental fertiliser – can be a revenue stream. For example, a biogas plant employing a CHP engine can generate income or reduce expenditure from the electricity and heat generated and the digestate produced. Similarly, a biogas plant upgrading biogas to biomethane can generate income from the biomethane and also potentially from carbon dioxide and digestate.

5.1.5. Examples of existing AD plants in city contexts

AD of food waste is an established technology. It has been implemented widely for the treatment of food waste and wastewater streams from sewage. Selected global examples are cited below^{5,6,7}.

- **RESIDENTIAL FOOD WASTE** – Munich (Germany), Milan (Italy), Forbach (France), Madrid (Spain), Vienna (Austria), Upsala (Sweden), Oslo (Norway)⁸, Zurich (Switzerland), Wijster (the Netherlands), Hinjewadi, Pune (India)⁹, Malur (India)^{10,11}.
- **COMMERCIAL FOOD WASTE** – Bernau (Germany), Hartberg (Austria), Skrzatusz (Poland)¹², London (UK)¹³, Chennai (India)¹⁴, Chiba (Japan)¹⁵.
- **FOOD AND DRINKS PROCESSING INDUSTRY**
 - **BREWERIES** – Heineken (Nigeria), SABMiller (Uganda) AB InBev (Russia), Diageo (Kenya, Ghana), Beer Thai (Thailand)¹⁶, Khon Kaen Brewery (Thailand)¹⁷, Brakina Brewery (Burkina Faso)¹⁸;
 - **ABATTOIRS** – Jan Kempdorp Abattoir (South Africa)¹⁹, Grossfurtner St Martin (Austria)²⁰;
 - **FRUIT AND VEGETABLE PROCESSING** – Bonduelle (Hungary)²¹;
 - **DAIRY PROCESSING** – Lactalis Retiers (France), Danone (Belgium), Amul Dairy (India)²²; and
 - **CONFECTIONARY** – Mars, Veghel (Poland)²³.
- **MUNICIPAL WASTE WATER WITH FOOD WASTE** – Riihimäki (Finland)²⁴, Ulsan (South Korea)²⁵, Radeberg (Germany)²⁶, Sheboygan Regional Wastewater Treatment Facility, Wisconsin, the West Lafayette Wastewater treatment facility, Indiana (USA)²⁷.

5.2. The Process of AD

5.2.1. Description of biogas plant processes

A biogas plant treating food waste will consist of a reception area, where the food waste from various sources is received. The waste will reside in the reception area for some hours whilst it is loaded into the next stage - pre-treatment.

⁵Bin2Grid (2016) Good practice on segregated collection of food waste http://www.bin2grid.eu/documents/73603/136534/D2.1_Good+practice+on+segregated+collection+of+food+waste.pdf

⁶Bin2Grid (2016) factsheets on Good Practice of Biogas upgrade http://www.bin2grid.eu/documents/73603/136970/Eng_Bin2Grid_revision.pdf/2dbe8c8b-1656-4336-8438-a15fcd632331

⁷Waterleau (2014) Environmental solutions for the food and beverage industry http://barley-malt.ru/wp-content/uploads/2014/03/food-and-beverage_eng.pdf

⁸City of Oslo (not dated) Circular economy in practice <https://www.oslo.kommune.no/english/politics-and-administration/green-oslo/best-practices/circular-economy-in-practice/#gref> accessed on 27/02/2018

⁹Indian Biogas Association (2017) Biogas Magazine 03 <https://biogasindiantechassociation.app.box.com/v/Biogas-Magazine-E03>

¹⁰Mantri G (2017) How this Bengaluru company is leading the way in turning wet waste into green fuel <https://www.thenewsminute.com/article/how-bengaluru-company-leading-way-turning-wet-waste-green-fuel-71908>

¹¹Kakkar H (2017) Good Businesses 2017: Masters of Waste https://www.outlookbusiness.com/specials/good-businesses_2017/masters-of-waste-3744

¹²FABbiogas. Best Practice: Biogas plant in Skrzatusz, Wielkopolska http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_Skrzatusz_english.pdf

¹³Xergi Case Study: Willen Biogas <https://www.xergi.com/cases/willen-biogas.html> Accessed on 05/03/18

¹⁴Ministry of New and Renewable Energy (2017) Akshay Urja Newsletter Volume 10 Issue 4&5 <http://mnre.gov.in/file-manager/akshay-urja/january-april-2017/EN/Images/41-43.pdf>

¹⁵Global Environment Centre (2012) Waste recycling technologies adopted in Eco-towns in Japan http://nett21.gec.jp/ECotowns/WRT_Eco-towns.pdf

¹⁶Beer and Brewer magazine (2011) Asian breweries realise the overlooked green energy potential of waste water http://www.globalwaterengineering.com/media/Asian_breweries_realise_the_overlooked_green_energy_potential_of_waste_water.pdf

This generally involves maceration of the feedstock, screening and pressing. Packaging, such as plastic bags, is stripped out, while any metallic items such as cutlery may be removed using magnetic devices to prevent damage to moving parts. In addition, grit (such as glass, egg shells, ceramics, bones and sand) may need to be removed at the pre-treatment stage, if the digester does not have an internal capability of extracting these. If not removed, grit may build up at the bottom of the tank over a period of time leading to loss of volume and failure of the system.

After the pre-treatment process, the food waste is fed to the digester where it undergoes decomposition in the absence of oxygen. This process can take place at different operating temperatures and system set-ups (discussed further below). During this process, biogas is released and collected in biogas storage tanks or in an inflatable dome. To reduce the sulphur content in biogas, it is piped to a desulphurisation unit. The biogas, which is rich in methane, may be processed further depending upon the desired end use: electricity, heat, cooling or vehicle fuel. Within the digester,

the organic material that is left over after digestion, or digestate, is extracted and may then undergo pasteurisation, followed by composting or separation of wet and dry solids for application to agricultural land, depending on the use and regulations of the jurisdiction.

The AD process is shown in Figure 8 below:



Figure 8: The AD process – inputs, outputs and processes

¹⁷Envirex Thailand brewery installs wastewater treatment plant, generating biogas and reducing sludge volume <http://www.evoqua.com/en/brands/Envirex/Pages/boon-rawd-brewery-thailand-cd.aspx> Accessed 17/12/2017

¹⁸FasoBiogaz (2015) General information http://www.fasobiogaz.com/wp-content/uploads/2017/05/FasoBiogaz_General-information.pdf

¹⁹Global Methane Initiative (2013) Successful applications of anaerobic digestion from across the world <https://www.globalmethane.org/documents/GMI%20Benefits%20Report.pdf>

²⁰Fab Biogas. Best-Practice: Biogas Plant in St Martin, Upper Austria. http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_St.Martin_english.pdf

²¹Veolia. Europe's leading producer of canned goods reduces its energy bill thanks to biogas. <https://www.veolia.com/en/our-customers/achievements/industries/food-beverage/hungary-bonduelle>. Accessed on 17/12/2017.

²²Ministry of New and Renewable Energy (2017). Newsletter Jan-April 2017. <http://mnre.gov.in/file-manager/akshay-urja/january-april-2017/EN/Images/41-43.pdf>.

²³Veolia. Mars turns its wastewater into clean energy. <https://www.veolia.com/en/our-customers/achievements/industries/food-beverage/netherlands-mars>. Accessed on 17/12/2017.

²⁴Watrec. Solution to Circular Economy's biowaste challenge. <http://www.watrec.com/references/our-projects/biogas-plants/riihimaki-biogas-plant/>. Accessed on 17/12/2017.

²⁵Kang Ho (2013). IEA Task 37 South Korea Country Report. <http://task37.ieabioenergy.com/country-reports.html>.

²⁶Fab Biogas. Best-Practice: Biogas Plant in Radeberg, Germany. http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_Radeberg_GER_english.pdf.

²⁷U.S. EPA (2014). Food Waste to Energy: How Six Water Resource Recovery Facilities are Boosting Biogas Production and the Bottom Line https://www.epa.gov/sites/production/files/2016-07/documents/food_waste_to_energy_-_final.pdf.

5.2.2. Within the digester

Many different types of anaerobic digesters are available. These vary in configuration, retention time, pre- and post-treatment requirements and operating temperature among other things, depending upon the principal feedstocks being treated. During AD, the breakdown of organic compounds is achieved by a combination of many types of bacteria and archaea (microbes).

The biomass added to the digester is broken down into sugars, amino acids and fatty acids (hydrolysis), fermented to produce volatile fatty acids and alcohols (acidogenesis) followed by the conversion into hydrogen, carbon dioxide and ammonia and, finally methanogens produce biogas from acetic acid and hydrogen. These stages are shown in Figure 9 below²⁸.

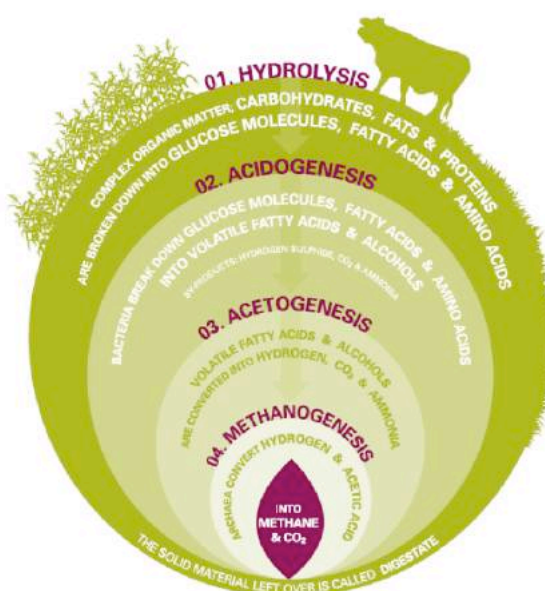


Figure 9: The four stages of the AD process

AD of food waste takes place at two optimum temperature ranges, 35-40°C (mesophilic) and 55-60°C (thermophilic)²⁹. Most food waste AD plants around the world operate in the mesophilic range as less heat is required to maintain that temperature and also the digestion process is more stable under these conditions; examples are plants in London,

UK³⁰, the town of Hartberg, Austria, and city of Milan, Italy³¹.

Thermophilic reactors, though requiring greater attention to operate, are sometimes installed as they accelerate degradation rates, creating higher yields of biogas and reduce pathogens in the digestate produced.

²⁸ADBA (2017). *The Practical Guide to AD (Second Edition)*. <http://adbioresources.org/library/purchase-the-practical-guide-to-ad>.

²⁹ADBA (2017). *The Practical Guide to AD (Second Edition)*. <http://adbioresources.org/library/purchase-the-practical-guide-to-ad>.

³⁰Agrivert. North London AD Facility. <https://www.agrivert.co.uk/where-we-operate/north-london-ad-facility>.

³¹Bin2Grid (2016). *Good practice on segregated collection of food waste*. http://www.bin2grid.eu/documents/73603/136534/D2.1_Good+practice+on+segregated+collection+of+food+waste.pdf.

Thermophilic digesters are in operation in, among others, the cities of Augsburg (Germany), Forbach (France) and City of Zurich (Switzerland). These digest

municipal, commercial and industrial food waste as well as green waste³². Hermitage Municipal Authority (USA) co-digests food waste with wastewater³³.

5.2.3. Digester configurations

Based on the constituents and consistency of the food waste treated, an anaerobic digester can be designed as a 'wet', 'dry', 'liquid' or 'co-digestion' system. Figure 10 provides information about these configurations³⁴.

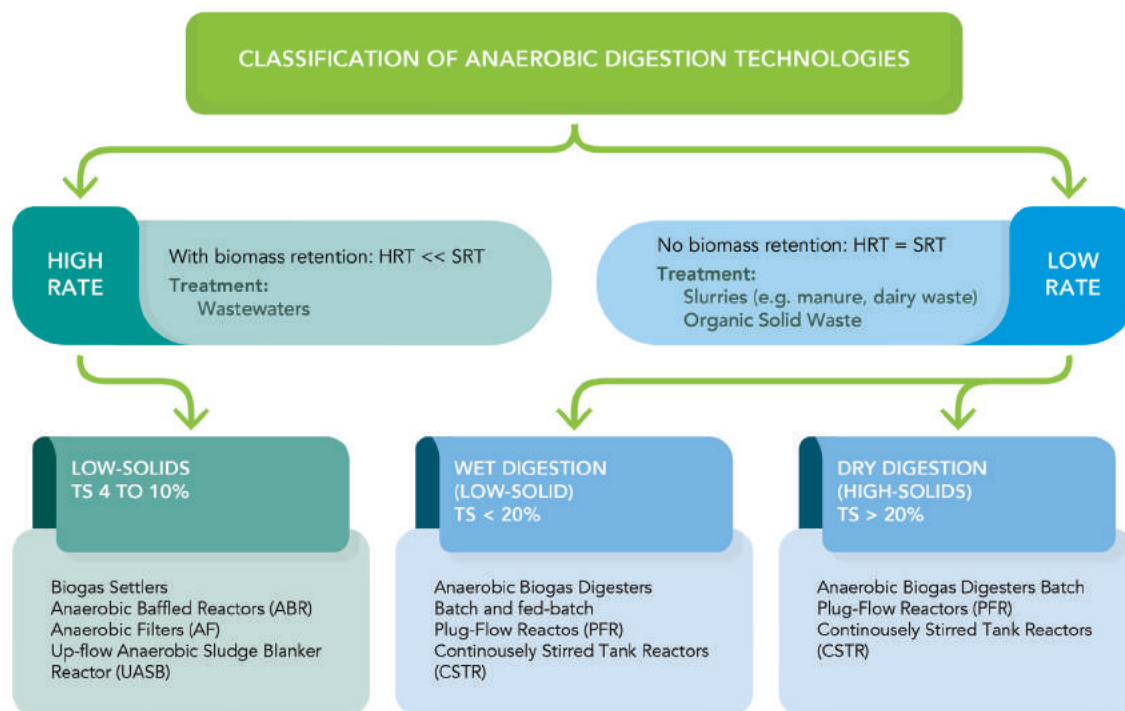


Figure 10: Different types of AD technology (HRT: Hydraulic Retention Time, SRT: Solids Retention Time)

Wet Digestion

Wet digestion is suitable for AD of most food wastes such as source segregated food waste collection from residents, commercial and industrial organic wastes from supermarkets, food processing plants and food services. Digestion of food waste in a wet system may take place in a CSTR (Completely/Continuously Stirred Tank Reactor) digester, a term often misused for a

displacement digester, where a small volume of fresh feed is input to displace an equal amount of digestate exiting from the outlet. The feedstock contains typically less than 15% dry solid matter but can be up to 20%. In a CSTR digester, all stages of the AD, namely hydrolysis, acidification and methanogenesis, occur in parallel. These are the more common, cylindrical shaped digesters.

³²Bin2Grid (2016). Factsheets on good practice of biogas upgrade. http://www.bin2grid.eu/documents/73603/136970/Eng_Bin2Grid_revision.pdf/2dbe8c8b-1656-4336-8438-a15fcd632331.

³³Waste Management World (2016). VIDEO: Food Waste Co-Digestion a Success at Pennsylvania Wastewater Plant. <https://waste-management-world.com/a/video-food-waste-co-digestion-a-success-at-pennsylvanian-wastewater-plant>.

³⁴Spuhler D (not dated) Anaerobic Digestion (General) <https://www.sswm.info/sswm-university-course/module-6-disaster-situations-planning-and-preparedness/further-resources/anaerobic-digestion-%28general%29>

Plug flow digesters, on the other hand, treat food waste entering the system as a distinct unit that undergoes the various stages of AD sequentially, with little or no mixing. While horizontal plug flow systems operate within the 25-40% dry solids range, vertical systems can treat feedstock with 45-50% dry solids. These are more efficient than the CSTR as reactions take place under closer to optimum conditions and there is less likelihood of untreated feedstock leaving the digester.

In multistage systems, the processes of AD take place sequentially in multiple tanks. Typically, the acidogenesis stage of the process is carried out in one tank while the methanogenesis stage in another. This accounts for the different pH levels and process times required during these two stages for optimum biogas production, resulting in smaller digester volume or higher biogas yield. Wet digestion can take place under either mesophilic or thermophilic conditions.

Dry Digestion

Dry digestion is most suitable for organic waste with a higher component of solids such as food waste that is collected along with garden waste. It is a minimal disruption option for composting plants looking to upgrade or upscale their operations or who wish to improve odour or space management.

Static dry digestion systems work under mesophilic conditions and are designed like

garages (i.e. a simple concrete room with a door), where new feedstock is mixed in with the digestate from the previous batch to provide microorganisms to start the digestion process. Factoring in the recirculation, the hydraulic retention time is about 50 days. While there is little pre-treatment required for dry digestion, post digestion it is important to remove contaminants like plastic, metals and ceramics, stabilise the digestate to minimise emissions and run-off, and potentially pasteurise it to reduce pathogens, to obtain an organic soil amendment that is nutritionally high and does not pose a risk to plant and human health or the environment.

Examples of towns where dry digestion has been implemented include San Jose (USA)³⁵, Munster (Germany)³⁶, Munich (Germany)³⁷ and Busan (South Korea)³⁸. It is a good option for emerging economies where the contamination rates in source segregated food waste may be difficult to control and reduce.

Liquid Digestion

Liquid digestion is most suited for food and drink industries which generate large volumes of wastewater with low suspended solids such as effluent from breweries, sugar factories, drinks factories, starch factories, potato processing and confectionary manufacturing. Some examples from around the world are noted in Section 5.1.5. These systems typically have low hydraulic retention times of less than two days by forming a granular microbial

³⁵U.S. EPA. Zero Waste Case Study: San Jose. <https://www.epa.gov/transforming-waste-tool/zero-waste-case-study-san-jose>.

³⁶Organic Waste Systems. DRANCO plant Munster Germany. <https://www.youtube.com/watch?v=mk22oKWYPcQ&feature=youtu.be>.

³⁷Abfallwirtschaftsbetrieb München. Renewable Energy for Munich – Green Electricity from Biowaste. https://www.awm-muenchen.de/fileadmin/PDF-Dokumente/awm/Folder_TFA_2012_englisch_fin_72dpi.pdf.

³⁸Korea Environmental Industry and Technology Institute. Electric power production technology with food waste. http://www.eliskorea.org/01_EnvironmentalTech/01_newTech_down.asp?schMenuCode=M9300&schTabCode=&strIdx=805&strFileIdx=1&schCom=&schSearch=&intPage=1.

structure around a fixed membrane to maintain a high density of microbes and microbial activity. Thereafter, the process is similar to that explained above for wet digestion, biogas is utilised for energy and digestate is transported for utilisation on land.

Co-digestion

Cities can benefit from the possibility of treating their food waste along with wastewater sludge from sewage plants, where environmental regulations allow. Such co-digestion of different waste streams appears to be on the increase because there are benefits to both parties. Wastewater treatment plants or recovery facilities which typically have high energy requirements benefit from the high energy value of food waste while food waste collectors benefit from any excess capacity of the wastewater treatment plants and lower capital cost of upgrading existing facilities – the economies of scale of larger sites. Together these make the AD of both food waste and

wastewater sludge environmentally and economically more feasible.

There are a number of examples of co-digestion of wastewater sludge and food waste in the USA: the Central Marin Sanitation Agency, San Rafael, California; Sheboygan Regional Wastewater Treatment Facility, Wisconsin; West Lafayette Wastewater treatment facility, Indiana; and Janesville Wastewater Treatment facility, Wisconsin³⁹. It has also been implemented in South Korea in many plants, including Yongyeon, Ulsan, Hyuncheon Goyang-si, Anrak Busan, Seobyun Daegu and Dongchun Incheon⁴⁰, Riihimäki, and Oulu in Finland⁴¹, Zirl in Austria⁴² and Radeberg in Germany⁴³.

Co-digestion of food waste with manure and other agricultural residues has also been implemented globally, though as these plants are generally situated in rural areas. These operations are not discussed further in this report, as the focus is on urban food waste.

5.2.4. Composition of biogas

Biogas is composed primarily of methane and carbon dioxide with trace amounts of nitrogen, hydrogen, oxygen, water vapour, hydrogen sulphide and ammonia. Table 3 shows typical ranges of these compounds in biogas⁴⁴.

TABLE 3: TYPICAL COMPOSITION OF BIOGAS FROM NORMALLY FUNCTIONING DIGESTERS

Compound	Chemical	Range %
Methane	CH ₄	50 – 75
Carbon dioxide	CO ₂	25 – 50
Nitrogen	N ₂	0 – 10
Hydrogen	H ₂	0.01 – 5
Oxygen	O ₂	0.1 – 2
Water vapour	H ₂ O	0 – 10
Hydrogen sulphide	H ₂ S	10 – 30,000 ppm
Ammonia		0.01 – 2.5 mg/m ³

³⁹U.S. EPA (2014). Food waste to energy: How six water resource recovery facilities are boosting biogas production and the bottom line. https://www.epa.gov/sites/production/files/2016-07/documents/food_waste_to_energy_-_final.pdf.

⁴⁰Kang Ho (2013). IEA Task 37 South Korea Country Report. <http://task37.ieabioenergy.com/country-reports.html>

⁴¹Gasum. <https://www.gasum.com/en/About-gas/biogas/Biogas-plants/>. Accessed on 16/12/2017.

⁴²FABBiogas (2015). Best Practice: Biogas Zirl, Tyrol, Austria http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_Zirl_english.pdf

⁴³FABBiogas (2015). Best Practice: Biogas plant in Radeberg, Germany http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_Radeberg_GER_english.pdf

⁴⁴ADBA (2017). The Practical Guide to AD (Second Edition). <http://adbioresources.org/library/purchase-the-practical-guide-to-ad>.

The methane in biogas is energy rich and combustible. It is the constituent responsible for its energy content and varies depending on feedstock. Hydrogen sulphide in the biogas is highly toxic and can cause corrosion of plant equipment. Water vapour interferes with pipework, gas flow and combustion of biogas. Therefore, both are undesirable and are removed from the biogas before it is used. Desulphurisation and drying of biogas are now standard procedures and are needed to achieve the full expected lifespan of the equipment.

The ammonia present in the biogas is also flammable and toxic to humans. When biogas is combusted, ammonia is converted into nitrous oxide which is a greenhouse gas.

However, it is present in very small quantities and if its percentage rises, it interferes with the digestion process itself and is hence managed during the AD process. Another impurity which is sometimes found in biogas is siloxanes. Siloxanes are produced from AD of materials found in soaps and detergents. On combustion, these form silicon dioxide and cause build-up of matter on the engine and exhaust gas surfaces. Hence, processes must be in place to either avoid feedstock with siloxanes or biogas must be treated to remove them to maintain the efficiency of the equipment.

The extent to which cleaning is required varies with the equipment needed for the utilisation of biogas. A rough guideline is provided in Table 4⁴⁵.

TABLE 4: REQUIREMENTS TO REMOVE COMPONENTS DEPENDING ON BIOGAS UTILIZATION

Application	H ₂ S	CO ₂	H ₂ O	Siloxanes
Boiler	< 1000 ppm	No	No	No
Cooker	Yes	No	No	No
Stationary engine	< 250 ppm	No	No	Yes
Vehicle fuel	Yes	Recommended	Yes	No
Natural gas grid	Yes	Yes	Yes	Eventually

5.2.5. Biogas production relative to feedstock inputs

The rate and quantity of biogas production depends upon a number of factors including the proportion of digestible volatile solids in the feedstock, the operating temperature and hydraulic retention time of the digester and the digestion technology used. Table 4 gives examples of food waste feedstocks

and indicative values of biogas that can be produced, and what they mean in terms of the amount of electricity generated or the distance that can be travelled by different vehicle types when running on biomethane produced from one tonne of food waste feedstock^{46,47,48}.

⁴⁵ADBA (2017). *The Practical Guide to AD (Second Edition)*. <http://adbioreources.org/library/purchase-the-practical-guide-to-ad>.

⁴⁶ADBA (2017). *The Practical Guide to AD (Second Edition)*. <http://adbioreources.org/library/purchase-the-practical-guide-to-ad>.

⁴⁷Zafar S (2015) Biogas from slaughterhouse waste <https://www.bioenergyconsult.com/biogas-from-slaughterhouse-wastes/> Accessed on 26/02/2018

⁴⁸Fuel economy for double-decker gas bus: 2Km per kg; fuel economy for Scania 18T rigid gas truck: 3.8Km per kg – both provided by Scania Group; fuel economy for CNG car: 5.6kg/100km (<http://www.cng4you.cz/en/how-much-is-it/calculator.html>)

With all waste streams, the purity of the waste will determine its performance inside the digester. Contamination from plastics, glass, sand or gravel will slow down the process, reduce gas yields and

lead to increased cleaning and maintenance of the plant. It is therefore necessary to stress the need for clean feedstocks to maximise plant operations and biogas yields.

TABLE 5: EXAMPLES OF FOOD WASTE FEEDSTOCK, THEIR BIOGAS POTENTIAL AND ALTERNATIVE USES

Food waste feedstock source	Biogas produced (m ³ /wet tonne)	Distance travelled by different vehicles when running on biomethane produced from 1 tonne of feedstock (km)			Electricity generated (MWhe/tonne)
		Car	Double-decker bus	Heavy goods vehicle	
Potatoes (18%-20% TS)	100-120	872	98	186	0.27
Bread	400-500	3,567	400	759	1.09
Cheese	>600	4,756	533	1,012	1.45
Vegetables	50-80	515	58	110	0.16
Mixed food (e.g. supermarket, restaurant)	75-140	852	95	181	0.26
Molasses (80-90% TS)	450-579	4,079	457	868	1.24
Brewery waste (20% TS)	60-100	634	71	135	0.19
Abattoir waste	120-160	1,110	124	236	0.34

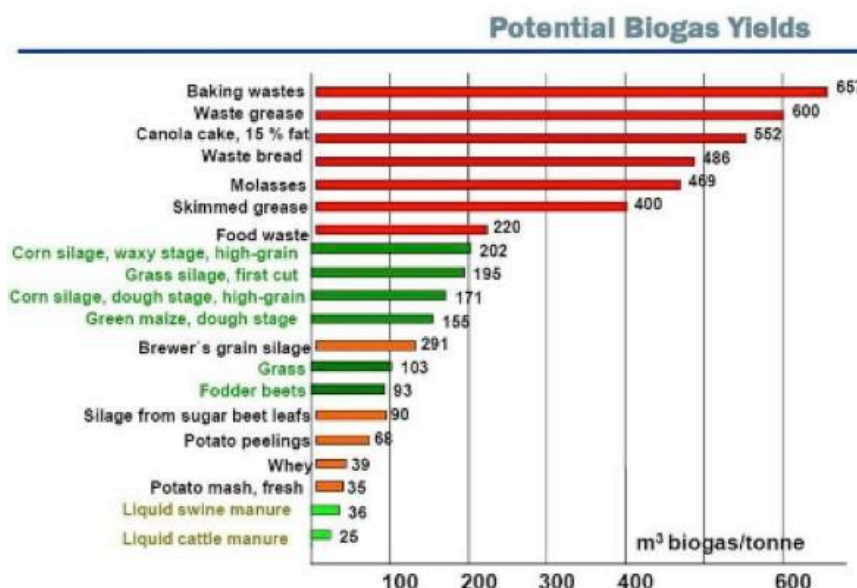


Figure 11: Potential Biogas yields⁴⁹

5.2.6. Biogas utilisation

As discussed previously, biogas is the main product of AD and its energy can be used for the production of heat, light, electricity, cooling, or vehicle fuel. Each of these technologies are discussed in detail in Chapter 6.

5.2.7. Digestate production and use

For every tonne (1,000kg) of feedstock entering an AD plant, 900 to 950kg of digestate is produced, before any account is taken of water that may be added to the process to ensure the solid content of the digester is suitable for the process and technology. Digestate is rich in available nutrients and of significant value as a soil amendment for agricultural land, city

landscaping and urban gardening (depending on the digestate quality and any local legislative requirements).

Depending on the consistency and the end use of digestate, digestate can be used either as a final product, or further treated into higher value products as shown in Figure 12⁵⁰.

⁴⁹Bruce Dorminey (2012). Biogas Technology: "Cow Power" Catching On in US. <http://www.renewableenergyworld.com/articles/2012/04/biogas-technology-cow-power-catching-on-in-us.html>. Accessed on 03/01/2018.

⁵⁰FUCHS, W. and DROSG, B. (2013). Assessment of the state of the art of technologies for the processing of digestate residue from anaerobic digesters. *Water Sci Technol.* 2013, 67(9), 1984-1993

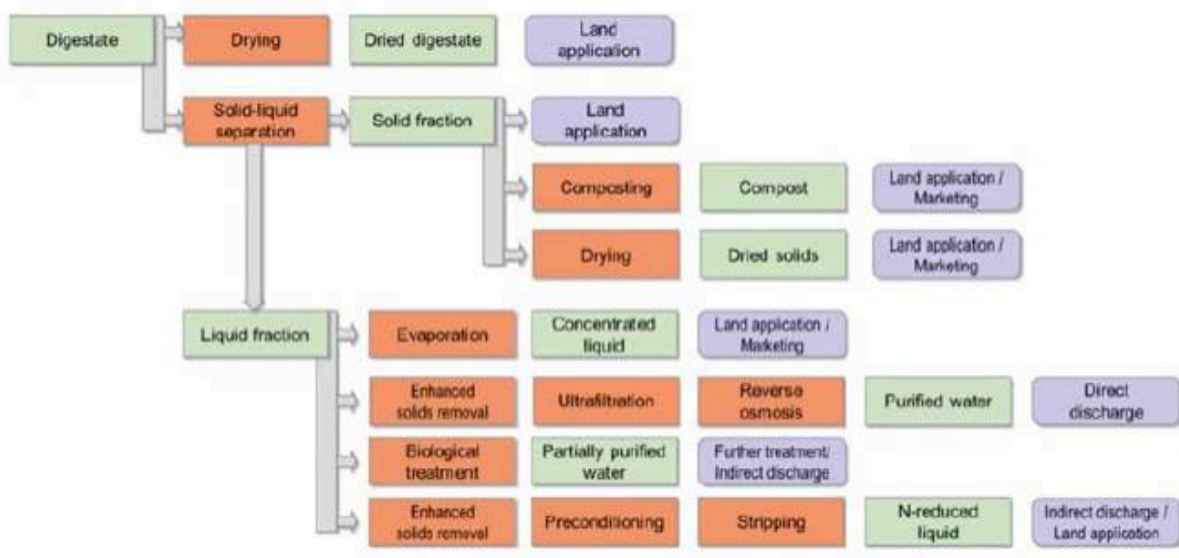


Figure 12: Overview of viable options for digestate processing

Digestate may be used whole or separated into solid and liquid parts. The solid fractions may be processed into compost and/or dried into dried solids for land application. The liquid fractions may be concentrated into liquid fertiliser or partially treated and sent to a wastewater treatment facility or fully treated and discharged. When digestate is separated into

liquor and fibre (>15% dry matter) fractions, soluble nutrients (in particular ammoniacal nitrogen and potash) remain mostly in the liquor, while phosphate remains mostly in the fibre.

The benefits and utilisation of digestate is discussed in detail in Chapter 6.

5.3. Financial considerations

The long-term financial sustainability of a food waste collection and digestion system heavily relies on having a sound financial model. The costs likely to be incurred in establishing the processes and infrastructure of food waste collection systems are discussed in Chapter 3. In this section, the turnkey cost of a food waste digestion plant is explored, the methods of financing it are discussed and the various potential income streams via sale of its products and benefits are considered.

5.3.1. Capital cost

The capital cost of developing an AD plant is the upfront investment required for:

- Feasibility study;
- Planning and permitting procedures;
- Purchasing of land/site for the plant;
- Connection to electricity and gas grids and water supplies;
- Connection to road systems to access plant;
- Connection to effluent treatment for wastewater (if applicable);
- Civil engineering works;
- Equipment for pre-treatment of feedstock such as macerator, de-packaging equipment and pasteuriser;
- Feeding technology including mixing pits, pumps and feeder;
- Digester equipment including steel/concrete tanks, mixer, heating circuits, sensors, cover and gas storage;
- Post digestion storage of digestate and gas storage;
- Equipment for biogas cleaning;
- Equipment for biogas utilisation including boilers, CHP engine, heat exchangers and upgrading technology;
- Digestate storage and treatment including tanks, separation or composting technology where applicable; and
- Machinery to move waste around the plant (mechanical diggers, forklifts, bulldozers and conveyor belts).

These costs vary with country-specific permitting procedures and regulations (e.g. on permitting, licensing, pasteurisation, digestate standards), the technology installed (e.g. level of automation, dry or wet digestion), size of the plant, condition of the incoming food waste, contractual arrangements between the operator and any construction companies and differing local costs of commodities such as steel and concrete. Chapter 6 discusses in detail the costs related to the use of biogas such as installing a CHP engine or upgrading technology and connecting to the respective grid, digestate treatment such as separation of liquid and solid fractions and other possible products and by-products of AD such as capturing carbon dioxide. Based on data available from the USA, Denmark, the UK and Italy, the capital cost for a 30,000 tonne per year capacity plant may be \$400-\$600/tonne of annual capacity. A larger 50,000 tonne plant may have a capital cost of \$300-\$400/tonne^{51,52,53,54}. A 30,000 tonne annual capacity plant would therefore cost between USD 12 and 15 million. These are example costs only and a detailed feasibility study is required on a project-specific basis due to variability in pricing, as discussed earlier.

The breakdown for the capital costs is estimated as follows⁵⁵:

- Up to 10% will go towards development costs, e.g., planning, designing, tendering process;
- 10-20% will go towards civil works including purchase of land for the site;
- 50-60% will go towards the building of the digester and associated mechanical and electrical equipment, e.g., the biology, digester, mixer, pre-treating the waste, dealing with the digester waste; and
- 20-30% will go towards the energy generation components. For gas-to-grid this includes the upgrading equipment, grid connection costs, injection, boiler, etc.

⁵¹Denmark Country report (2017) <http://task37.ieabioenergy.com/country-reports.html>

⁵²Department of Energy and Climate Change (2014) RHI Biomethane Injection to Grid Tariff review https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/315608/Biomethane_Review_Final_-_FOR_PUBLICATION.pdf

⁵³National Renewable Energy laboratory (2013) Feasibility study of anaerobic digestion of food waste in St. Bernard, Louisiana <https://www.nrel.gov/docs/fy13osti/57082.pdf>

Table 5 below gives select examples of food waste digesters that have been implemented around the world and their costs. As seen, the capital cost varies with the feedstock, country, year

of construction and the end use of biogas and digestate. These examples have been compiled to give the reader an estimate of the order of magnitude of investment required.

TABLE 6: EXAMPLES OF FOOD WASTE DIGESTERS

Plant name/site	Country	Capacity (tonnes/yr)	Utilisation	Headline capital cost (USD)	Year
Harvest Energy Garden, Lake Buena Vista, Florida ⁵⁶	USA	130,000	Electricity and heat (CHP)	30,000,000	2014
UW-Oshkosh Urban Dry Digester, Oshkosh, Wisconsin ⁵⁷	USA	10,000	Electricity and heat (CHP)	4,700,000	2011
New Horizons Energy, Athlone, Cape Town ⁵⁸	South Africa	200,000	Biomethane	30,000,000	2017
Elgin Fruit Juices, Grabouw, Western Cape ⁵⁹	South Africa	20,000	Electricity and heat (CHP)	1,600,000	2013
Grossfurtner, St. Martin ⁶⁰	Austria	10,000	Electricity and heat (CHP)	2,100,000	2003
Biokraft, Hartberg ⁶¹	Austria	7,000	Electricity and heat (CHP)	2,400,000	2004
AVA, Augsburg ⁶²	Germany	55,000	Biomethane-to-grid	20,000,000	2013
Ganser Umwelt, Munich ⁶³	Germany	30,500	Electricity	3,600,000	1997
Finsterwalkder Umwelttechnik, Bernau ⁶⁴	Germany	6,000	Electricity	1,700,000	2000
Agrivert, West London ⁶⁵	UK	50,000	Electricity	15,000,000	2014
Tamar, Hoddesdon ⁶⁶	UK	66,000	Electricity	19,500,000	2015
Boleszyn, Mazury ⁶⁷	Poland	43,900	Electricity and heat (CHP)	6,200,000	2012
Skrzatusz, Wielkopolska ⁶⁸	Poland	33,600	Electricity and heat (CHP)	6,200,000	2012

⁵⁴ Dr Confaloneiri A and Dr Ricci M (2017) communication with Italian Composting and Biogas Association <https://www.compost.it/>

⁵⁵ Department of Energy and Climate Change (2014) RHI Biomethane Injection to Grid Tariff review https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/315608/Biomethane_Review_Final_-_FOR_PUBLICATION.pdf

⁵⁶ American Biogas Council (2014) Biogas project profile: Harvest Energy Garden – Central Florida <https://www.americanbiogascouncil.org/projectProfiles/lakeBuenaVistaFL.pdf>

⁵⁷ American Biogas Council (not dated) Biogas project profile: UW-Oshkosh Urban Dry Digester https://www.americanbiogascouncil.org/projectProfiles/oshkosh_wi.pdf

⁵⁸ GreenCape (2017) The business case for biogas from solid waste in the Western Cape <https://www.greencape.co.za/assets/Uploads/GreenCape-Biogas-Business-Case-Final.pdf>

⁵⁹ GreenCape (2017) The business case for biogas from solid waste in the Western Cape <https://www.greencape.co.za/assets/Uploads/GreenCape-Biogas-Business-Case-Final.pdf>

⁶⁰ Fab Biogas. Best-Practice: Biogas Plant in St Martin, Upper Austria. http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_St.Martin_english.pdf

⁶¹ Bin2Grid (2016) Good practice on segregated collection of food waste http://www.bin2grid.eu/documents/73603/136534/D2.1_Good+practice+on+segregated+collection+of+food+waste.pdf

⁶² Bin2Grid (2016) Factsheets on good practice of biogas upgrade http://www.bin2grid.eu/documents/73603/136970/Eng_Bin2Grid_revision.pdf?d2be8c8b-1656-4336-8438-a15fcd632331

⁶³ Bin2Grid (2016) Good practice on segregated collection of food waste http://www.bin2grid.eu/documents/73603/136534/D2.1_Good+practice+on+segregated+collection+of+food+waste.pdf

⁶⁴ Bin2Grid (2016) Good practice on segregated collection of food waste http://www.bin2grid.eu/documents/73603/136534/D2.1_Good+practice+on+segregated+collection+of+food+waste.pdf

⁶⁵ WBA member data (ADBA)

⁶⁶ WBA member data (ADBA)

⁶⁷ Fab Biogas. Best-Practice: Biogas Plant in Boleszyn, Poland. http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_Boleszyn_english.pdf

⁶⁸ Fab Biogas. Best-Practice: Biogas Plant in Skrzatusz, Wielkopolska, Poland http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_Skrzatusz_english.pdf

5.3.2. Financing an AD plant

Based on the nature, scale and objectives of a food waste digestion project, funding may be accessed via private capital, venture capital, banks, governments, international agencies or funds or a combination of these. Some of these sources are listed below⁶⁹. These vary considerably for each project and all available resources should be evaluated for a sound and sustainable financial model:

PRIVATE SECTOR

- Public Private Partnerships – joint ventures/partial divestures, construction/service contracts, lease agreement, concession
- Infrastructure Investment Funds
- Privatisation/full divestiture
- Private risk mitigation
- Crowdfunding
- Corporate and municipal bonds

INTERNATIONAL ORGANISATIONS

- Green and Climate Funds
- Concessional Loans
- Export agencies
- Partial financing – partial loans,

viability gap funding, challenge funds, technical assistance grants

- Sharia compliant finance
- Public risk mitigation

PUBLIC SECTOR

- Capital grant schemes
- Municipal development funds
- Development Financing Institutions

OTHER SCHEMES like tax exemptions, pooled financing, viability gap funding, public risk mitigation are possible sources of funding.

The cost of financing will depend upon the source of financing and may vary considerably. As in any industrial enterprise, funders will often be looking for a specific rate of return on a project, which is weighed against the risk of the project, before deciding whether to invest.

5.3.3. Operating costs

Operating costs consist of staff costs, equipment maintenance and replacement, parent company overheads, specialised consultancy, testing costs and the disposal cost of de-packaged and contaminated materials (e.g., plastic, metal), energy and water consumption, machinery fuel and machinery maintenance and repairs. Excluding any cost of de-packaged and

contaminated material, the operating cost may be \$35-\$55/tonne for a 30,000 tonne per year plant and \$30-\$45/tonne for a 50,000 tonne per year plant^{70,71,72}.

The disposal cost for de-packaged and contaminated material depends on the amount produced and the waste facilities these are taken to.

⁶⁹ James Alexander, City Finance Programme, C40 Cities – Presentation at CCAC Waste Initiative Global Workshop for City Leadership, 28th September 2017, Baltimore, USA.

⁷⁰ Department of Energy and Climate Change (2014). RHI Biomethane Injection to Grid Tariff Review. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/315608/Biomethane_Review_Final_-_FOR_PUBLICATION.pdf.

⁷¹ Denmark Country report (2017). <http://task37.ieabioenergy.com/country-reports.html> - EUR/GJ figure quoted, converted to \$/tonne of feedstock based on assumption of 30,000 tonnes per annum average plant size.

⁷² NREL (2013). Feasibility Study of Anaerobic Digestion of Food Waste in St. Bernard, Louisiana. <https://www.nrel.gov/docs/fy13osti/57082.pdf>.

5.3.4. Income

The primary income generated from AD is from the sale of electricity, heat or biomethane produced from the biogas. In addition, there may be income from receiving gate fees for accepting the incoming waste, sale of digestate as organic fertiliser and various government support schemes relating to the production of renewable energy. Income can also be measured in terms of avoided costs. A waste collection operator or municipality currently discharging food waste to landfill or incineration will usually face a landfill gate fee (see below) to dispose of the waste. In more economically developed nations a landfill gate fee will often be that imposed by the landfill operator which covers the cost of landfill management; plus, a landfill tax imposed by State or regional authorities, imposed as a disincentive to tipping at landfill. Landfill gate fees vary enormously from region to region and within countries. To take one example, the landfill tax fee in the United Kingdom is £86/tonne on top of which the landfill management fee is added. Landfill costs therefore usually exceed £120/tonne of waste discharged (2017 figures). Discharging source segregated waste at an AD plant in the UK can cost as little as £30/tonne, leading to a saving for the waste collection operator of £90/tonne.

These savings can help pay for the cost of implementing segregated food waste collections.

In less economically developed countries, landfill gate fees can vary from zero upwards. Landfills in Brazil typically charge a tipping fee of less than US\$20/tonne ⁷³ whilst open dumping at zero cost is also rife.

The revenue streams are discussed in detail in the following section.

Tipping or Gate Fees

A 'tipping fee' or 'gate fee' is a fee that may be charged by food waste digester operators, energy-from-waste plants or landfill operators for responsibly disposing of the organic waste generated. The fee may be charged by the weight or volume of waste received and this may vary according to purity, quality, biogas production potential and quantity.

Typically, a gate fee will have to be priced to compete with other forms of treatment. Where zero gate fees apply to open and uncontrolled dumping of waste, charging a gate fee for treatment in an AD plant may be difficult. In fact, no recovery or recycling operation can compete with the zero cost of open dumping, the environmentally worst option for any waste.

Where landfill gate fees are applied, often these

determine the charges an AD plant may implement. Clearly, regulations to avoid food waste being disposed of at landfills are needed to ensure this waste is delivered to recovery plants. Taxes on landfill disposal and landfill bans on food waste are examples of policies which can be used (see Chapter 7).

Sale and utilisation of electricity

Currently the most common form of income generation for biogas plants is the sale of electricity generated via an internal combustion CHP engine. The electricity generated is often first used to meet the electricity demand of the biogas plant itself (this is called its 'parasitic load'). The excess may then be sold to neighbouring enterprises via micro-grids or to a bigger utility via a grid connection.

⁷³ Ribeiro S G (2010) Waste Management in Brazil <http://www.seas.columbia.edu/earth/wtert/meet2010/Proceedings/presentations/GUERREIRO.pdf>

The electricity generated may be sold to the utilities or traders at the wholesale price that applies to any generator whether from renewable or fossil sources. Prices for the sale of electricity will be determined by local factors and markets. In free market conditions these will rise and fall according to market demand and supply, both locally and nationally.

In other situations, local energy costs are dictated by political rather than market factors, which can maintain, for example, lower prices than free market conditions would otherwise create. Controlled and subsidised markets are unattractive for new energy producers and partially explain the failure to take up new renewable energy technologies in these countries. A map of global energy subsidies along with the explanation of their consequences is available from the International Monetary Fund ⁷⁴.

Beyond the sales price of the electricity itself into a local market grid, the electricity produced via digestion of food waste is renewable and has additional benefits for the environment and society. This fact has been acknowledged by some city, state and national governments who have tried to incentivise generation of renewable electricity or stimulate this via regulatory requirements and direct cash back schemes such as the feed-in tariff. Here, renewable energy producers are paid above market prices, which is achieved by adding an amount to the consumers' final electricity

bill, which is then paid to those renewable producers. Market-based mechanisms such as tradable renewable energy certificates are also widespread. Under these market-based systems, generators of energy (such as utility companies) are obliged to source a certain percentage of their production from renewable energy sources, including biogas in some cases. The generators of renewable energy are given a certificate for every unit of energy produced. This certificate can be used to meet their own renewables obligations or traded with other generators who are short of meeting their renewables obligation. These certificates therefore acquire a monetary value and create a source of income for the renewable energy generator that allows them to charge a higher than market price for the biogas produced.

Chapter 7 discusses the various regimes of incentives used to stimulate the growth of renewable biogas production as part of a policy options review. In brief, both feed-in tariffs and renewable energy certificates have been widely used all around the globe. Feed-in tariffs for renewable energy production are implemented in more than 100 countries/states for many different sources of renewable energy production; however relatively few include energy from biogas⁷⁵ within those frameworks. Renewable energy certificates have been implemented in countries like Australia⁷⁶ and the USA⁷⁷. The UK has transitioned from the certificates to a feed-in tariff policy.

⁷⁴ Gasper V (2015). How large are global energy subsidies? <http://www.imf.org/en/News/Articles/2015/09/28/04/53/sp051815>. Accessed on 04/01/2018.

⁷⁵ Renewable Energy Policy Network for the 21st Century (2017). Renewables 2017: Global Status Report. http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf.

⁷⁶ Clean Energy Regulator, Australian Government (2017). REC Registry. <https://www.rec-registry.gov.au/rec-registry/app/home>.

⁷⁷ United States Environmental Protection Agency (2017) Green Power Markets <https://www.epa.gov/greenpower/green-power-markets>

Sale and utilisation of heat

Of the energy potential of biogas produced, typically 35-40% is captured in the form of electricity while much of the rest can be captured as heat via a CHP engine. Similar to the electricity generated, the heat produced is first used to meet the heat demands of the digester, for example for maintaining feedstock temperature or pasteurisation. The excess heat generated may be used for heating onsite buildings or processes to save costs, or exported and sold for additional revenue for district heating, food processing, greenhouses, aquaculture or drying of cereals/spices, among many other uses⁷⁸. Capturing heat from biogas, and being able to monetise it, is critical to the long-term financial feasibility of a biogas plant. Given the benefits of renewable heat generation from AD, various incentive schemes have been implemented in Europe. The UK has incentivised heat production via a cash back scheme known as the Renewable Heat Incentive while Austria, Estonia, Finland and the Netherlands support heat production via feed-in premium schemes. Under feed-in premium schemes the generator of heat may be compensated for the price difference between wholesale and renewable heat generation prices or by a fixed additional payment for use of CHP⁷⁹. These incentives for heat are less common than those for electricity due to challenges in the transmission and utilisation of heat.

Sale of upgraded biogas or biomethane

The biogas produced during AD of food waste may be upgraded to remove carbon dioxide, sulphur gases and water, and match the properties of natural gas or renewable natural gas. Biomethane can be bottled⁸⁰, injected into the gas grid or transported via tank trucks to be used as natural gas substitute in gas grids, for industrial purposes or for use as transport fuel including in passenger cars, buses, heavy goods vehicles and waste collection trucks.

While upgrading biogas to biomethane has a higher upfront cost than installing a CHP engine, it may be a more viable option in countries where an extensive gas distribution network is already available, like UK, Italy, Belgium and the Netherlands, or where there is infrastructure to support and fuel natural gas vehicles, such as in Sweden. In some countries, governments are further incentivising the upgrade to

biomethane by offering financial incentives such as Renewable Heat Incentive in the UK⁸¹, tax exemptions offered in Sweden⁸² or the Stimulerend Duurzame Energieproductie (SDE+), an operating grant in the Netherlands⁸³ to stimulate the adoption of digestion of organic waste.

Monetising GHG emissions

Digestion of food waste results in mitigation of greenhouse gas emissions. Quantifying and monetising this mitigation potential will depend on the business-as-usual scenario in the local context and can create additional revenue streams and stimulate deployment of capacity. Table 6 below gives indicative values of the greenhouse gases mitigated if the energy generated from food waste is used in transport, for the production of electricity or for the production of heat.

⁷⁸ WIP Renewable Energies (2015). *Sustainable Heat Use of Biogas Plants – A Handbook*, 2nd Edition. http://www.biogasheat.org/wp-content/uploads/2015/03/Handbook-2ed_2015-02-20-cleanversion.pdf.

⁷⁹ European Commission (2017). *Optimal use of biogas from waste streams*. https://ec.europa.eu/energy/sites/ener/files/documents/ce_delft_3g84_biogas_beyond_2020_final_report.pdf.

⁸⁰ Valorgas (2012). *Valorisation of food waste to biogas*. [http://www.valorgas.soton.ac.uk/Deliverables/120825_VALORGAS_241334_D5-2_rev\[0\].pdf](http://www.valorgas.soton.ac.uk/Deliverables/120825_VALORGAS_241334_D5-2_rev[0].pdf).

⁸¹ Ofgem (2017). *Tariffs and payments: Non-Domestic RHI*. <https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi/contacts-guidance-and-resources/tariffs-and-payments-non-domestic-rhi>.

⁸² IEA Bioenergy. *Member Country Reports. Sweden*. <http://task37.ieabioenergy.com/country-reports.html>.

⁸³ Netherlands Enterprise Agency (2017). *Stimulation of Sustainable Energy Production (SDE+)*. <https://english.rvo.nl/subsidies-programmes/sde>.

TABLE 7: GREENHOUSE GAS EMISSIONS REDUCTION BY ALTERNATIVE USES OF FOOD WASTE BASED BIOGAS

Food waste feedstock source	Biogas produced (m3/wet tonne)	GHG emissions reduction if used in transport (kg CO2e)	GHG emissions reduction if used in electricity (kg CO2e)	GHG emissions reduction if used for heat (kg CO2e)
Potatoes (18%-20% TS)	100-120	1,946	1,899	1,976
Bread	400-500	2,506	2,315	2,631
Cheese	>600	2,753	2,499	2,920
Vegetables	50-80	1,872	1,844	1,890
Mixed food (e.g. supermarket, restaurant)	75-140	1,942	1,896	1,972
Molasses (80-90% TS)	450-579	2,612	2,394	2,756
Brewery waste (20% TS)	60-100	1,896	1,862	1,919
Abattoir waste	120-160	1,995	1,936	2,034

**Assumed the food waste would have gone to an open landfill instead with no landfill gas recovery ⁸⁴; when used for transport, diesel vehicles ⁸⁵ are used as a comparator; when used for electricity, the global electricity mix ⁸⁶ is used as a comparator; when used for heating, the EU fossil heat average ⁸⁷ is used as a comparator.*

Since carbon or greenhouse gas emissions are not natural commodities or utilities that can be sold in the market, carbon markets have been created by various governments and inter-governmental organisations to price the mitigation of emissions.

Carbon markets function by capping the total number of permissible emissions within the jurisdiction of the market. Emissions allowances are then distributed between countries/ industries corresponding to the cap. Under this mechanism, surplus allowances can be traded and sold to other countries/industries or carbon credits may possibly be sourced from outside the market to meet their emission

reduction targets. The key to the success of this mechanism is to ensure the amount of emission allowances in the market is sufficiently scarce and penalties for emitting more than the cap are sufficiently high. By the law of demand and supply, the more entities demand the allowances, the higher the price of the allowances will become. Under these conditions, the countries/industries are incentivised to invest in carbon abatement technologies to sell resulting surplus allowances. Low demand for allowances could indicate a downturn in the economy or the lowering of mitigation costs due to technological improvements or an overestimation of distributed allowances (which can be adjusted on an annual basis).

⁸⁴ US Environmental Protection Agency (2015) Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM) https://www3.epa.gov/warm/pdfs/WARM_Documentation.pdf

⁸⁵ Joint Research Center (2013) Joint Research Centre EUCAR-CONCAWE project http://iet.jrc.ec.europa.eu/sites/about-jec/files/documents/report_2013/wtt_v4_pathways_1-oil_gas_july_2013.xlsx

⁸⁶ International Energy Agency (2017) CO2 emissions from fuel combustion <https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustionHighlights2017.pdf>

⁸⁷ NFCC (2016) Assessment of impact on biogas producers of proposed changes to sustainability criteria https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/577055/Annex_E_-_Report_on_sustainability_criteria.pdf

Since 2015, four new carbon pricing initiatives have been implemented:

- The Republic of Korea ETS started on January 1, 2015;
- The Portugal carbon tax entered into force on January 1, 2015, covering all energy products used in non-EU ETS sectors;
- On January 1, 2016, British Columbia launched an ETS that will cover the liquefied natural gas (LNG) facilities that are currently under construction, once they become operational;
- Australia is back on the carbon pricing map with the introduction of a safeguard mechanism to limit and price emissions on July 1, 2016. This establishes a new ETS, following the abolishment of the Australian Carbon Pricing Mechanism in 2014.
- In 2015, China announces its plans for a national ETS.

Tally of carbon pricing initiatives implemented or scheduled for implementation

Level	Implemented or scheduled for implementation	Implemented or scheduled for implementation	Implemented or scheduled
National level	10	42	21
Subnational level	2	23	25

The three maps show carbon pricing initiatives across North America, Europe, and Asia. The legend indicates three categories: green for 'Implemented or scheduled for implementation', purple for 'Implemented or scheduled for implementation', and orange for 'Implemented or scheduled'. The table below summarizes the tally of these initiatives at national and subnational levels.

Figure 13: Summary map of regional, national and subnational carbon pricing initiatives implemented, scheduled for implementation and under consideration (ETS and carbon tax)

Integrating food waste digestion projects with these mechanisms can incentivise wide-scale deployment of collection and digestion infrastructure. This requires the recognition of avoided GHG emissions from biogas production within the emission trading systems so that such plants can be eligible for carbon credits that can then be monetised on carbon credit trading markets, for example via one of the CDM approved methodologies, such as 'AMS.I.I.' (biogas/biomass thermal applications for households/small users).

⁸⁸ REN 21 (2017) Renewables 2017 Global Status Report http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf

⁸⁹ World Bank Group (2017) State and Trends of carbon Pricing 2017 https://openknowledge.worldbank.org/bitstream/handle/10986/28510/wb_report_171027.pdf?sequence=5&isAllowed=y

⁹⁰ World Bank and Ecofys. 2016. "Carbon Pricing Watch 2016" (May), Washington, DC. <https://openknowledge.worldbank.org/bitstream/handle/10986/24288/CarbonPricingWatch2016.pdf?sequence=4&isAllowed=y>

⁹¹ World Bank Group (2017) State and Trends of carbon Pricing 2017 https://openknowledge.worldbank.org/bitstream/handle/10986/28510/wb_report_171027.pdf?sequence=5&isAllowed=y

Sale and utilisation of digestate

The value attached to digestate varies significantly from country to country, based on the treatment it has undergone and the final form in which it is marketed. In semi-arid countries such as the Sahel region in Africa, Bangladesh, Egypt and Tunisia, where the soil carbon and hence its water retention capacity is low, carbon- rich digestate and compost is highly valued. Use of digestate and compost in these countries can lead to higher yields, improved farm incomes, stabilised communities, reduce forced emigration and reduce poverty- induced hunger. In most EU countries, the composting of digestate from municipal waste has been made mandatory. This adds to the initial capital cost of the digester, but in the long run improves the digestate revenue stream. The nutrient value of digestate and its market value are well established in Italy. A number of countries

operate certification programmes like the American Biogas Council Digestate Certification scheme⁹² and European Compost Network- Quality Assurance Scheme (ECN-QAS)⁹³ have developed standards and certification schemes for digestate which enables its monetisation as a marketable product. However, in some high-income countries such as the UK and Australia where farming uses large volumes of synthetic fertiliser, the value of digestate is not recognised. Despite its high nutrient value, many biogas plants give away the digestate to agricultural enterprises for free. Examples of digestate markets that have remained isolated to individual initiatives are the integration of food waste digestate into a gardening supplies business by Richgro in Australia⁹⁴. Having clear regulations around safety and quality standards can enable the monetisation of digestate and create additional revenue.

5.4. Health and safety

Ensuring that every individual working for and at an AD facility has a safe environment to work in is the primary responsibility of every employer running an AD plant. Basic training and safety procedures can help prevent a vast majority of incidents from occurring, while also enabling employees to identify and respond effectively to situations as they may arise , which can threaten safety, plant performance or the environment. Implementing simple health and safety measures can not only save lives but also save money ⁹⁵. Risk assessment is the process of evaluating each activity and process taking place on site and can be broken down into the following five steps ⁹⁶:

⁹² American Biogas Council. <http://digestate.org/>. Accessed on 17/12/2017.

⁹³ European Compost Network. <https://www.compostnetwork.info/ecn-qas/>. Accessed on 17/12/2017.

⁹⁴ Landia. UK Companies Join Forces for New Richgro AD Plant in Australia. <http://www.landia.co.uk/Display-of-news?Action=1&NewsId=325&M=NewsV2&PID=711>.

⁹⁵ This section heavily derives from ADBA (2017). The Practical Guide to AD (Second Edition). <http://adbioreources.org/library/purchase-the-practical-guide-to-ad>.

⁹⁶ Health and Safety Executive. Risk -Controlling the risks in the workplace. <http://www.hse.gov.uk/risk/controlling-risks.htm>. Accessed on 28/11/2017.

IDENTIFY THE POTENTIAL HAZARDS:

- To identify potential hazards, the operator of the plant should go step by step, considering processes, activities and substances present on the site that may pose a risk to health and safety. Some potential hazards at a biogas plant may be vehicle movements on site, use of mobile plant and machinery such as forklifts, production and storage of explosive gas, electrical systems, moving parts of machinery such as pumps, shredders, conveyor belts, and walking floors, working in confined spaces and working at heights.

WHO MAY BE HARMED AND HOW:

- This step involves considering each potential hazard identified and evaluating which person or job role may be impacted and how, taking into account the different needs of individual workers such as those who are young, expectant mothers, people with disabilities, people whose first language is different from the primary language of communication and temporary workers.

EVALUATE THE RISK OF THE INCIDENT TAKING PLACE AND APPROPRIATE PRECAUTIONS:

- The next step after identification of potential hazards and their impact, is taking all reasonably practical

steps to manage the risk. These will include personal protective equipment and clothing (such as use of gloves, steel toe boots), administrative controls (identifying and implementing procedures to make work place safe), engineering controls (using work equipment or other measures to control risk), substitution (replacing the potentially hazardous material or machinery with a less hazardous one) and elimination (designing out the hazard).

RECORDING THE FINDINGS:

- Keeping written records of risk assessment is important for ongoing and effective risk management. These records should be made easily accessible for reference. Written communication of procedures ensures clearer understanding and consistency across the business.

REVIEWING AND UPDATING RISK ASSESSMENT:

- It is important to review the risks and update the assessment on a regular basis to keep up with the changing activities, processes and people working at the AD plant. It may be done on a yearly or biannual basis or when there are any changes, based on the plant and how it is run.

As AD operations are complex and deal with a highly explosive gas (methane), both personal and process safety measures must be undertaken. If an incident happens, lapses in procedures should be identified, learnt from and corrected. Regular inspections from the health and safety enforcing authority of the jurisdiction can ensure compliance and accountability of duty-holders.

5.5. Establishing good practice

Stakeholders involved in the anaerobic digestion food waste – such as industrial/commercial generators, waste management and environment arms of jurisdictions, companies providing food waste collection services, operators of biogas plants, developers, consultants, suppliers, insurers, regulators and other trade bodies related to the sector – may organise themselves into groups to establish and share sector best practices to improve operational, environmental and health and safety performance. This activity has been shown to facilitate the improved understanding and sharing of good practice.

In addition to improving plant performance and return on investment, sharing best practices can reduce operational risks and the cost of insurance premiums, further improving the financial performance of the plant. The sharing of best practices can take the form of practical guidance, case studies with outstanding features highlighted, or check lists on risk

management, procurement or operational performance ⁸⁴, or an industry certification scheme as has recently been launched in the UK ⁸⁵. Voluntary certification schemes can play a big role in driving high standards as they typically involve independent auditing and reviews of processes and an ongoing commitment to continual improvement.

5.6. Comparison of technologies

The table below lists the treatment technologies discussed in Chapter 4 and 5 and how they compare against the following set of parameters:

- **SUPPORT FOR FOOD WASTE REDUCTION** – as outlined in chapters two and three, the introduction of separate food waste collections supports food waste reduction as households and businesses become more aware of the quantity and cost of the food waste they are creating.
- **COST COMPARISON** – This column compares the relative costs of procuring and implementing the technology. Since these vary significantly based on the level of sophistication, the existing infrastructure, regulations and local parameters, the comparison is on a scale with 1 being the least and 5 the most costly technology. This is based on a number of studies that report on the cost of the different municipal solid waste (MSW) treatment technologies, including the ISWA UNEP Global Waste Management Outlook report⁸⁶ and others^{87,88}.
- **RENEWABLE ENERGY PRODUCTION** – Does the technology lead to the generation of energy as a product? For example, landfilling on its own is just a means of storing waste, but does not produce biogas for energy, in comparison to LFG extraction.
- **NUTRIENT RECOVERY** – Does the technology recover the nutrients in the food waste such as nitrogen, phosphorus and potassium? For example, after liquefaction, the nutrients in the food waste are lost to the sewer or burnt with the biodiesel produced, whereas these can be recovered and recirculated by rendering, composting, AD and MBT.
- **ABILITY TO BUILD SOIL ORGANIC MATTER** – Soil organic matter is important for retention of water and nutrients and prevention of erosion. The contribution of the technology to building soil organic matter and hence agriculture is evaluated in this column.

⁸⁴ADBA (2017). Best Practice Checklists. <http://adbioresources.org/our-work/best-practice-scheme/best-practice-checklists/>.

⁸⁵ADBA (2017). Best Practice Scheme. <http://adbioresources.org/our-work/best-practice-scheme/>.

⁸⁶UNEP and ISWA (2015) Global Waste Management Outlook <http://web.unep.org/ietc/what-we-do/waste-management-outlooks>

⁸⁷Eunomia Research and Consulting (not dated) Costs of Municipal Waste Management in the EU <http://ec.europa.eu/environment/waste/studies/pdf/eucostwaste.pdf>

⁸⁸PlasCarb (2015) Evaluation of the regional and political waste management strategies across Europe http://www.plascarb.eu/assets/content/20151208_FoodWasteReport_WP9_final_publish.pdf

TABLE 8: COMPARISON OF TECHNOLOGIES TABLE

TECHNOLOGY	SUPPORTS FOOD WASTE REDUCTION	COST SCALE 1-5 (LOW-TO-HIGH)	ENERGY PRODUCTION	NUTRIENT RECOVERY	CAN BUILD SOIL ORGANIC MATTER
FOOD WASTE SEPARATELY COLLECTED					
Anaerobic digestion	✓	4	✓	✓	✓
In-vessel composting	✓	3	x	✓	✓
Windrow composting	✓	2	x	✓	✓
Liquefaction	✓		Dependent on context		✓
Rendering	✓		Dependent on context		✓
FOOD WASTE COLLECTED IN RESIDUAL WASTE					
Gasification	x	5	✓	x	x
Incineration and energy recovery	x	4	✓	x	x
Landfill without gas extraction	x	1	x	x	x
LFG extraction	x	2	✓	x	x
MBT	x	2	✓(with AD)	x	x
Pyrolysis	x	5	✓	x	x

This table shows that AD is a technology that enables renewable energy generation, nutrient recovery and building of soil organic matter, essential for mitigating climate change, sustainable growth and industrialisation. Due to the multiple benefits of AD, it is already the preferred method of recycling food waste for a number of businesses, industries, institutions and cities and is the focus of this report.

5.7. Conclusion

As a technology for food waste utilisation, AD is flexible, effective and sustainable and contributes towards a circular global economy. The following chapter explores the various products of AD which can further provide the benefits of production of renewable energy, climate change mitigation, energy and food security and sustainable and inclusive growth for all.

6. PRODUCTS OF ANAEROBIC DIGESTION

This chapter illustrates the use of the products of anaerobic digestion (AD), notably biogas, electricity, heat, biomethane, digestate, carbon dioxide and cooling.

- **How much biogas is available and which technology is best suitable for use at this scale?**
- **Are there any onsite energy needs that can be met from the energy captured from biogas? In what form?**
- **Are there any local businesses or industries that could use the energy? In what form?**
- **Is a connection to the electricity or gas grid feasible?**
- **Which products of biogas have a currently operating market?**
- **Where is the most feasible final destination of the digestate produced?**
- **Are there any financial incentives available for the products of biogas?**
- **Are there any operating biogas plants in the jurisdiction?**
- **Are there any local factors that have enabled their success?**
- **Is a new technology available that others have not yet taken up?**

6.1. Biogas for cooking and lighting

The simplest and easiest way of using biogas is to directly burn it and use the heat and light generated for cooking, heating and lighting. This set up is usually most feasible for micro-scale digesters which digest food from a family or a community and the biogas produced can substitute fossil fuel kerosene and liquified petroleum gas (LPG), or traditional solid biomass fuels like wood and coal. Direct use of biogas is implemented where the micro-scale of digestion makes the use of combined heat and power (CHP) engines financially prohibitive.

In Africa and Central and Eastern Europe, over 30% of fine particulate matter in the urban air originates from domestic burning of solid fuel such as wood and charcoal for heat and cooking. Using biogas to cook instead of biomass reduces particulate matter pollution in kitchens by 80%¹. The use of biogas in place of fossil fuel can improve air



Image: Biogas stove

quality, contributing to reduce the 4.2 million premature deaths that result from air pollution worldwide². Utilising biogas stoves and gas lamps for cooking and lighting can prevent these emissions and is better for indoor air quality, and the health of the residents.

Domestic and community food waste digestion plants offer decentralised treatment of organic waste which is a challenge that many developing countries' municipalities face. On a household level, food waste digestion has been successfully implemented in Alappuzha, Kerala, India^{3,4}, as a waste management strategy.

¹Berkeley Air Monitoring Group (2015) Quantifying the health impacts of ACE-1 biomass and biogas stoves in Cambodia http://www.snv.org/public/cms/sites/default/files/explore/download/quantifying_the_health_impacts_of_ace-1_biomass_and_biogas_stoves_in_cambodia.pdf

²World Biogas Association (2017) Factsheet 1: How biogas can help improve urban air quality <http://www.worldbiogasassociation.org/wp-content/uploads/2017/07/WBA-Urban-Air-Quality-Biogas-factsheet1.pdf>

Community level digestion of food waste has been implemented in a few Amma Canteens, where the waste generated at the establishment is combined with nearby vegetable market waste for digestion and the biogas produced is used in cooking at the canteen, substituting a fraction of the LPG⁵.

Small-scale biogas plants are, however, not common in densely populated urban areas due to limitation of the area/space available. Where implemented, households with the digester are known to accept food waste from neighbours to meet the capacity of the digester and produce sufficient biogas at the required pressure. In rural areas, the micro-scale AD model is well established due to availability of animal manure and crop residues to supplement food waste.

Pilot small-scale biogas plants⁶ and products^{7,8}, are being experimented in developed countries to evaluate the feasibility of AD of food waste in urban areas.

6.2. Biogas boilers

Biogas can be burned directly in a boiler to generate hot water or steam which may be used to meet the operational needs of the biogas plant or 'parasitic load', used on site for process heating or transported via a district heating network. Biogas boilers can capture up to 85% of the energy in the biogas in the form of hot water.

Compared to the other uses of biogas (burning in a CHP engine or upgraded for use in the gas grid or as transport fuel), very little gas cleaning is required, reducing investment and operational costs. The extent to which biogas needs to be cleaned varies with the size and type of boiler. However, it is recommended that hydrogen sulphide be kept below 1,000 parts per million (ppm), and the dew point around 150°C to prevent corrosion and deterioration of equipment.

Boilers are made from cast iron or mild steel, the former giving longer operational life and the latter being cheaper to purchase. Once the biogas has been cleaned, conventional gas burners and gas lamps can easily be adjusted to biogas by changing the air to gas ratio⁹.

The food and drink industry is an example where biogas boiler technology is well established and implemented. Some examples include Toyama City Eco Town where food waste based biogas boilers provide energy for Mitsubishi Rayon Toyama Production Centre¹⁰, Bonduelle canning facility in Nagykoros, Hungary¹¹, Elgin Fruit Juices in South Africa¹² and Diageo's Glendullan distillery in Scotland¹³.

³United Nations Environment Programme (2017) Solid approach to waste: how 5 cities are beating pollution. <https://www.unenvironment.org/news-and-stories/story/solid-approach-waste-how-5-cities-are-beating-pollution>. Accessed on 05/12/2017.

⁴The Print (2017). What India can learn from this scenic Kerala town about waste management. <https://theprint.in/2017/12/03/india-learn-alappuzha-waste-management/>. Accessed on 5/12/2017.

⁵Sarumathi, K (2015). Green food. <http://www.thehindu.com/features/downtown/green-food/article7239236.ece#>.

⁶LEAP Micro-AD. <http://communitybydesign.co.uk/pages/the-project>. Accessed on 06/12/2017.

⁷SimGas <http://www.simgas.com/products/urban/gesi550/item27> Accessed on 05/03/2018

⁸Homebiogas 2.0. <https://homebiogas.com/>. Accessed on 06/12/2017.

⁹This section derives from ADBA (2017). Practical Guide to AD. <http://adbioreources.org/library/purchase-the-practical-guide-to-ad/>.

¹⁰Mitsubishi Rayon (2014). Corporate Social Responsibility Report. https://www.m-chemical.co.jp/en/csr/pdf/csr_report_mrc_2014.pdf.

¹¹Veolia. Europe's leading producer of canned goods reduces its energy bill thanks to biogas. <https://www.veolia.com/en/our-customers/achievements/industries/food-beverage/hungary-bonduelle>. Accessed on 22/12/2017.

¹²GreenCape (2017). The business case for biogas from solid waste in the Western Cape. <https://www.greencape.co.za/assets/Uploads/GreenCape-Biogas-Business-Case-Final.pdf>.

¹³Clearfleau (2016). Whisky power: bio-energy transforms distillery sector. <http://clearfleau.com/diageo-whisky-power-bio-energy-transforms-distillery-sector/>.

6.3. Electricity

The energy in biogas can be captured in the form of electricity via engines. The technologies available to do this conversion are numerous and well established. These include gas engines (Pilot injection engines, Gas-Otto engines), fuel cells, micro-gas turbines, Rankine Cycles (Organic and Clausius), Kalina Cycles, Stirling Engines, exhaust gas turbines or CHP engines¹⁴.

Of all these available options, use of CHP engines is most common as they have an overall energy efficiency of up to 85%¹⁵, of which up to 35% is in the form of electricity and 50% as heat. The heat is captured in the form of hot water from the engine cooling jacket and high-grade heat from the exhaust gases. The hot water and heat from exhaust gases may be used as is, or captured for further generation of electricity. The electricity produced can be used to meet the operational needs of biogas production or 'parasitic load' (such as pumps, macerators, agitators), used for onsite processes (such as building lighting, process electricity), transmitted to a local consumer via mini-grid or injected into a local electricity network. Like biogas boilers, in order to use biogas in CHP engines, siloxanes, hydrogen sulphide and water content should be brought within permissible limits.

The capital cost of a CHP engine can be expected to be between \$750 and \$1800 per kW^{16,17,18,19}, depending on a number of factors including the engine type, engine size, whether or not heat recovery is added, and whether it is a custom-built or package engine. The cost of connecting to the grid, if applicable, varies with the distance from the plant, connection assets required and voltage level. These parameters vary with the provider and grid and will be negotiated on a project-specific basis.

Examples of successfully operating food waste based biogas plants generating renewable electricity are available all around the world at various scales, including: local food courts in Malaysia using food scraps to generate electricity to light a few bulbs²⁰; Harvest Energy Garden processing food waste from Walt Disney World Resort and other industrial, commercial and institutional sources to generate 3.2 MW of electricity (and 2.2 MW of recoverable heat)²¹; City of Chiba, Japan digesting food waste from food manufacturing industries, retailers and households²²; and Elgin Fruit Juices, South Africa running part of their juicing operations on electricity generated from fruit, vegetable and other food waste²³.

¹⁴WIP Renewable Energies (2015). *Sustainable Heat Use of Biogas Plants – A Handbook*, 2nd Edition. http://www.biogasheat.org/wp-content/uploads/2015/03/Handbook-2ed_2015-02-20-cleanversion.pdf.

¹⁵ADBA (2017). *The Practical Guide to AD (Second Edition)*. <http://adbioresearch.org/library/purchase-the-practical-guide-to-ad>.

¹⁶UK MARKAL Model Documentation (2007). <http://www.ucl.ac.uk/energy-models/models/uk-markal/uk-markal-manual-chapter-5-appendix>.

¹⁷Midwest CHP Application Center http://www.midwestchptap.org/Archive/pdfs/060216_CHP_and%20AnaerobicDigester_Applications.pdf.

¹⁸Carbon Trust (2010). *Introducing combined heat and power*. https://www.carbontrust.com/media/19529/ctv044_introducing_combined_heat_and_power.pdf.

¹⁹U.S. EPA (2017). *Catalog of CHP Technologies*. https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf.

²⁰Chen, Grace (2017). *Food courts tested on green technology*. <https://www.thestar.com.my/metro/metro-news/2017/11/11/food-courts-tested-on-green-technology-local-councils-in-three-states-aggressively-promoting-waste-mv>.

²¹American Biogas Council (2014). *Harvest Energy Garden - Central Florida*. <https://www.americanbiogascouncil.org/projectProfiles/lakeBuenaVistaFL.pdf>.

²²Global Environment Centre Foundation (2011). *Waste Recycling Technologies and Recycling Promotion Initiatives in Eco-towns in Japan*. http://nett21.gec.jp/Ecotowns/data/et_a-07.html.

The electricity produced in this way can:

- Mitigate climate change;
- Replace fossil fuel energy with renewable energy;
- Help meet regulatory requirements for emissions;
- Meet both base load and peak energy demands;
- Bring energy security and independence;
- Result in operational cost savings; and
- Diversify income via additional income stream.



Image: CHP Engine on a biogas plant (Schwedt)

6.4. Heat

Utilising heat is critical to the economic and environmental performance of a biogas plant. Up to 50% of the energy captured in biogas is available as heat via a CHP engine. Of the heat generated, 20-40% is required to meet the needs of the biogas plant such as heating the tanks and pasteurisation of feedstock/digestate and the rest is surplus. This surplus heat may be used to generate additional electricity or may be used for space heating, process heat, drying, district heating, cooling and other uses.

Typical consumers of heat from biogas plants are those with a usually high and continuous heat demand throughout the year, e.g. large meat producers, cheese

factories, breweries, aquacultures, laundries, recreation centres, hospitals, swimming pools and spas. The demand of hotels, canteens, food storages, schools and private residential housing is usually less regular.

For the planning of heating systems, the total, annual and peak heat demands as well as the temperature of heat required by the end user should be assessed in as much detail as possible.

While there is plenty of heat available and many uses to which it can be put, there are a few challenges with its utilisation that have prevented its adoption on a similar scale as electricity:

²³GreenCape (2017). The business case for biogas from solid waste in the Western Cape. <https://www.greencape.co.za/assets/Uploads/GreenCape-Biogas-Business-Case-Final.pdf>.

- **Seasonal variation in heat demand** – While heat is produced all year round with a CHP engine, there is competing demand for it during winter and little demand for it in summer. For example, in winter, the requirement for heat to maintain the digester temperature increases and also there is a higher demand for heat in greenhouses and district heating networks. During summer, the demand of both digesters as well as greenhouses and district heating is negligible. This seasonality in demand causes wastage of heat in summer. However, this can be overcome by converting it into cooling using vapour absorption or absorption chillers, or upgrading biogas to biomethane to be injected into the gas grid where it may be used to meet baseload energy, or storing biogas to generate heat when needed. Heat storage facilities can help balance these variations but are very cost intensive. In warmer climates, where seasonality is not an issue, the need for heat is limited by the proximity of industrial uses.
- **Need for an end user of heat** – As mentioned earlier, the parasitic load of heat of a digester accounts for about 20-40% of the heat produced, the rest being available for other uses. The infrastructure required to transport heat is expensive and incurs significant heat losses. Hence it is important that an onsite or local end user of heat be identified to make its capture most profitable.
- **Heat temperature and quantity** – Another factor in utilisation of heat is the temperature and the quantity of the heat produced and required. While some industrial processes such as drying require high grade heat, maintaining digester and greenhouse temperatures need low grade. While a CHP engine can produce both, a match in the demand and supply is needed for efficient use.
- **Cost of infrastructure** – Laying the infrastructure of heat transfer (insulated, pressure resistant pipes, building a mini grid) can be expensive and often has to compete with existing fossil fuel based infrastructure.

Some potential uses of heat that have been successfully implemented are discussed below.

6.4.1. District heating

District heating (or heat networks) is a network of insulated pipes which deliver heat, in the form of hot water or steam, from the point of generation to the end user. It is a system for distributing heat generated in a centralised location to residential and commercial enterprises to meet their space and water heating requirements.

District heating networks vary considerably in size and length – small-scale systems

can supply heat to only a few households, whereas large-scale systems can service entire communities, industrial areas or cities.

A biogas-based heat network would carry heat captured from a CHP engine or boiler in the form of hot water or steam. Such a network can benefit an off-grid or poorly serviced local community or industrial/commercial enterprise without its own reliable heating source.

Besides energy independence, a biogas heating system also mitigates greenhouse gas emissions by substituting fossil fuels. It is also an additional source of income for the biogas plant. The installation of a district heating system for waste heat from biogas plants is associated with considerable capital costs. The pipes carrying the hot water or steam need to be very well insulated and are usually installed underground, though there are systems with aboveground pipes. Additional equipment may include heat exchangers and connection equipment, heat storage systems and calorimeters²⁴. The larger the distance between the biogas plant and the heat consumer, the higher the costs and losses. But once set up, district heating networks can be a steady source of income for the biogas plant.

District heating networks are in operation in multiple towns such as Polderwijk, Netherlands, where biogas,

produced from co-digestion of food waste with animal manure, is combusted in two separate CHP units, one serving the digester on site while the other is located in a residential area 5km away from the plant. In order to reduce costs and heat loss, biogas is transported via a biogas-pipeline instead of a heat-pipeline for use in the second CHP unit. The heat from this second CHP unit is used for district heating. The project, a collaboration between the municipality, a local energy company and a farm, is a good example of how to create an area with a sustainable and energy efficient heating system, whereby the heat released by the CHP unit is used for district heating in a residential area²⁵.

Other examples of long-term successfully operating projects include the municipality of Este, in the Veneto region of Italy²⁶, Hengelo in Netherlands^{27,28}, and Dannenberg, Germany²⁹.

6.4.2. Heating greenhouses

Greenhouses often have a high energy demand in order to create the optimum growing conditions for plants - 20-25°C. Heating costs can therefore be among the highest operational costs of food production using greenhouses. Thus, use of heat from biogas plants can constitute a reliable and cheap heat source. As with district heating, minimising the distance between the greenhouse and biogas plant will help in keeping costs and heat losses low.

Examples of successful integration of biogas-based heat use in greenhouses are Vehmaan biogas plant in Finland³⁰, Kaisei plant in Japan³¹ and Leamington/Kingsville in Ontario, Canada³².

²⁴WIP Renewable Energies (2015). Sustainable Heat Use of Biogas Plants – A Handbook, 2nd Edition. http://www.biogasheat.org/wp-content/uploads/2015/03/Handbook-2ed_2015-02-20-cleanversion.pdf

²⁵IEA Bioenergy (2011). Biogas Pipeline for Local Heat and Power Production in a Residential Area, Zeewolde, NL. http://www.iea-biogas.net/files/daten-redaktion/download/Success%20Stories/success_story_zeewolde2011.pdf.

²⁶Mayors in Action (2016). Webinar: Enhancing heating & cooling strategies at local level. http://www.mayorsinaction.eu/fileadmin/user_upload/general_folder/Events/Webinars/STRATEGO_webinar/DeFilippi_STRATEGO_webinar.pdf.

²⁷OWS. Hengelo 2011. <http://www.ows.be/biogas-plants/references/hengelo-2011/>. Accessed on 22/12/2017.

²⁸Verstichel S (2015). DRANCO Technology for anaerobic digestion of organic waste <http://www.synpol.org/cm4all/mediadb/Murcia%2009%20S.%20Verstichel.pdf>

²⁹Fab Biogas. Best-Practice: Biogas plant & bio-methane filling station Dannenberg. http://www.fabbiogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_Dannenberg_english.pdf.

³⁰Gasum. Vehmaa biogas plant. <https://www.gasum.com/kaasusta/biokaasu/biokaasulaitokset/vehmaan-biokaasulaitos/>.

³¹Ushikubo A (2013). Recycling of food waste in Japan. https://www.oecd.org/site/agrfcn/Session%204_Akikuni%20Ushikubo.pdf.

³²Waste Management World (2012). Biogas from AD: A winner for Ontario Greenhouse Grower. <https://waste-management-world.com/a/biogas-from-ad-a-winner-for-ontario-greenhouse-grower>. Accessed on 22/12/2017.

6.4.3. Industrial process heating

Industrial facilities use heat for a wide variety of applications including washing, cooking, sterilising, drying and process heating (heating an industrial vessel to raise the temperature to the required level). Food processing industries such as breweries, fruit and vegetable canning industry and dried herbs and spice industries have a high heat requirement, some of which can be met by the heat generated by a biogas boiler or a CHP engine.

In many instances, waste generated by those industries transforming foodstuffs can be used as feedstock in the digester, thereby not only reducing the operational energy cost but also offering a viable method for waste

management. In addition, use of biogas heat can help industries meet their permitted emission limits, ensure a reliable source of renewable energy, reduce their dependence on fossil fuels and reduce costs.

Use of heat for onsite industrial processes has been implemented in Grossfurtner in St. Martin, Austria³³ and a Remo-Frit plant in Belgium³⁴.

If located next to an industrial plant, the heat from a biogas plant can be exported such as in Chiba, Japan, where food waste from households and businesses is digested and the biogas is supplied to the neighbouring JFE Steel plant where the biogas is combusted for electricity and steam to be used as process heat³⁵.

6.5. Upgrading biogas to biomethane

The upgrading of biogas to biomethane refers to the process of increasing the methane content of biogas to more than 90%, while removing carbon dioxide, hydrogen sulphide and water. The standards for quality of biomethane vary with use, country and existing infrastructure.

Biogas produced by digestion of food waste can be converted into biomethane for injection into the gas distribution grid, or for use as renewable transport fuel.

Technology to upgrade biogas to biomethane

has matured and has been widely implemented all around the globe. An estimated 500 upgrading plants are currently operating globally, with about 187 in Germany, 90 in the UK and 62 in Sweden. Many other countries including the USA, South Korea, Netherlands and Switzerland also operate biomethane plants, some focussing on injection to gas grid, while others use it as vehicular fuel. While only some of these plants digest food waste, the average scale of food waste digesters makes upgrading of biogas a viable choice.

³³FAB Biogas. Best-Practice: Biogas Plant St. Martin, Upper Austria. http://www.fabblogas.eu/fileadmin/user_upload/Download/D3.2_factsheet_St.Martin_english.pdf.

³⁴Remo-Frit Sustainability. <https://www.remofrit.be/en/sustainability/>. Accessed on 22/12/2017.

³⁵Chiba Biogas Center. <http://nett21.gec.jp/ECotowns/data/img/a07-1L.pdf>. Accessed on 22/12/2017.

Upgrading of biogas to biomethane has the following advantages:

- **HIGH ENERGY EFFICIENCY** – The percentage of energy captured by upgrading of biogas can theoretically approach 100%.
- **ENERGY STORAGE** – In the form of biomethane, energy can be stored and transferred when it is required and to where it is needed.
- **EXISTING EQUIPMENT** – Once biogas has been upgraded to the established standard, it can be used via existing infrastructure and equipment for natural gas without needing any modifications.
- **POTENTIALLY MULTIPLE SOURCES OF INCOME** – In addition to income through sale of captured energy and digestate, the sale of carbon dioxide can add an additional income stream to the business.
- **REDUCED DEPENDENCE OF FOSSIL FUELS** – Biomethane produced from food waste is a renewable form of energy and can replace natural gas which is a fossil fuel.

Several technologies for biogas upgrading are commercially available. Five of the most common ones are presented below:

TABLE 9:

UPGRADING TECHNOLOGY	DESCRIPTION ³⁶	PURITY OF METHANE (CH ₄) ³⁷
Pressure Swing Adsorption (PSA)	CO ₂ is separated from the biogas by adsorption on a surface under elevated pressure. The adsorbing material is usually activated carbon.	>96%
Water wash (Physical absorption) (Pressurised water scrubbing)	Solution of CO ₂ in water under high pressure (CO ₂ has a higher solubility in water than CH ₄ , therefore it will be dissolved to a higher extent than CH ₄ , particularly at lower temperatures).	>96%
Amine scrubbing (Amine gas treating) (Chemical absorption)	Chemical reaction of CO ₂ with aMDEA (activated methyldiethanolamine) to remove it from the biogas.	>99%
Membrane	Permeation of CO ₂ through hollow fibre membranes to separate the gases.	>99%
Cryogenic	Newly developed technique that involves the staged cooling of biogas to allow the extraction of CO ₂ . This technique makes use of the distinct boiling/sublimation points of the different gases.	>99%

³⁶IEA Bioenergy (2009). Biogas upgrading technologies – developments and innovations. https://www.iea-biogas.net/files/daten-redaktion/download/publi-task37/upgrading_rz_low_final.pdf.

³⁷Clearleau (2017) Summary report on biogas for commercial vehicle fuel <http://clearleau.com/summary-of-report-on-biogas-for-commercial-vehicle-fuel-july-2017/>

Membrane separation and water wash are the two most widely used technologies for upgrading biogas to biomethane in Europe³⁶.

The choice of technology depends on the standard of biomethane needed, available funds, available technology providers and operating cost. These factors depend on individual circumstances of the plant, so a full feasibility study will need to be conducted to choose the most appropriate technology.

The total cost for biogas upgrading depends on a number of factors, including:

- ◇ The quality of raw biogas and biomethane required;
- ◇ Scale of operation – cost per unit decreases with increase in scale;
- ◇ Location of the plant with respect to distribution system;
- ◇ Technology used for upgrading;
- ◇ The available auxiliary power; and
- ◇ Environmental regulations³⁷.

An International Renewable Energy Agency (IRENA) technology brief on biogas in transport reports the following specific cost for upgrading³⁸:

TABLE 10: COSTS FOR BIOGAS UPGRADING

RAW BIOGAS UPGRADING CAPACITY (M ³ /HR)	COST (USD/M ³ CH ₄)
20	1.07
50	0.50
100	0.35
200	0.25
500	0.17-0.25
1,000	0.14-0.18
2,000	0.09-0.16

For larger industrial waste plants of raw biogas capacity ranging between 1,000 and 2,000 m³/hr, the costs of upgrading range between \$0.09 and \$0.18 per m³ of biomethane produced. This means that for a 30,000 tonne/year plant (which produces a maximum of 7.8 million m³ of biomethane per year), upgrading would add between \$700,000 and \$1,400,000 in costs.

³⁶IEA Bioenergy. Task 37 Member Country Reports. <http://task37.ieabioenergy.com/country-reports.html>.³⁹IRENA (2017). Biogas for Road Vehicles Technology Brief. http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_Biogas_for_Road_Vehicles_2017.pdf.

³⁷ IRENA (2017). Biogas for Road Vehicles Technology Brief. http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_Biogas_for_Road_Vehicles_2017.pdf.

³⁸ IRENA (2017). Biogas for Road Vehicles Technology Brief. http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_Biogas_for_Road_Vehicles_2017.pdf.

6.5.1. Gas production – biomethane-to-grid

Once the biogas has been upgraded into biomethane, for those countries that have a gas distribution network (GDN), it can be injected into the gas grid.

For the gas to be injected into the grid, the quality of biomethane required is determined by the network or the country regulations. In order to facilitate a connection, the GDN will need to know a series of characteristics from the AD operator including the location of the biomethane production facility, the anticipated volumes and hourly flow profile, anticipated gas composition (e.g. 96% methane) and the date at which they intend to connect. While the exact specifications for gas quality vary, the parameters include: Wobbe index, methane content, gas relative humidity, dust levels, carbon dioxide, oxygen and hydrogen percentages, and hydrogen sulphide and sulphur levels. An example of an upgrading standard used by Switzerland is shown in Table 11 below³⁹.

The quality and volume of injected gas is monitored at the point of entry into the grid. The point of injection is usually operated via a remote valve that allows the grid operator to shut off a plant injecting into the grid at any point, if they believe the gas is not compliant⁴⁰.

To inject the gas into the grid, two additional costs are required (on top of the digester costs): the cost of upgrading (covered in previous section) and the cost of injecting into the gas grid. The cost for biomethane grid injection (based on cost analysis in Germany) amounts to between USD 0.06 and \$0.12 per m³ of methane produced⁴¹. This means that for a 30,000 tonne/year plant (which produces a maximum of 7.8 million m³ of biomethane per year), grid injection would add between \$470,000 and \$930,000 in costs.

Food waste-based gas-to-grid plants are operating in Oulu⁴² and Riihimäki⁴³ (Finland), Dagenham (UK)⁴⁴ and Zurich (Switzerland)⁴⁵.

TABLE 11: EXAMPLE OF NATIONAL UPGRADING STANDARD (SWITZERLAND)

PARAMETER	UNIT	DEMAND IN STANDARD
Methane content	Vol-%	>96
Gas relative humidity	phi	<60%
Dust	-	Technically free
CO ₂	vol-%	<6
O ₂	vol-%	<0,5
H ₂	vol-%	<5
H ₂ S	mg/ nm ³	<5
S	mg/ nm ³	<30

³⁹ IEA Bioenergy (2006). Biogas Upgrading to Vehicle Fuel Standards and Grid Injection. http://task37.ieabioenergy.com/files/daten-redaktion/download/publi-task37/upgrading_report_final.pdf.

⁴⁰ ADBA (2017). The Practical Guide to AD (Second Edition). <http://adbioresources.org/library/purchase-the-practical-guide-to-ad>.

⁴¹ IRENA (2017). Biogas for Road Vehicles Technology Brief. http://www.irena.org/DocumentDownloads/Publications/IRENA_Biogas_for_Road_Vehicles_2017.pdf.

⁴² Gasum. Oulu biogas plant. <https://www.gasum.com/kaasusta/biokaasu/biokaasulaitokset/oulu-biokaasulaitos/>. Accessed on 22/12/2017.

⁴³ Gasum. Riihimäki biogas plant. <https://www.gasum.com/kaasusta/biokaasu/biokaasulaitokset/riihimaen-biokaasulaitos/>. Accessed on 22/12/2017.

⁴⁴ ReFood. <https://refood.co.uk/refood-opens-latest-state-art-ad-facility-london/>. Accessed on 22/12/2017.

⁴⁵ IEA Task 37 (2014). Biowaste and sewage sludge recovery: separate digestion, common gas upgrading and heat supply. <http://task37.ieabioenergy.com/case-studies.html>.

6.5.2. Vehicle fuel production – biomethane for transport

Biogas, once upgraded to a well-defined standard, may be used as fuel in any passenger or heavy goods vehicle that can run on gas. Upgraded biomethane can be used in both dedicated gas vehicles and dual-fuel vehicles which offer diesel and gas-mix compression ignition engines.

Biomethane as a vehicle fuel uses the same engine and vehicle configuration as natural gas, therefore vehicles that previously ran on natural gas can be used to run on biomethane – they just need to be configured to run on

the right fuel (compressed natural gas [CNG], compressed biomethane [CBM], liquid natural gas [LNG], liquid biomethane [LBM]).

There are more than 1 million natural gas vehicles all over the world with new models regularly released. Argentina, Brazil, China, Colombia, Germany, India, Iran, Italy, Pakistan, Sweden and Switzerland have relatively well-developed natural gas vehicle infrastructures, for which biomethane could easily be implemented as a renewable alternative to fossil natural gas⁴⁶.

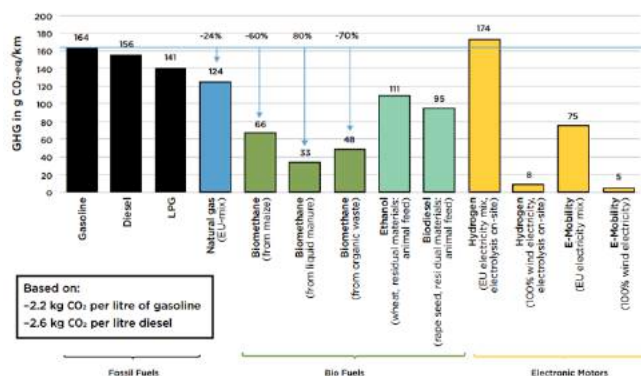
Vehicles running on biomethane have distinct advantages as compared to diesel vehicles:

- ✓ **Very low pollutant emission levels: particulate matter and nitrogen oxides especially**
- ✓ **Very low CO₂ emissions, up to 65% less than an equivalent Euro V diesel (well-to-wheel greenhouse gas emissions can be reduced by 80-95% compared to convention fuels)**
- ✓ **Low-noise engines: significantly lower than an equivalent Euro V diesel**

Biomethane derived from organic wastes can achieve 70% greenhouse gas emission reductions in passenger cars when compared to gasoline⁴⁷, as shown by the chart in Figure 14 below. These emission

reductions are greater than electric cars (54% reduction under the current electricity mix in the EU) due to still high use of non-renewable sources for the generation of electricity.

Figure 14: Comparative GHG emissions from passenger cars running on different fuels



⁴⁶IRENA (2017). Biogas for Road Vehicles Technology Brief. http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_Biogas_for_Road_Vehicles_2017.pdf.

⁴⁷IRENA (2017). Biogas for Road Vehicles Technology Brief. http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_Biogas_for_Road_Vehicles_2017.pdf.

TABLE 12: EXAMPLES OF CITIES USING BIOMETHANE VEHICLES

CITY	OPERATORS	NUMBER AND TYPE OF VEHICLE POWERED BY BIOGAS
Berlin ⁴	Berlin City Cleaning Services (BSR)	150 garbage trucks
Lille	Lille Métropole Communauté Urbaine (LMCU) authority	430 buses
Madrid	EMT Madrid	945 buses
Santa Monica	City of Santa Monica	100 buses
Reading	Reading Buses	39 buses
Nottingham	Nottingham City Transport	53 buses

The requirement of quality for biomethane to be used as vehicle fuel is different from that needed for injection in grid. While exact specifications vary, the parameters of quality include: Lower Wobbe index, motor octane number, water dew point and sulphur and ammonia levels. As an example, standards for Sweden are shown in Figure 15 below⁸:



Image: Biogas bus - City of Oslo

Figure 15: Example of national standard for biomethane

Swedish national standard for biomethane		
PARAMETER	UNIT	DEMAND IN STANDARD
Lower Wobbe index	MJ/nm ³	43,9 – 47,3 ¹
MON (motor octane number)	-	>130 (calculated according to ISO 15403)
Water dew point	°C	<1 ² -5
CO+O+N ₂	vol-%	<5
O ₂	vol-%	<1
Total sulphur	mg/ nm ³	<23
NH ₃	mg/ nm ³	20

Once the biogas has been upgraded to biomethane, it can either be:

1. Transported to the filling stations via public gas pipelines: In this case, the biomethane needs to be compressed to the pressure at which the pipeline is operated (more below), and abide by the gas quality requirements. The grid injection unit also needs to be planned, financed, built and operated.
2. Bottled or transported by trucks in high-pressure (200-250 bars) gas bottles: Here, the biomethane must also reach certain quality requirements for methane and water vapour content. This option involves additional transportation and capital equipment costs and most likely extra costs for compression at the filling station.
3. Directly used at a filling station at the location of biomethane production.
4. For any of the above options, to use biomethane as a transport fuel, it must either be compressed or liquefied. This is to make it easier to store and distribute.

Compressed biomethane (CBM)

The biomethane is compressed to 250-300 bar pressure to reduce the storage volume (to less than 1% of the volume it occupies at standard atmospheric pressure) and increase the energy density to useful levels. It is then stored in a bank of storage cylinders ready for fuelling. The equipment in a compressed gas refuelling station usually consists of gas conditioning to remove any residual moisture and contaminants, a compressor, storage and a dispenser. There are many examples where biomethane is used on its own or combined with natural gas in public transport buses and waste collection trucks including Lille (France)⁴⁸, Reading (UK)⁴⁹, Chennai (India)⁵⁰ and South Korea⁵¹.

Liquid biomethane (LBM)

Liquid biomethane is usually created by compressing and cooling the biomethane to well below zero (methane has a boiling point of -164°C), which converts the gas to a liquid and cuts its volume to 1/600th of the original, making it possible to ship the LBM in special tankers. LBM is a way of transporting biomethane long distances when pipelines are not an option. The infrastructure for LBM can be extensive and expensive.

Liquid biomethane fuels Santa Monica's Big Blue Bus program in California, USA; the City's transit department operates a significant proportion of its bus fleet on renewable natural gas (biomethane) liquefied into LBM, reducing the fleet's carbon footprint by nearly 90%⁵².

An LBM plant has been in operation since 2012, in Linköping, Sweden. The plant produces transport fuel for cars, trucks and buses⁵³.

Comparison of Compressed Biomethane and Liquid Biomethane

Table 10 below gives a financial evaluation from Clearfleau of both CBM and LBM options as an alternative to a 250kW CHP unit, based on data for a medium-scale creamery site:

TABLE 13: FINANCIAL EVALUATION FROM CLEARFLEAU OF BOTH CBM AND LBM OPTIONS

	Units	CBM	LBM	
			Exc. CO2	Inc. CO2
Capital investment	£k	5,323	6,416	6,516
IRR (15 years)	%	13.9	9.3	11
NPV	£k	1,038	-237	305
Profit	£k/yr	930	856	967
Payback (discounted by 10%)	years	8.8	13.4	11.2
Payback (simple)	years	5.7	7.5	6.7

⁴⁸Lille Metropole. Biomethane production and its use in captive fleets. https://www.polisnetwork.eu/uploads/Modules/PublicDocuments/biogasmx-torun_lille.pdf.

⁴⁹Gas Vehicle Hub. CNG buses in Reading. <http://www.gasvehiclehub.org/case-studies/10-case-studies/80-cng-buses-in-reading>.

⁵⁰Mahindra World City. <http://www.mahindraworldcity.com/press/mahindra-inaugurates-its-bio-cng-plant-in-mahindra-world-city-mwc.aspx>. Accessed on 22/12/2017.

⁵¹IEA Bioenergy Task 37. Member Country Reports. <http://task37.ieabioenergy.com/country-reports.html>.

⁵²Clean Energy. Big Blue Bus Raises the Green Standard with Renewable Natural Gas. <https://www.cleanenergyfuels.com/customer-success-stories/big-blue-bus-success-story/>.

⁵³Backman M, Rogulska M. Biomethane use in Sweden. The Archives of Automotive Engineering – Archiwum Motoryzacji. 2016; 71(1): 7-19. <http://dx.doi.org/10.14669/AM.VOL71.ART1> and http://archiwummotoryzacji.pl/images/AM/vol71/PIMOT_71_Backman_7-20.pdf.

The evaluation shows an attractive payback, but individual projects will require detailed evaluation. The LBM solution involves higher capital cost and generates the longest payback but also facilitates capture and re-use the CO₂ removed from the biogas. LBM is better for long-haul operations because it has a higher energy density and so more fuel can be stored in the same space. This extends vehicle range and reduces refuelling frequency.

On top of the infrastructure and capacity needed to produce the biomethane, to roll out biomethane use in transport there also needs to be sufficient availability of biomethane vehicles and refuelling infrastructure (that is – a market and access to it).

CNG stations have pressurised dispensers and use a compressor that can deliver biomethane to vehicles at a pressure of 200 bar. These stations are connected to the gas grid via a pipeline connection. The costs of such systems depend on the overall pressure of the relevant gas grid (i.e. higher gas grid pressures mean that the amount of additional compression required is reduced, thereby reducing costs).

LNG stations consist of leak-tight dispensers and a cryogenic tank for storing the LNG fuel. LNG is delivered to these stations by road tanker. Refuelling stations need planning appropriately and need access to gas mains at the correct pressure as well as electricity to power the refuelling station.

Costs of refuelling stations include direct costs of fuelling (equipment on site, costs of gas/electricity

grid) and indirect costs of fuelling (costs for building structures, land). Analysis indicates that costs for CNG stations are around \$0.27 per litre (compared to approximately \$0.07 per litre for petrol/diesel stations). These costs cover transport to site, operations at site and operations refuelling⁵⁴.

Studies have found the cost of a 10,000 kg/day CNG refuelling station, which includes both capital and infrastructure costs, to be around USD 1.15 million. This amounts to around \$115/kg, or \$8/kWh. For a smaller 1,000 kg/day station, the cost was found to be around \$355,000, amounting to \$355/kg or \$26/kWh^{55,56}.

For LNG, the cost for refuelling stations was found to be lower. For a 10,000 kg/day LNG refuelling station, total costs were estimated at \$530,000, amounting to \$53/kg or \$4/kWh. For the smaller 1,000 kg/day station, the cost was estimated at \$140,000, amounting to \$140/kg or \$10/kWh⁵⁷.

Three more detailed case studies are outlined below:

CASE STUDY 1:

John Lewis Partnership, UK

The John Lewis Partnership (JLP) operates 12 heavy trucks on biomethane and had 43 more on order due to be delivered before the end of 2017. The vehicles fill up at a grid connected filling station at Leyland in Lancashire. The gas is certified as biomethane via the Renewable Transport Fuel Obligation (RTFO) scheme, ensuring that it meets the sustainability criteria laid out by the UK Government. The gas is created from food waste and food processing sources.

⁵⁴Ricardo Energy & Environment (2016). The role of natural gas and biomethane in the transport sector. https://www.transportenvironment.org/sites/te/files/publications/2016_02_TE_Natural_Gas_Biomethane_Study_FINAL.pdf.

⁵⁵Ricardo Energy & Environment (2016). The role of natural gas and biomethane in the transport sector. https://www.transportenvironment.org/sites/te/files/publications/2016_02_TE_Natural_Gas_Biomethane_Study_FINAL.pdf.

⁵⁶LowCVP (2011). Biomethane for Transport - HGV cost modelling <http://bit.ly/2oQcQEs>

⁵⁷Ricardo Energy & Environment (2016). The role of natural gas and biomethane in the transport sector. https://www.transportenvironment.org/sites/te/files/publications/2016_02_TE_Natural_Gas_Biomethane_Study_FINAL.pdf.

The biomethane lorries emit 84% less carbon dioxide than diesel equivalents, noise levels are halved and driver reaction has been very positive. Although the lorries are more expensive to buy than diesel trucks, the fuel is lower priced so in the long term it is financially more beneficial. The JLP plans to replace the majority of their diesel heavy trucks with gas as they come up for replacement.

Justin Laney, General Manager of Fleet, said “There were several barriers to overcome before we had a viable alternative to a diesel truck. The last of these was achieving a 500-mile range using compressed gas. Now that’s been overcome, our gas trucks can do the same work as our standard diesel trucks. They have significant environmental and driver benefits and a sound business case.”

CASE STUDY 2:

Berlin City Cleaning Services, Germany ⁵⁸

The Berlin City Cleaning Services (BSR) operates a biomethane plant in Ruhleben, Berlin. The plant uses 60,000 tonnes per year of source segregated food waste, which comes from weekly collection of food waste by garbage trucks, to produce 4.5 million m³ biomethane per year (550 m³/hr). The biomethane produced by the plant powers 150 Mercedes Benz Econic CNG garbage trucks, which represent over 50% of its fleet. The BSR owns three of its own gas filling stations. Benefits include 2.5 million litres of diesel and 12,000 tonnes of CO₂ avoided every year, and electricity not used to cover its own demand is exported into the grid.

CASE STUDY 3:

Lille Metropolitan Region, France ⁵⁹

The metropolitan region of Lille currently runs a fleet of about 430 waste-to-energy buses on biogas. The buses run on 108,000 tonnes per year of the organic wastes produced by the city’s 500,000 inhabitants (4,111,000 m³/yr of biogas produced, equivalent to 4,480,000 m³ of diesel). The project, budgeted at €75 million, started in 1994 with four of these buses, and has since expanded to the current number. The buses, powered by a mix of natural gas and biogas, are refuelled directly in three bus depots located next to biogas producing plants. Through installing an Organic Valorisation Centre in the peripheral neighbourhood of Sedequin, half of the city’s bio-wastes are turned into biomethane to fuel these buses. Residuals produce 25,000-30,000 tonnes of compost per year for agriculture, reducing dependence on synthetic fertilizers for local and regional farmers (60% of LMCU’s communes are rural), contributing to strengthening food and energy security. The city has recently started to power its waste collection trucks with pure biomethane too.

⁵⁸European Biogas Association (2016). Biomethane in Transport. <http://european-biogas.eu/wp-content/uploads/2016/05/BiomethInTransport.pdf>.

⁵⁹UrbanNEXUS CaseStudy_Lille http://www2.giz.de/wbt/4tDx9kw63gma/07_UrbanNEXUS_CaseStudy_Lille.pdf

6.6. Digestate – a valuable co-product

After food waste has been anaerobically digested and biogas released, the residual material that remains is called digestate or biofertiliser. Digestate is rich in micro-organisms, carbon, micronutrients and other nutrients including nitrogen, phosphate, potash, calcium, magnesium and sulphur. In batch and dry digesters, a fraction of the digestate is returned to the digester to ‘seed’ the fresh feedstock with the micro-organisms responsible for AD. When returned to land as soil amendment or conditioner, it improves soil water holding capacity while nutrients that were absorbed during the production of the food become

available for further production. In many countries, after adequate treatment, digestate can be applied to agricultural land or used as bedding material for urban landscaping projects, home gardens, in horticulture or in forestry ⁶⁰. One tonne of digestate can be worth up to USD \$6 in the UK ⁶¹, and after composting into certified compost, up to USD \$20 in Italy⁶². From ‘wet’ digestion, digestate can be used ‘whole’, without any separation of fibre and liquid fractions. Or the fibre and liquid fractions can be separated, with the fibre fraction then in many cases itself being composted (see ‘Digestate into Compost’ section below)

The nutrients and market value of digestate vary according to the type of feedstock and digestion process used. An example of nutrient composition of food waste-based digestate is in Table 14 below⁶³.

TABLE 14: EXAMPLE OF NUTRIENT CONTENT OF FOOD WASTE-BASED DIGESTATE

NUTRIENT	CONTENT (KG/TONNE OF FRESH WASTE)
Dry Matter (%)	3.3
pH	8.3
Total Nitrogen (N)	5.4 kg
Total Phosphate (P2O5)	0.8 kg
Total Potash (K2O)	1.9 kg
Total Calcium (Ca)	1.2 kg
Total Magnesium (MgO)	0.14 kg
Total Sulphur (SO3)	0.62 kg

Use of digestate on agricultural land results in

- Reduced use of manufactured fertilisers – The nutrient value of digestate (outlined above) reduces the need to purchase artificial fertilisers as it works as a substitute.
- Increased crop yield – By replacing the use of manufactured fertilisers, the same level of digestates can further enhance yields. This is due to the impacts on soil biology, supply of micronutrients and trace elements, and the existence of plant hormones. Results will vary according to digestate type, crop type, geography and climate.

⁶⁰ WRAP (2011). New Markets for Digestate from Anaerobic Digestion. http://www.wrap.org.uk/sites/files/wrap/New_Markets_for_AD_WRAP_format_Final_v2.c6779ccd.11341.pdf.

⁶¹ WRAP (2009). Waste Protocols Project. Anaerobic Digestate. http://www.organics-recycling.org.uk/uploads/category1060/Financial_impact_assessment_for_anaerobic_digestate.pdf.

⁶² CIC (2009). https://www.compost.it/attachments/617_Nota_Mercato_2010.pdf.

⁶³ WRAP (2016). Field experiments for quality digestate and compost in agriculture. http://www.wrap.org.uk/sites/files/wrap/DC-Agri_Work_Package_2_-_Digestate_nitrogen_supply_and_environmental_emissions.pdf

- Reduced land degradation – In semi-arid countries, like Mali and Oman, digestate adds carbon content to the soil which improves its water retention capacity and also returns nutrients to the soil. This mitigates land degradation due to nutrient and carbon depletion.
- Cost saving – Nutrient rich, waste-based biofertilisers are highly valued in countries where farmers are heavily dependent on expensive and imported mineral fertilisers.
- CO₂ mitigation – Plants photosynthesise carbon from the atmosphere into complex carbohydrates which directly or indirectly, through food chain, constitute as food for human beings. Digesting food waste carries it further to biogas and digestate. The carbon in biogas is returned to the atmosphere, but the carbon present in the digestate is captured and stored in the soil, thereby removing it from the atmosphere, thus helping in CO₂ mitigation.
- Reduced energy usage – Manufacturing inorganic fertilisers is an energy intensive process. Substituting them with digestate reduces the energy demand of agriculture and the corresponding greenhouse gas emissions.
- Digestate is a wet material in its natural state and the addition of moisture to soil is an added value in the more arid regions.



Image: Digestate

However, like nutrients, impurities may also be present in digestate. Examples are pieces of inert materials or larger pieces of digestible ones, biological contaminants such as pathogens and weed seeds.

Other contaminants such as heavy metals and persistent organic pollutants, may be present in digestate when food waste is co-digested with wastewater. The presence of these unwanted substances is dependent on their presence in the feedstock. While thermophilic digestion or pasteurisation removes biological contamination, inert materials and larger pieces of digestible materials can be dealt with in pre- or post-

treatment stages of digestion. Heavy metals and persistent organic pollutants remain a problem and can be avoided by carefully selecting the feedstock.

In order to minimise the spread of pathogens, food waste digestate is heavily regulated in many countries. The required standards of quality and stability vary in different countries. While some countries require pasteurisation of digestate, others require composting and storage. It is important to contact the environmental regulators in your jurisdiction to discuss how and where it can be used.

Digestate certification schemes have been set up such as American Biogas Council Digestate Certification scheme⁶⁴, European Compost Network-Quality Assurance Scheme (ECN-QAS)⁶⁵ and Sweden Waste Management digestate certification which certifies close to 70% of digestate produced from biowaste^{66,67}. While certification is an upfront cost, it can ensure long-term revenue for the biogas plant by increasing its marketability.

Best practice dictates that digestate should be stored in tanks with gas-tight covers with biogas collection – this is to ensure that no gases (methane, ammonia, hydrogen sulphide) are released into the atmosphere. Additional infrastructure such as bunding for spillage safety, or spillage and leakage detectors, may also be required, but this is up to each regulating body. The location of the digestate tank can either be at the AD plant where it is produced or at the place where the digestate will be used/applied. Whilst stored, the digestate will need to be stirred or agitated to ensure homogeneity before it is applied or transported.

When planning a biogas plant, it is important to take into consideration the possible avenues of markets for digestate keeping in mind the treatment, transport and application costs and benefits.

If transportation is required, the form of digestate (whole or separated liquids and solids), the transformation of digestate (e.g. by drying) before or after transport, the number of vehicles required, the distance between the biogas plant and destination for application and access to the user, all have cost implications. In addition, availability of the land to take the digestate must be

considered as these will be dictated by seasonal restrictions and crop requirements.

Examples of agreements between biogas plants and farmers for digestate sale are common. Examples of integration of food waste digestate into a gardening supplies business is Richgro in Australia⁶⁸.

DIGESTATE INTO COMPOST

Where the transformation of digestate from municipal waste into compost is required prior to marketing as a soil amendment, as in much of the EU, the standards and quality considerations for compost apply. In the following text some detail about the market for compost is provided.

First among the critical elements is contamination. Compost produced containing hidden or visible contaminants is often banned from sale where regulations exist or can only be used for low value applications such as daily landfill cover.

Hidden contaminants include heavy metals which are present in the initial feedstock. Sewage sludge often contains heavy metals (e.g. lead, cadmium, nickel, chrome, copper, zinc) due to contamination from industrial processes. Other hidden contaminants include Persistent Organic Pollutants (POPs) such as dioxins and polychlorinated biphenyls (PCBs), which again derive largely from industrial processes. As POPs are bio-accumulators, their presence in compost then spreads to soil that is used to produce food and for animal grazing, which is potentially hazardous for human and animal health.

⁶⁴American Biogas Council. <http://digestate.org/>. Accessed on 17/12/2017.

⁶⁵European Compost Network. <https://www.compostnetwork.info/ecn-qas/>. Accessed on 17/12/2017.

⁶⁶Avfall Sverige (2017) Swedish Waste Management https://www.avfallsverige.se/in-english/index.php?eID=tx_securedownloads&p=139&u=0&g=0&t=1520343550&hash=d3b80beb8360689eb8ca0ff00a20934bd7834c92&file=/fileadmin/user_upload/Publikationer/Avfallshantering_2017_eng_low.pdf Accessed on 21/12/2017

⁶⁷IEA Task 37 (2016). Member Country Reports. Sweden. <http://task37.ieabioenergy.com/country-reports.html>.

⁶⁸Landia. UK Companies Join Forces for New Richgro AD Plant in Australia. <http://www.landia.co.uk/Display-of-news?Action=1&NewsId=325&M=NewsV2&PID=711>.

It is useful therefore to note which feedstocks will commonly have potential to contain hidden contaminants. For example, leaves collected from public areas alongside busy roads are likely to contain high concentrations of lead (where this is still used in petrol) and particulate from diesel emissions.

It is therefore useful to create quality standards for the final compost produced from aerobic composting of digestate to ensure that contamination from heavy metals and chemical compounds are kept within limits acceptable for animal and human health. Such regulations exist in most advanced economies, including Italy where some 6.5 million tonnes of food and garden waste were composted in 2017, that form the end of life standards for food waste (D.Lgs.75 of 2010 [legislative decree]). The USA has State rather than Federal standards but the USA Composting Council has a programme called 'Seal of Testing Assurance Program' which certifies compost quality.

Visible contaminants include those which are non-compostable and remain at the end of the process as they have failed to biodegrade. As noted above, these may include potential compostable fractions, such as oversize pieces of wood, that have not yet broken down. These may be recycled into the composting process time and time again or shredded to smaller pieces to increase the speed of biodegradation.

Non-compostable contaminants that remain at the end of the process are present because they were collected with the food or garden waste. Composting does not produce contaminants but cannot biodegrade non-

compostable materials. The most common of these are plastics of various types which pollute the food and garden waste streams. Similarly, aluminium cans, glass containers and bottles and ceramics, all of which are present in catering and kitchens, often are thrown in mistakenly with food scraps and arrive at the compost plant.

Most commonly, plastics are found with food and garden waste, for two reasons: firstly, plastics are ubiquitous so we find them in almost every packaging used to contain food – from yoghurt cups to vegetable bags to meat and fish containers to drink bottles; plastic films are particularly present in food waste because much food is wrapped in these. But secondly, and most importantly, plastics cannot be composted and are a contaminant whether the digestate is composted or not. Their presence in the digestate presents a technical as well as a cost issue, for their removal is necessary in either case. These plastics either need to be avoided in the collection process or sorted and extracted before and after the process (by screening). This is discussed further in Chapter 3 on collections.

The use of compostable films (recognised and certified by a harmonised European standard known as EN13432/2000 and in the USA by ASTM 6400) in collections and in some food packaging can help to overcome the contamination problem, as these plastics are designed and certified to naturally biodegrade within the composting process. Collection systems which use these compostable plastic materials (or other compostable materials such as paper bags) are therefore designed

to reduce contamination upstream. The City of Milan, which collects food waste separately from its 1.4 million citizens, uses compostable bin liners and has a contamination level below 5% of the total volume collected and treated ⁶⁹.

Compostable materials are made from renewable plant extracts such as starches and sugars and from fossil fuel polymers. The final performance of compostable materials has in fact little to do with the polymers they are made of but all to do with the bio-chemical engineering of their end-of-life. So paradoxically a totally plant based polymer may be designed to not biodegrade whilst a totally fossil fuel based polymer may be designed to biodegrade.

The final material at the end of the composting process needs to be free (by some standards, such as the UK and Italy) of at least 99.5% of all visible contaminants, including pieces of gravel, stones, plastics and glass. Further, the material needs to be free of potentially harmful levels of hidden contaminants such as heavy metals and POPs and infestant seeds such as weeds.

Once certified the compost material has several destination options:

1. BULK TO FARMERS

This is the main and traditional market for composting plants, the sale of large volumes of un-packed, untreated compost to farmers for spreading on their fields. Agronomical analysis of soils is needed to show how much compost is needed to add desired quantities of N, P, K, and organic matter to maintain fertility. This may be as much as 50t/hectare annually for field crops, less for fruit trees/vines.

Typically, a farmer will not pay more than the value of the N, P, K delivered by the compost and thus sales

values of bulk compost rarely surpass €15/20 per tonne, including delivery to the field. Depending upon distance, the price can often be zero.

2. FLORICULTURE AND HOBBY MARKETS

In these market places smaller quantities of compost are required by end users, often as little as 20 litre bags for domestic users. The composted material, as it leaves the composting plant, needs additives to give sufficient nutrient value to ornamental plants and this must be further treated by a producer of gardening substrates. Typically, these may contain peat, chips of wood bark, animal bone flour, or guano. One of the more sophisticated examples of compost converted into high quality garden substrata can be seen here: <https://www.fertil.it/catalogo-2017/>.

Prices for these materials depend upon the mixes, the packaging, the end use, and the marketing ability of the producers. Typically, a 15 litre bag will cost around €10-15 at the retail point and will convert back to a per tonne price to the composting plant/converter in excess of €300/tonne. Clearly, the conversion costs, marketing, sales force, transport and distribution, packaging and additives constitute a large part of this. Nevertheless, the opportunity for additional income from higher value products is obvious.

3. SPECIALISED AGRICULTURAL MARKETS

The lack of organic matter in many regions of the world, especially the arid areas, creates enormous market opportunities for organic matter such as that delivered by compost. In Tunisia, small composting plants on the outskirts of Tunis visited by one of our authors in 2010 even paid farmers to bring organic wastes to their plants to transform into compost as the sales price of the compost (€100/tonne +) guaranteed the profitability of the exercise.

⁶⁹CIC (2015). Annual report of the Italian Composting and Biogas Association. http://www.renewablematter.eu/partners/CIC/CIC%20annual_report2015eng.pdf.

In the Nile Valley where crops may be cultivated and harvested throughout the year, organic matter is at a premium and is paid in excess of €100/tonne by Nile farmers. In Bangladesh, the compost plant at Dhaka sells the final product also in excess of €100/tonne to local farmers despite this being among the poorest countries of the world⁷⁰.

Other market places for compost exist in site – specific areas, such as for soil remediation; for green areas such as public parks and gardens; for golf courses and sport grounds; in the USA seeded compost is sprayed onto newly formed roadside banked areas to accelerate plant growth and avoid soil erosion; in the vineyards of Tuscany, food waste from Tuscan cities is recycled into compost specifically designed to improve vine growth and to repress potentially damaging fungi.

The issue of compost quality is elaborated on because there is a common thread into AD, as seen in Chapter 5. Where digestate is used as a raw product it obtains a virtually zero value from the farming market. Where digestate is further transformed into higher value products through a post-anaerobic process, its potential value is higher though there are costs associated in this transformation.

There are many limiting factors in the production of compost and not least among these is the available area of the production site, not an issue in the vast expanses of many countries, but certainly a problem to be taken into account in crowded urban areas where space is at a premium.

The maturing period for compost can take as long as 60 days and space for these volumes needs to be found. Storage of compost prior to market takes further space, whether packaged or not. Material flows caused by seasonality both in the feedstocks entering into composting and in the final products and their use, requires the flexibility of storage space. Distance from dwellings needs to be maintained because the composting process produces odours and if not well contained within the plant can be a nuisance to the local community. The external maturing process will also cause some odours. The noise from heavy goods vehicles entering and exiting the plant can be tiresome for neighbours and being a plant which treats waste, it will be open to receiving deliveries at least six days a week.

Composting technologies are however, mature, well-known, tried, tested and relatively easy to design, build and operate within a time frame of one to two years. Composting can be a first and rapid answer to treating food and other biogenic wastes coming from urban collection systems.

Indeed, in many developed economies such as Germany, Italy, Netherlands, Belgium, France, composting has been the mainstay of food waste treatment since the early 1990s. The arrival of fiscal incentives for the production of renewable energy subsequently led to the increase in AD technologies for these waste streams and new plants were built incorporating AD into compost. In other nations, where composting of food waste was

⁷⁰Sinha A H M M(2012) Public-private partnership and decentralised composting approach in Dhaka, Bangladesh http://www.uncrd.or.jp/content/documents/04_Sinha-Waste%20Concern-Bangladesh.pdf

not widely practiced, such as the UK, the renewable energy incentives led to the development of an AD industry without the aerobic composting of digestate and garden waste incorporated, leading to operators

looking for markets for digestate rather than higher added value products.

Below are images from digestate composting section the AD plant of Bassano del Grappa (VI), Italy⁷¹.



Images: Digestate composting section of the AD plant of Bassano del Grappa (VI), Italy (Provided by ETRA SpA)

6.7 Carbon dioxide (CO₂)

30-40% of biogas is carbon dioxide (CO₂), its second largest constituent. When biogas is upgraded to biomethane, the carbon dioxide is removed to increase the percentage of methane (CH₄) in the gas. Methane carries the energy content of biogas and is used for the generation of heat or as a transport fuel as already covered earlier in the chapter.

The by-product and often undervalued product of this process is CO₂. CO₂ produced in this way can be used by industries and agriculture for additional revenue stream such as in carbonated beverages, food processing applications such as chilling and freezing, modified atmosphere packaging and temperature control for products being stored and transported⁷², water treatment applications such as pH reduction to neutralise process and waste water streams, and as

an automotive component in many gas mixtures. The CO₂ used therefore displaces CO₂ produced from fossil fuels, reducing the industry's carbon footprint.

Some examples of CO₂ utilisation around the world are the New Horizons Energy Athlone, South Africa plant which upgrades biogas from organic fraction of municipal solid waste and bottles CO₂ produced from the upgrading biogas for food and beverage, agriculture and industrial uses⁷³. Ecofuels in Netherlands captures CO₂ from its upgrading operations to be used as gaseous fertiliser in greenhouses, cooling agent in industrial applications or for production of dry ice⁷⁴.

An additional area which is being explored is the use of renewable CO₂ for the growing of algae. Growing algae requires nutrients, water, sunlight and CO₂.

⁷¹ Provided by ETRA SpA

⁷² Air Liquide <https://industry.airliquide.co.uk/sa-industrial-carbon-dioxide> Accessed on 05/03/18

⁷³ GreenCape (2017) The business case for biogas from solid waste in the Western cape <https://www.green-cape.co.za/assets/Uploads/GreenCape-Biogas-Business-Case-Final-v12-with-cover2.pdf>

⁷⁴ Pentair Haffmans Ecofuels, Netherlands Case Study <https://foodandbeverage.pentair.com/en/case-studies/ecofuels> Accessed on 22/12/2017

Using CO₂ from the AD process can help reduce costs for growing algae. The algae can then be used to produce clean energy in the form of biodiesel, bioethanol or again used as a feedstock in AD.

Power to gas:

The CO₂ produced in the digester, can be further converted into biomethane in process commonly referred to as 'power-to-gas' or 'biomethanation'. In this process, CO₂ from the digester and hydrogen from an external source

are biologically converted into methane via hydrogenotrophic methanogenesis by single celled microorganisms called archaea. This reaction is highly exothermic or generates heat, which can be captured and reused. The methane produced goes through a similar gas cleaning process as biogas and can be injected into the gas grid or used as vehicle fuel.

This process may take place within the digester or by using a separate stream of CO₂ produced as a by-product of upgrading as shown in the figure below⁷⁵.

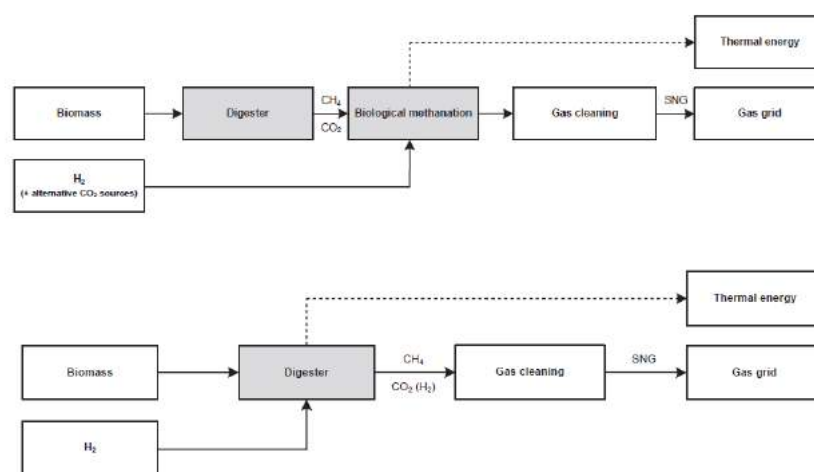


Figure 16: Process flow diagrams for biological methanation in a separate reactor (above) and for in situ biological methanation (below)⁷⁶

While this process can be achieved by purely catalytic reactions, combining it with biogas production has the following advantages:

- Existing source of CO₂;
- Heat generated during biomethanation can be used to maintain the temperature of biogas digester; and
- Gas cleaning process of upgraded biogas and methane generated from power-to-gas system is the same, which results in reduced capital and operational costs.

⁷⁵Gotz M, Lefebvre J, Mors F, Koch A M, Graf F, Bajohr S, Reimert R and Kolb T (2016) Renewable Power-to-Gas: A technological and economic review, Renewable Energy, Volume 85, Pages 1371-1390

⁷⁶Gotz M, Lefebvre J, Mors F, Koch A M, Graf F, Bajohr S, Reimert R and Kolb T (2016) Renewable Power-to-Gas: A technological and economic review, Renewable Energy, Volume 85, Pages 1371-1390

Power-to-gas methane technology has been implemented successfully at the Audi e-gas plant in Wertle Germany and has been operational since 2013. Industrial and agricultural biowaste are digested at the Hitachi Zosen Inova biogas plant. The biogas upgraded

and the CO₂ stream is supplied to the nearby Audi AG power-to-gas plant where it is used for methanation. The waste heat from this process is supplied back to the biogas plant for regeneration of amine scrubbing solution used in the upgrading process⁷⁷.

6.8 Cooling

Though seldom used, the heat from biogas can be used for chilling by using trigeneration or ‘combined heat, power and cooling’ (CHPC) systems. In these systems, there is a flexibility of using heat when needed and when not, heat can be converted for cooling. These systems work through vapour absorption or absorption chillers. So, for example, in winter, heat from a CHPC can be used to warm a building, while in summer it may be used to cool it. CHPC systems also have application in food and drinks industry where cooling is often required. Such a system has been installed in the Municipality of Este, Veneto, Italy by the operator SESA SpA.

6.9 Conclusion

Biogas from food waste can be put to many uses to the benefit of the people, environment and economy. In order to make the collection and digestion of food waste a norm, in cities and industries, a number of barriers need to be overcome. With the required knowledge and policy support, this can be achieved.

Chapter 7 highlights the ways that developers and policy makers can help in creating an environment where food waste collection and digestion becomes profitable and the chosen method of waste management.

⁷⁷Hitachi Zosen Inova http://www.hz-inova.com/cms/en/home?page_id=5178

Anaerobic Digestion of Food Waste: the case of the AD plant of Bassano del Grappa (VI)

City/District served

District of Vicenza and few municipalities of the district of Padua – Region Veneto

Type of authority collecting the food waste

Food waste is mostly collected by ETRA SpA (the same company which owns and run the AD plant), a public company in charge of the integrated waste management system (collection and treatment) in the districts Vicenza and part of the district of Padua. In some municipalities food waste is collected by other waste collection companies.

Type of establishments served

Mainly from households and commercial establishment whose waste is assimilated to municipal waste

Number of households/people/businesses/industries served

Around 480,000 inhabitants (around 73,5 kg/inh/y, as calculated by ETRA)

Volume of food waste treated annually (tonnes).

In 2016 the plant has treated around 41,000 t/y (35,000 t/y food waste and 6,000 t/y garden waste)

Co-digestion of food waste with other feedstocks

Basically the plant digests only food waste mixed with garden waste; actually, garden waste has a negligible biogas production potential; its primary

scope is to facilitate the release of biogas from the digester.

Biogas produced on an annual basis

Around 5,000,000 m³/y in 2016 (142 m³/tonne food waste)

Biogas utilisation

Electricity production. The company is moving toward biogas upgrading; biomethane will be used as a transport fuel

Heat utilisation

A small amount of heat is exploited for the pre-heating of the feedstock to digestion (to a temperature of 37 °C). The plant is about to implement a new heat recovery unit for several applications within the plant boundaries (i.e. heating of offices)

Digestate utilisation

Digestate is separated into a liquid phase (to WWTP) and a solid phase (mixed with garden waste and composted); The solid-liquid separation is done through screw squeezing and further centrifugation of the liquid phase. Solid phase composting is done by Advanced Composting technology (ACT) in which digestate is turned and forcedly ventilated through windows followed by curing and finally screening through 10mm holes as shown in images above.



Case Study: Provided by Italian Composting and Biogas Association and ETRA SpA

Income/revenue streams

Incomes come from food waste and garden waste gate fees and electricity production. No data available, but interestingly the plant declares that gate fees are variable and calculated on the basis of the amount of Incomes come from food waste and garden waste gate fees and electricity production. No data available, but interestingly the plant declares that gate fees are variable and calculated on the basis of the amount of impurities in food waste collected from each municipality. Until 2015 the plant benefit of subsidies for each kWh put into consumption, according to a green certificates granting scheme

Policies have enabled digestion of food waste

Increasing landfill gate fees pushed forward the implementation of separate collection schemes; region Veneto has always been at the top of the ranking among Italian regions in terms of separate collection performances (now 72.91% against an average national rate of 52.54%) and the organic fraction (food waste + garden waste) are the main drivers. Anaerobic digestion.

The plant was initially intended as an integrated facility for the anaerobic treatment of both food waste and mixed MSW in separate digesters. The introduction by region Veneto of an exemption from the MSW pre-treatment obligation before landfilling (set by the 1999/31/EC Directive) whenever MSW contains until 15% putrescible organic waste has further pushed forward the separate collection of food waste; AD of mixed MSW was soon abandoned by the plant.

Barriers faced

At the beginning, the main barrier was represented by technical constraints when treating mixed MSW (frequent digesters clogging and extraordinary maintenance costs); in this sense, the treatment

of food waste from separate collection must be considered a net advantage rather than a barrier

Unique and outstanding features

Connection of the plant with the Waste Water Treatment Plant settled 1 km far from it, where liquid digestate is pumped and treated; from liquid digestate Ammonia is recovered as Ammonium sulfate (according to a stripping technology) and put into consumption for different potential applications, such as nutrient for WWTPs, catalyst for resins hardening and mineral fertilizer. The WWTP is supplied by the electricity produced by the AD plant. Another important feature consists in the relationships with the surrounding territory (see below); after initial tensions with the population, a hard work has been made to set up a dialogue which ended with the implementation of a Committee involving company, citizens and the administrations of the municipality of Bassano del Grappa and the adjacent one, which discuss and solve all the problems related to the plant operations (mostly referable to odor emissions)

Public perception

Households are settled in the nearby, few hundred meters far from the plant. After the first years of activity, during which concerns were expressed by the population mainly associated to odor emissions, the company is now generally well accepted by the territory. This is due to the high environment protection levels assured (the plant is entirely run in closed buildings kept under negative pressure, with exhaust air depuration with a scrubber+biofilter system), the periodical monitoring of the emissions to the atmosphere and the implementation of a Committee involving company, citizens and the administrations of the municipality of Bassano del Grappa and the adjacent one, which discuss and solve all the problems related to the plant operations

7. POLICY RECOMMENDATIONS, BARRIERS AND IMPLEMENTATION

In this final chapter, recommendations are made to decision-makers and policy-makers – above all, that, with the global commitments that have been made, separately collecting food waste from businesses and households is of vital and urgent importance and should be implemented, and that anaerobic digestion (AD) is the most cost-effective treatment technology in full cost analyses. The barriers to developing biogas projects and ways of overcoming these are considered. The policies and associated implementation measures form part of a “How to” implementation guide for municipalities and countries seeking to implement food waste management solutions.

In previous chapters, the benefits of food waste collection and AD were discussed in detail: climate change mitigation, renewable energy generation, sustainable industrialisation, food security, and better health and sanitation. Chapter 3 looked at examples of municipalities, industries and businesses that have successfully integrated these collections into existing waste management systems. Although no formal global statistics of food waste collection exist, it is clear that, even with progress in some jurisdictions, food waste digestion is only in its infancy and there is great scope for development. This chapter therefore provides the framework for municipalities to implement better food waste management policies, while adjusting to their own circumstances.

7.1. Policy recommendations

As was highlighted in Chapters 3-6, separate collections of food waste has significant advantages over other food waste collection and treatment techniques. Although there will be initial set-up costs, over time, separate food waste collection for households and businesses will deliver societal savings compared to all other options. Given the importance of prevention activities described in Chapter 2, therefore, the following policy recommendations can be considered:

- **Undertake large-scale food waste awareness-raising and prevention campaigns;**
- **Require businesses to separately collect food waste;**
- **Provide separate collections of food waste to households; and**
- **Require use of all food waste in line with the food management hierarchy, whether this is through use as animal feed, composting or AD.**

These policies are essential for urban areas and the wider world to reach their commitments under the climate change treaty and the SDGs. The following sections explain the barriers to implementation of these policies, the wider policy context that local policy-makers might be working in, and the implementation process that should be followed.

7.2. What are the principle barriers to developing better food waste management policies?

The benefits of food waste collection and treatment are numerous. Besides lack of awareness of these benefits, the possible reasons for why this form of collection and treatment is not a norm globally are explored.

7.2.1. Low cost of landfilling, no cost to illegal dumping

Globally, landfilling is still the most widely used method of disposal of municipal solid waste, as shown in Figure 14 below¹. Besides landfills, which are often managed and closed areas, up to 33% of waste is still illegally dumped in low-income and middle-income countries in open, unmanaged dumps or directly into the environment (city streets, fields, rivers, lakes, the sea)².

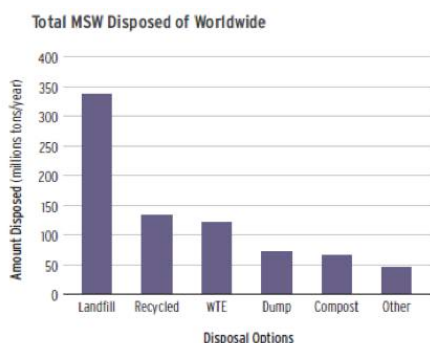


Figure 17: Disposal of MSW worldwide

In most countries, sending waste to landfill is very low cost, and in some countries there is no direct cost at all. Fees mostly account for direct management costs of the sites, but do not consider costs of the environmental damage, waste of resources, GHG emissions and immediate health impacts resulting from this practice. The costs of any alternative waste management options or policies to avoid waste, have to compete with these prices, and therefore these low or non-existent prices are a significant disincentive for municipalities and businesses to invest in separate

food waste collection and treatment infrastructure.

Other forms of waste management beyond dumping are difficult to achieve without internalising the external costs of landfilling. Regulation, for example through a landfill tax, and comprehensive controlling mechanisms to guarantee compliance, can help make climate-friendly methods more competitive.

7.2.2. Investment costs and access to finance

The upfront cost of food waste collection and digestion is a barrier to its adoption. As discussed in Chapter 5, the cost of a 30,000 tonne per year capacity plant may be \$400-\$600/tonne of annual capacity. A larger plant may have a capital cost of \$300-\$400/tonne. The relatively high upfront cost, a perception of financial risk, difficulty in importing technology due to currency barriers, and structuring finance to provide for operating costs are challenges faced by jurisdictions and businesses in obtaining finance for the projects. Outlined in Section 7.3 are the initiatives, mainly from national governments, that support the financial case for the digestion of food waste. In Thailand, national government support helped make AD viable for starch mills, breweries and palm oil mill effluent. The government aided building of biogas plants initially through capital grants and then soft loans and co-financing biogas projects. Once familiarity increased, more banks were willing to lend and corporate financing became available, thus improving access to finance³.

¹The World Bank (2012) *What a Waste: A Global Review of Solid Waste Management* https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf

²The World Bank (2012) *What a Waste: A Global Review of Solid Waste Management* https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf

³Situer J (2016) *Rapid deployment of industrial biogas in Thailand: factors of success* <http://www.ieabioenergy.com/wp-content/uploads/2016/05/P13-Rapid-deployment-of-industrial-biogas-in-Thailand-factors-of-success-Situer.pdf>

IN MANY COUNTRIES, SYNTHETIC NITROGEN FERTILISERS ARE ALSO SUBSIDISED , FURTHER DIS-INCENTIVISING THE USE OF RENEWABLE, LOW CARBON FERTILISERS SUCH AS DIGESTATE.

7.2.3. Availability of subsidised fossil fuel energy and fertiliser

An estimated \$5.3 trillion was spent worldwide on subsidising fossil fuels in 2015, of which nearly half was spent on coal subsidies ⁴. Over the course of decades, these subsidies heavily distort the energy market in favour of fossil fuel based energy.

The low energy prices resulting from these subsidies pose a challenge for renewables-based energy to compete with. With increased scale of implementation and maturing of technology, the cost of producing energy from food waste is decreasing, however, it is still not always competitive and also needs to be supported.

In many countries, synthetic nitrogen fertilisers are also subsidised ⁵, further disincentivising the use of renewable, low carbon fertilisers such as digestate.

7.2.4. Lack of technical know how

To start a food waste collection and digestion programme in countries where it is already widely implemented, such as in Sweden, the

USA and Korea, or sectors such as breweries, abattoirs and restaurants, the technical and regulatory knowledge as well as supply chain may be readily available. The parties interested in setting up a new biogas plant are able to visit and learn from the experiences of both successful and unsuccessful attempts at implementation.

However, in countries and sectors in which AD has not been implemented yet, technical knowledge, regulatory support and procurement of equipment, are often missing.

This challenge may be faced at the time of initial conceptualisation and construction, or operation and maintenance of the biogas plant.

The lack of knowledge may be remedied by undertaking site visits, study tours, consulting experts and respected academicians, getting in touch with the relevant trade associations, learning from early adopters' experiences and successful case studies in other countries or sectors, or hiring consultants. The authors of this report (WBA and the C40 Cities Food, Water and Waste Programme), are available to help in this respect.

⁴Coady D, Parry I, Sears L and Shang B (2017) How large are global fossil fuel subsidies, *World Development*, Volume 91, March 2017, Pages 11-27 <http://www.sciencedirect.com/science/article/pii/S0305750X16304867>

⁵An economic appraisal of withdrawing fertilizer subsidies in India (English) <http://documents.worldbank.org/curated/en/180341468253188752/An-economic-appraisal-of-withdrawing-fertilizer-subsidies-in-India>

7.2.5. Lack of long term policy frameworks and political will

An AD industry needs initial regulatory and financial support to deliver climate, energy, food and health benefits. Some of these benefits, such as climate change mitigation and food security, are not visible in the short term.

The timeline for implementation of a project from conceptualisation to start of operation may also be up to three years or even more depending on the regulatory environment in the country. Formulation and implementation of policy and building food waste and digestion infrastructure can take up to five years, varying from country to country. Development of an AD industry requires long term, sustained commitment from the government and often suffers from the lack of political will to support it.

This challenge may be addressed by raising the awareness about the many benefits of AD of food waste among policy makers as well as commercial and industrial enterprises.

7.2.6. Low monetary value of biogas and digestate

While over 100 countries have a feed in tariff incentive in place for renewable electricity generators, not all of these include the production of energy from biogas. Similarly, heat produced from biogas and digestate produced from digestion of food waste has to compete with the heavily subsidised prices of fossil fuel based heat and mineral fertilisers in many jurisdictions.

The climate change mitigation, energy independence, food security and health benefits of AD are not internalised into the monetary value that biogas fetches, just like the damage caused by fossil fuel based energy is not factored into its monetary value.

This challenge requires action on a global scale

to rethink and restructure our energy, carbon and health valuation of commodities and actions. Local authorities and national governments can however act, and within the framework of the SDGs and the Paris Agreement, these policies can be formulated.

7.2.7. Lack of public awareness

The success of a separate food waste collection and digestion system depends very heavily on public participation. Achieving the desired quantity and quality of food waste segregation requires additional effort on the part of households. Industries that install digesters on-site are required to make an investment and weigh the costs and benefits of doing so. Commercial and retail establishments are required to separate their food waste which needs processes in place for each employee to follow.

Each of these establishments are asked to do something different from “business as usual”. In order to fully adopt and integrate these processes, they are asked to buy into the benefits of AD. In order to make separation of food waste a norm, rather than an exception or extra effort, public education and continuous communication is required.

This challenge can be addressed by the administration of the jurisdiction, in schools and universities, in local community centres, high rise buildings, door-to-door canvassing, local shops, by trade organisations, at tradeshow and exhibitions through a variety of communication mediums.

7.2.8. State of infrastructure for biogas utilisation

Another challenge faced by developers of biogas plants is the state of the infrastructure required to fully utilise the products of digestion, such as a stable electricity grid to connect to, or an existing district heating network within reasonable distance, or a gas grid to inject upgraded biomethane.

This is a challenge that can be addressed at the planning stage of a project by looking for local base load and peak load consumers. A number of currently successful plants have been built on sites which needed high amounts of energy for their own processes or could help a local community or neighbouring

industry meet its energy demands. For example, in Chiba, Japan, food waste from households and businesses is digested and the biogas is supplied to the neighbouring JFE Steel where the biogas is used combusted to produce electricity and steam to be used as process heat.

7.2.9. Availability of feedstock

While food waste is generated in cities, often only a small percentage of it is available for digestion as it is not being currently separated and collected. This creates an artificial limitation of feedstock. A number of digesters in Germany and the UK are facing feedstock shortages and are not running to capacity. This prevents new biogas plants from being built due to concerns about profitability and capacity management.

This challenge can be addressed at the planning stage of the project by realistically considering the sources of feedstock from surrounding industries. Similar to selling biogas products to neighbouring industries, feedstocks may be obtained from them, such as from food and processing industries, local community, fruits and vegetable markets and so on.

7.3. Mechanisms and policies to support food waste digestion

The section below explores different mechanisms and policies that can help incentivise the roll out of food waste collections for digestion. They help overcome many of the barriers outlined above, and ensure that when the cost-benefit analysis of separate food waste collections and treatment through AD are undertaken, more of the benefits, such as renewable energy, are recognised financially. These policies are frequently implemented at national or supranational level. In many cases it will be the role of the municipality only to understand how the mechanisms work and how they can be accessed, not to implement them themselves. As outlined in Section 7.4 below, municipal policy-makers need to understand how to access any national policy support. This section is therefore for reference rather than for municipal policy-makers to necessarily implement themselves.

7.3.1. The role of targets

High level targets set by countries and cities set the intent of the government and direction of future growth. These can be a very useful driver in triggering collection of source segregated food waste and use of AD for its recycling.

Targets have a number of benefits:

- **They encourage policy-makers to clarify and prioritise the most important policy goals;**
- **They allow any available funds to be channelled to meet the agreed target; and**
- **They encourage quantification and measurement of policy goals, discouraging vague commitments.**

Relevant targets that can be considered are outlined below.

Emissions reduction targets

In 2015, 195 parties signed the Paris Agreement, of which 174 have ratified it or officially accepted it ⁶. These parties are now working on their Intended Nationally Determined Contributions (INDCs) with the expectation that the sum of all their contributions will keep the rise in global temperature to well below 2°C and pursue efforts to limit it below 1.5°C ⁷.

In 2007, the European Union (EU) had set a target of reducing its greenhouse gas emissions by 20% from 1990 level by 2020. By 2016, it had already reached a 23% reduction and is aiming to reach a 40% by 2030. The figure below shows the progress towards these targets ⁸. Projections suggest that with the current measures, the 2030 target will not be achieved and further measures are required – hence the recently-agreed Circular Economy package

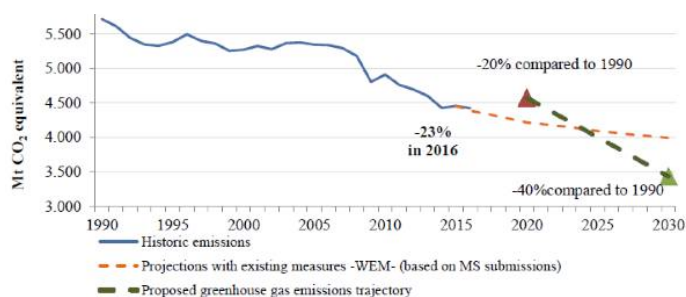


Figure 18: Progress towards meeting Europe 2020 and 2030 targets (total EU GHG emissions)

making separate food waste collection obligatory by the end of 2023 across the EU under the revised Waste Framework Directive ⁹.

The Swedish government, for example, has set a goal of zero net GHG emissions by 2050 and a fossil fuel free vehicle fleet by 2030. These have been identified as key drivers for the development of the biogas industry in the country ¹⁰.

Renewable energy targets

One of the main advantages of the digestion of food waste is the energy produced from it, in the form of biogas. As discussed in earlier chapters, this energy can be used as it is or converted to heat, electricity, cooling or biomethane for grid injection or vehicle fuel. Almost all countries have targets for meeting their primary and overall energy needs from renewables¹¹. These may be part of reaching its carbon emission reductions targets, improving national energy independence and security, and sustainable development.

In 2009, the EU set itself a renewable energy target of 20% of primary energy demand by 2020. This target was then devolved to a specific target for each country in the EU. This policy has been a huge success in increasing the share of renewables in the energy system, with the renewable share of energy supply doubling in 11 years¹². Biogas based energy represents about 7.6% of the primary renewable energy production in the EU¹³.

⁶United Nations Climate Change: Paris Agreement http://unfccc.int/paris_agreement/items/9485.php Accessed on 08/03/2018

⁷bid

⁸European Commission (2017) Two years after Paris – Progress towards meeting the EU's climate commitments https://ec.europa.eu/clima/sites/clima/files/strategies/progress/docs/swd_2017_xxx_en.pdf

⁹https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/towards-circular-economy_en

¹⁰European Commission (2016) Optimal use of biogas from waste streams https://ec.europa.eu/energy/sites/ener/files/documents/ce_delft_3g84_biogas_beyond_2020_final_report.pdf

¹¹REN 21 (2017) Renewables 2017 Global Status Report http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf

¹²Eurostat (2017) Renewable energy in EU <http://ec.europa.eu/eurostat/documents/2995521/7905983/8-14032017-BP-EN.pdf/af8b4671-fb2a-477b-b7cf-d9a28cb8beea>

¹³European Commission (2016) Optimal use of biogas from waste streams https://ec.europa.eu/energy/sites/ener/files/documents/ce_delft_3g84_biogas_beyond_2020_final_report.pdf

Biogas based energy production targets

Countries or jurisdictions may set targets to build a certain number of digesters or generate a targeted amount of electricity from AD or treat a targeted volume/weight/percentage of food waste via AD. Such targets identify AD as the choice of treatment for food waste and directly help in the development of the industry.

Austria, for example, has a target of adding 200MW of installed capacity from solid biomass and biogas during 2010-2020 while Thailand targets to achieve 600MW installed biogas based energy generation capacity by 2021. The Republic of Korea has set itself a target of 161GWh of biogas generation by 2030¹⁴.

Food waste prevention targets

As outlined in Chapter 3, the world has committed to reduce food waste by 50% per capita by 2030 under the SDGs. This can only be measured and achieved in countries and municipalities which have a full understanding of food waste sources and its relationship to consumer behaviour.

Japan and the United Kingdom have introduced food waste reduction targets within individual industries and at household levels¹⁵. In 2015, U.S. EPA and the U.S. Department of Agriculture (USDA) announced the U.S. food waste challenge, the nation's first-ever non-binding voluntary goal toward a 50 percent reduction in food loss and waste by 2020

through a combination of food loss prevention and recovery as well as industrial use, anaerobic digestion (AD) and composting of food waste¹⁶. Chapter 3 of this report discusses a number of initiatives that can be taken to prevent food waste such as raising awareness, communication, institutional and regulatory initiatives. In addition to these, introducing separate food waste collections can make citizens, industries and businesses more aware of the food waste being generated and can lead to reduced generation. This has been seen in Wales, where over the period in which separate food waste collections for households was introduced, the amount of food waste produced declined by 11%¹⁷.

Recycling targets

Food waste recycling targets may be introduced to specifically target the collection and recycling of food waste. The drivers behind these may be environmental benefits, resource efficiency, energy independence, sanitation, surface and marine water quality or lack of landfill space. These may be introduced as a part of overall recycling and waste management strategy or on its own for jurisdictions or businesses. A recycling target has the benefit of being simple and measurable compared to other waste management objectives, such as resource efficiency.

¹⁴REN 21(2017) Renewables 2017 Global Status Report http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf

¹⁵Parry A, Bleazard P and Okawa K (2015) preventing case studies: case studies <http://www.oecd-ilibrary.org/docserver/download/5js4w29cf0f7-en.pdf?expires=1513101671&id=id&accname=guest&checksum=9F4A499BCEF1ED1B6D43C3F98B004E13>

¹⁶USDA (US Department of Agriculture). 2015. USDA and EPA join with private sector, charitable organizations to set nation's first food waste reduction goals. Release no. 0257.15. September 2015. www.usda.gov/wps/portal/usda/usdahome?contentid=2015/09/0257.xml

¹⁷WRAP Cymru (2015) Household food waste in Wales <http://www.wrapcymru.org.uk/hhw2015>

For jurisdictions: The EU has a 50% recycling (including composting and AD) target for 2020, which will increase to 65% for 2035¹⁸. In USA, few communities have policies and/or regulations to mandate organic waste diversion or establish zero waste goals as shown in table below¹⁹.

TABLE 15:

CITY, STATE	GOALS (E.G., TARGETS) FOR PROGRESS TOWARD ZERO WASTE	TARGET YEAR(S)
Oakland, CA	Zero waste	2020
San Francisco, CA	Zero waste	2020
Minneapolis, MN	50/80 percent	2020/2030
Dallas, TX	40/60 percent/Zero waste	2020/2030/2040
San Diego, CA	75/90/100 percent	2020/2035/2040
Los Angeles, CA	Zero waste	2025
Seattle, WA	70 percent	2025
New York City, NY	90 percent relative to 2005 levels	2030
Austin, TX	Zero waste	2040

Source: Bodamer 2015

TABLE 16: RECYCLING TARGETS FOR FOOD RELATED BUSINESSES IN JAPAN

For sectors and businesses:
in Japan, the ‘food waste recycling law’ lays out recycling targets for food related businesses as shown in the table 16²⁰.

SECTOR	RECYCLING TARGET
Food manufacturers	85%
Food retailers	45%
Food wholesalers	70%
Catering services/restaurants	40%

Diversion from landfill targets

Targets for the reduction of organic waste sent to landfills are an effective mechanism to encourage the source segregation of food waste at collection point. While some may choose to use AD for treatment and recycling of the waste thus collected, it does not mandate energy and nutrient recovery. The food waste or organic waste thus collected may be treated using AD, composting or any other technology as discussed in Chapter 5 of this report. The EU, as part of its Landfill²¹ Directive, has laid down a 65% reduction target for the tonnage of biodegradable municipal waste being sent to

landfill , which member states are largely on course to achieve. Under the new Landfill Directive provisionally approved in 2018, no waste may be sent to landfill after 2035 that could be disposed of or recycled alternatively, and landfill must represent no more than 10% of any nation’s waste disposal options²². In the United States, five states—California, Connecticut, Massachusetts, Rhode Island, and Vermont—have adopted food waste disposal bans that primarily target the commercial and industrial sector (e.g., food wholesalers, distributors, manufacturers, processors; supermarkets, resorts, conference centers)²³.

¹⁸European Parliament (2017) Circular economy package: Four legislative proposals on waste [http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/599288/EPRS_BRI\(2017\)599288_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/599288/EPRS_BRI(2017)599288_EN.pdf)

¹⁹Bodamer, D. 2015. 10 Major U.S. Cities with Zero Waste Goals. 27 July 2015. www.waste360.com/waste-reduction/10-major-us-cities-zero-waste-goals.

²⁰Food waste recycling law, Japan http://nett21.gec.jp/ECotowns/data/et_c-08.html

²¹The Council of European Union (1999) Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste <http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:31999L0031&from=EN>

²²The Council of European Union (2018) EU ambassadors approve new rules on waste management and recycling <http://www.consilium.europa.eu/en/press/press-releases/2018/02/23/eu-ambassadors-approve-new-rules-on-waste-management-and-recycling/>

²³Leib, E.B., C. Rice, and J. Mahoney. 2016. Fresh look at organics bans and waste recycling laws. BioCycle. November 2016. www.biocycle.net/2016/11/10/fresh-look-organics-bans-waste-recycling-laws/

7.3.2. Policies to meet targets

While targets help focus policies on important areas, policies need to be implemented to reach these targets. Each of the policies below supports a specific benefit of AD of food waste, including: reduction of greenhouse gas emissions, production of renewable energy, waste management, sanitation, recirculation of nutrients, via market mechanisms, financial incentives, capital grants, and regulations.

Pricing greenhouse gas emissions

Food waste collection and digestion impacts greenhouse gas emissions from its management in multiple ways. These are mainly positive, but some negative:

- Methane emissions avoided from food waste degradation in landfills;
- Replacement of fossil fuel based energy with renewable energy, leading to GHG emission savings;
- Reduced emissions from production, mining and transport of mineral fertilisers by substituting with locally produced biofertiliser/digestate;
- Separate collection of food waste potentially leading to a reduction in its generation, and therefore in the associated emissions;
- Added emissions from construction and operation of digesters and associated equipment; and
- Added emissions from vehicles collecting food waste and delivering digestate unless these are powered by biogas or renewable electricity.

These emissions reductions are summarised below:

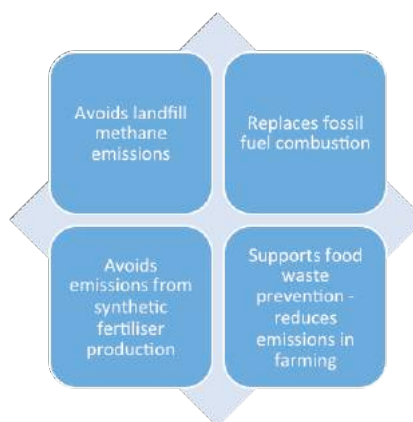


Figure 19: Emissions reductions delivered by separate food waste collections and AD

For the best environmental performance of a collection and digestion system, however, it is important to take all of these into consideration and optimise the collection routes, digestion plant location, final use of biogas and digestate. Well-designed systems result in considerable reduction in greenhouse gas emissions as compared to sending the food waste to a landfill or other treatment option. This reduction in emissions, if incentivised correctly, not only improves the environmental and economic performance of the digester, but also acknowledges the role of AD as a greenhouse gas abatement technology rather than only a renewable energy generation technology. It will also incentivise further innovation in cost-effective abatement.

Pricing greenhouse gas emissions effectively would significantly increase the cost of landfilling, fossil fuel-based energy, synthetic fertilisers and unsustainably produced food, making for a fairer playing field for low carbon, circular technologies like AD. For now, we are collectively footing a bill of trillions of dollars in environmental damage, climate change, deteriorating soil quality, poor health and sanitation. The two methods of pricing greenhouse gas emissions are through trading schemes and taxes. It is important that all the emissions that AD can avoid are included in these schemes (emissions from landfill, fertiliser manufacturing etc.).

A) Emissions trading schemes

Emissions trading schemes allocate emissions between businesses and/or citizens, with limits/caps then placed on total emissions. These caps are then reduced over time to target levels. Allocations can be free to participants below certain levels, or auctioned, or have minimum prices set. These allocations can be traded to ensure the most efficient allocation among participants – those who add most value per tonne of carbon dioxide-equivalent emissions would offer more than those who can add less value.

One of the first such mechanisms, implemented globally in 2006 under the Kyoto protocol, was the Clean Development Mechanism. It aimed at stimulating sustainable development and emission reductions via trading of Certified Emission Reduction (CER) credits. It registered 7,796 projects with 1.9 billion CERs issued (or abated tonnes of CO₂ eq.)²⁴.

California introduced a cap-and-trade scheme in 2013. This was the world's fourth largest scheme after the EU scheme (see below), the Republic of Korea's, and the Chinese province of Guangdong (with the rest of China due to adopt a scheme within the coming years). California's emissions trading system is expected to reduce greenhouse gas emissions from regulated entities by more than 16% between 2013 and 2020, and by an additional 40% by

2030²⁵. Like many other emissions trading schemes, the cap-and-trade rule applies to large electric power plants, large industrial plants, and fuel distributors (e.g. natural gas and petroleum).

The EU Emissions Trading Scheme (EU ETS) has been operating since 2005. It currently covers the electricity generation, iron and steel, mineral processing (for example, cement manufacture) and pulp and paper processing sectors. The EU ETS has also been plagued by persistently low carbon prices – for those that do have to pay for their pollution. Emissions allowances (EUAs) have cost less than €10 per tonne since late 2011, far below most estimates of the social cost of carbon and below the level thought to be necessary to drive deep decarbonisation²⁶.

B) Carbon taxes

A carbon tax directly sets a price on carbon by defining a tax rate on greenhouse gas emissions; an emitter of a greenhouse gas pays an amount per tonne of carbon dioxide-equivalent emitted. It is different from emissions trading schemes in that the emission reduction outcome of a carbon tax is not pre-defined but the carbon price is²⁷. It therefore does not guarantee reductions in emissions to target levels, but does provide certainty on the cost of emissions. The revenue from this tax can be diverted to the development of clean energy in the jurisdiction.

²⁴Clean Development Mechanism <http://cdm.unfccc.int/index.html> Accessed on 26/01/2018

²⁵Center for Climate and Energy Solutions: California cap and trade <https://www.c2es.org/content/california-cap-and-trade/> Accessed on 08/03/2018

²⁶Carbon Brief (2017) Q&A: Will the reformed EU Emissions trading System raise carbon prices <https://www.carbonbrief.org/qa-will-reformed-eu-emissions-trading-system-raise-carbon-prices>

²⁷The World Bank: Pricing Carbon <http://www.worldbank.org/en/programs/pricing-carbon> Accessed on 08/03/2018

Carbon taxation has been used extensively as a climate change and clean energy policy instrument across the globe. The value of the carbon tax varies from less than \$1 per tonne CO₂ eq. in Mexico, Poland and Ukraine to \$87 per tonne CO₂ eq. in Switzerland and \$140 per tonne CO₂ eq. in Sweden²⁸.

Carbon pricing initiatives have been implemented in 67 national and subnational jurisdictions covering 8 GT CO₂ eq. or 15% of global GHG emissions²⁹.

Renewable energy incentives

Many jurisdictions have provided incentives to renewable sources of energy in order to reduce fossil fuel combustion for electricity and heat generation, and for transport.

These fall into three broad categories:

1) Direct cash payments

The most common policy instrument for incentivising production of renewable electricity and heat is through direct cash payments such as ‘feed in tariffs’ and ‘feed in premiums’. The utilities or companies operating the electricity/heat grid are required to pay the renewable energy generator a fixed feed in tariff or a variable feed in premium above the market price of energy. This premium payment may be funded by passing on the extra expenditure to the consumers via billing, government funding or the tax payer via an additional tax. Feed in tariffs/premiums are typically guaranteed for a period of 15 to 20 years and are digressed as the technology starts to mature.

Feed in tariffs/premiums may be structured as percentage of retail/wholesale price of

electricity, fixed tariff in addition to the retail/wholesale price of electricity or a capped premium to cover the difference between the retail/wholesale price of electricity and the base price of electricity from renewable sources.

Feed in tariffs/premiums thus encourage the deployment of renewable energy technologies by providing certainty on returns to the generator. Feed in tariffs/premiums for renewable energy production are implemented in over 100 countries and states for many different sources of renewable energy production; however very few include energy from biogas³⁰ within those frameworks.

Feed in tariffs for electricity has been instrumental in the growth of biogas industry in Germany, Czech Republic, France³¹ and Thailand³². Feed in premium for electricity has been implemented in Denmark, France, Austria, Germany and Italy³³. Feed in premiums for heat has been implemented in Austria, Estonia, Finland and the Netherlands³⁴.

2) Quota obligations and renewable energy certificates

The production of renewable energy can also be stimulated top down, via market based mechanisms such as tradable renewable energy certificates. These have been used to encourage renewable electricity generation as well as renewable transport fuel or biomethane in this case. Under this mechanism, generators of energy (such as utility companies) are obliged to source a certain percentage of their production from renewable energy sources. Biogas is among those.

²⁸World Bank, *Ecofys and Vivid Economics (2017) State and Trends of Carbon Pricing 2017* (November), by World Bank, Washington, DC https://openknowledge.worldbank.org/bitstream/handle/10986/28510/wb_report_171027.pdf?sequence=5&isAllowed=y

²⁹Ibid

³⁰Renewable Energy Policy Network for the 21st Century (2017) *Renewables 2017. Global Status Report* http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf

³¹European Commission (2016) *Optimal use of biogas from waste streams* https://ec.europa.eu/energy/sites/ener/files/documents/ce_delft_3g84_biogas_beyond_2020_final_report.pdf

³²Sitaur J (2012) *Rapid development of industrial biogas in Thailand* <http://www.iipnetwork.org/IIP-10.%20BiogasCaseStudy.pdf>

³³European Commission (2016) *Optimal use of biogas from waste streams* https://ec.europa.eu/energy/sites/ener/files/documents/ce_delft_3g84_biogas_beyond_2020_final_report.pdf

³⁴Ibid

The generators of renewable energy are given a certificate for every unit of energy produced. This certificate can be used to meet their own renewables obligations or traded with other generators who are short of meeting their renewables obligation. These certificates therefore acquire a monetary value and create a source of income for the renewable energy generator that allows them to pay a higher than market price for the biogas acquired.

Renewable energy certificates have been implemented for electricity in Australia³⁵, Sweden and Norway (which operate a common market for these). Obligations and certificates for transport fuels have been implemented in the UK and the Netherlands and for heat in Romania. The UK has transitioned from the certificates to a feed in tariff policy, and Poland to power auctions.

3) Energy/Procurement Auctions

Another effective instrument for building biogas technology capacity is energy auctions, demand auctions or procurement auctions. This mechanism is based on governments or jurisdictions procuring renewable energy (biogas in this case) capacity and technology via an auction where project developers submit bids with the price per unit of electricity that they are able to deliver. The authority evaluates the bids on the proposed price and other criteria and enter into power purchase agreements with the successful bidder³⁶. Specific rules must be set to ensure high implementation rate of awarded projects in a timely manner.

The advantage of procurement auctions is that they are flexible in design and technology to enable the most cost-effective solutions. It informs the policy makers of the status of the market and actual price. It reduces

the financial and operational risk of the jurisdiction as development, operation and delivery is all in the hands of the project developer. It is a transparent system which enables an open and fair procurement process. The associated administrative and transactional costs are relatively high in this process and there is a danger of over aggressive bidding, leading to underbuilding and delays³⁷.

Argentina, Peru, South Africa, Italy and Spain have implemented biogas-based power auctions, some of which have been plagued with under subscription due to uncertainty of availability of feedstock³⁸.

Waste management policies

A number of waste management targeted policies may be implemented in order to reduce generation of food waste and maximise the source segregated collection of unavoidable food waste. Three are discussed here:

1) Pay-As-You-Throw (PAYT)

PAYT schemes are based on the 'polluter-pays' principle. The generators of waste, which may be households, industries or businesses, have to pay to contribute towards the disposal of the food waste generated by them. The payment could be based on the actual weight or volume of food waste generated or on the number of bins and collection frequency or prepaid bags used.

It is recommended to split the payment into a base minimum fee and a variable component. The fixed base fee minimises illegal disposal of waste and there is a strong driver to reduce the variable component. In a way, the base fee covers the unavoidable food waste while the variable part covers disposal of the partially avoidable or avoidable waste.

³⁵Clean Energy Regulator, Australian Government (2017) REC Registry <https://www.rec-registry.gov.au/rec-registry/app/home>

³⁶IRENA and CEM (2015), Renewable Energy Auctions – A Guide to Design http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_RE_Auctions_Guide_2015_1_summary.pdf

³⁷ibid

³⁸IRENA (2017) Renewable Energy Auctions: Analysing 2016. IRENA, Dhabi http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Jun/IRENA_Renewable_Energy_Auctions_2017.pdf

A PAYT system implemented in the County of Aschaffenburg, Germany for over 20 years is based on kerbside collections of waste. The scheme has been successful in increasing food waste capture and decreasing residual waste. It may be noted that the total waste management fee in the county has decreased over this time period due to the dramatic decrease in the residual waste and the corresponding expense, going to incinerators³⁹. PAYT has been implemented through Radio Frequency Identification (RF ID) in South Korea. It is based on actual weight of disposed food waste. The collection and billing system has been discussed in chapter five. The role of PAYT in food waste prevention has been discussed in Chapter 2.

2) Landfill bans

A number of jurisdictions have banned the disposal of organic waste via landfills, in a phased manner. This policy instrument is most generally applied to commercial organic waste generators over a certain capacity. This policy instrument works through a phased overhaul of the existing waste management systems towards separated food waste collections and recycling.

A ban on commercial organic waste disposal to landfills by businesses and institutions generating one tonne or more food waste per week has been imposed by the State of Massachusetts since 2014⁴⁰. The ban on organics to landfill goes hand in hand with setting targets for diversion of organics from landfills as discussed in Section 7.3.1

Similarly, Scotland has imposed a ban on biodegradable organic waste from landfills from 1st January 2021⁴¹.

3) Recycling requirements

Requirements may be laid down for businesses, institutions and industries to recycle food waste or make it available for recycling. This puts the obligation of disposal on the enterprises.

Scotland required larger generators of food waste (>50 kg per week) to separate food waste for collection from 2014, then increased the scope to smaller generators (>5kg per week) from 2016 and has now banned all biodegradable organic waste from landfills from 1st January 2021⁴².

The Scottish regulations lay out obligations and duty of care responsibilities:

- Food waste producer: minimisation of contamination to improve separate collection via clearly labelled containers.
- Food waste collector: to restrict collection to food waste that meets the requirements of the disposal facility like biogas plant or composting facility.
- Food waste treatment facility: to accept only good quality food waste needed to produce for digestate or compost that complies with regulatory standards and to notify the authorities about rejected loads and the reason for rejection.
- Farmers, contractors or land managers: to check the digestate/compost for quality and ensure compliance to animal by-product, fertiliser application, and other applicable regulations⁴³.

³⁹Morlok J, Schoenberger H, Styles D, Galvez-Martos J and Zeschmar-Lahl (2017) The impact of pay as you throw schemes on municipal solid waste management: the exemplar case of the county of Aschaffenburg, Germany www.mdpi.com/2079-9276/6/1/8/pdf

To achieve Japan's sector level recycling targets, as mentioned previously, individual food related businesses have annual incremental recycling rate requirements. Recycling requirement for food related businesses are determined based on the individual business's performance in the preceding year as shown in the Table 17 below⁴⁴.

TABLE 17: RECYCLING REQUIREMENTS FOOD RELATED BUSINESSES BASED ON PERFORMANCE IN JAPAN

STANDARD RECYCLING RATES FOR EACH YEAR= STANDARD RECYCLING RATES FOR PRECEDING YEAR + ADDITIONAL POINTS ASSIGNED ACCORDING TO STANDARD RECYCLING RATES FOR PRECEDING YEAR	
Preceding year's standard recycling rate class	Additional points
Businesses at 20% to <50%	2 %
Businesses at 50% to <80%	1 %
Businesses at 80% or more	Maintain or improve
♦ Inaugural year: FY 2008 ♦ If the recycling rate is less than 20% for FY 2007, the standard recycling rate is deemed to be 20% for the purpose of calculation.	

Capital grants

Another instrument for support and growth of the biogas sector are financial grants or making capital available at low interest rates for the biogas projects. When the technology is relatively unknown in a sector or country, the risk of such a project is perceived to be high and banks are either unwilling to lend capital or ask for collateral against it or charge a high rate of interest to cover that risk. By funding pilot projects or making capital grants for the first few adopters or making capital available at low interest rates, governments can help get the industry off the ground and build investor confidence.

This instrument has been used successfully to build the biogas industry in Thailand⁴⁵. The Chinese government is funding 100 pilot projects in 100 cities for recycling of kitchen waste from restaurants with a focus on AD⁴⁶. This investment is expected to seek the best solutions and kick start the recycling of food waste in China. In California, the Department of Resources Recycling and Recovery (CalRecycle) provides funding through its Organics Grant Program for public and private solid waste management projects such as composting and AD. During its first cycle of grants in Fiscal Year 2014-2015, CalRecycle awarded five grantees roughly US\$3 million each, for a total of US\$14.5 million. This past cycle (FY2016-2017), CalRecycle awarded 10 grants ranging from more than US\$500,000 to US\$4 million, for a grand total of US\$24 million⁴⁷.

⁴⁰Commonwealth of Massachusetts (2018) A success story: The Massachusetts Commercial Organics waste ban <http://www.mass.gov/eea/agencies/massdep/recycle/reduce/food-waste-video.html>

⁴¹Scottish Environment Protection Agency (2012) Waste (Scotland) Regulations 2012 <https://www.sepa.org.uk/environment/waste/zero-waste/>

⁴²Scottish Environment Protection Agency (2012) Waste (Scotland) Regulations 2012 <https://www.sepa.org.uk/environment/waste/zero-waste/>

⁴³Ibid

⁴⁴Food waste recycling law, Japan http://nett21.gec.jp/ECotowns/data/et_c-08.html

⁴⁵Situer J (2016) Rapid deployment of industrial biogas in Thailand: factors of success <http://www.ieabioenergy.com/wp-content/uploads/2016/05/P13-Rapid-deployment-of-industrial-biogas-in-Thailand-factors-of-success-Situer.pdf>

⁴⁶Mr Zhang Yue (2016) Municipal organic waste – methane and resource recovery in China at Global Methane Forum, Washington DC https://www.globalmethane.org/forum/presentations/biogas/tuesday-session-1/Tuesday_Biogas_ZhangYue_Global_Methane_Forum.pdf

⁴⁷CalRecycle. 2017. Organics Grant Program web page. Not dated, accessed November 2017. www.calrecycle.ca.gov/Climate/GrantsLoans/Organics/default.htm

7.4. “How to” process to implement food waste collection and anaerobic digestion

This report has explained why it is so critical to introduce food waste collections for digestion, and outlined the considerations regarding collection, communications, treatment options and related policies that need to be made.

A step-by-step guide to implementation of food waste collection and digestion in your jurisdiction is provided below. It can be used by urban politicians and officials as a checklist to implement sustainable food waste management policies.

This is a summary of the process, followed by a detailed description:

- **Assess waste sources – know your waste**
- **Establish the base case**
- **Assess the national policy and regulatory framework**
- **Identify the required expertise, potential partners**
- **Develop food waste prevention strategies**
- **Assess the feasibility and cost-benefit of different collection and treatment techniques**
- **Propose an integrated waste management strategy**
- **Run a pilot programme, phasing-in changes**
- **Prepare financing and implementation model**
- **Set sufficient budget for communications and public relations and continue public outreach over the long term**
- **Set high operational standards**
- **Monitor, evaluate and feedback improvements**

1) **Assess waste sources – know your waste**

The first step in any waste management improvement is to assess the waste sources within the geographical area. If food waste sources are currently unknown, this needs to be a particular focus. In each area there will be household, commercial and industrial producers of food waste, with different levels of homogeneity of material. For example, most households will generate mixed wastes, while some businesses may generate large quantities of a single material, such as oils

and fats, which may have particular value on the market due to their known properties. Therefore, the numbers of households, businesses and food processing facilities in the area need to be known. For households, the average amount of food waste produced per household needs to be estimated, possibly through simple exercises involving collecting and weighing. This needs to be differentiated by type of household (e.g. apartment vs. house, income group) and seasonality (different levels of food waste are produced over a year).

For businesses, the type of business will have an effect on the quantities of waste produced, so an understanding of the numbers of food retail, catering, food processing, offices and other food waste-generating businesses will be important.

As well as quantities of food waste, estimating participation rates in food waste collections will be important. While these can reach levels of nearly 90%, participation rates can be lower in certain household and businesses, such as where food waste caddy space is limited. Where food waste is heavily contaminated with material such as plastics, it will not then be suitable for digestion, so an assessment of the likelihood of contamination should be made as well as considering how to limit this.

The aim of this exercise is essentially to estimate the quantity and quality of food waste that can be collected. Food waste also needs to be characterised by measures such as its biogas and methane yield, solid fraction etc.⁴⁸. This will then need to be reduced following the success of any prevention activities – as outlined in (3) below.

2) Establish the base case

The next step is to establish the ‘base case’ for municipal, industrial and commercial food waste management processes in your jurisdiction. The ‘base case’ is essentially the existing waste management system, against which the costs of any changes to the collection and treatment operation need to be assessed. The current collection and treatment methods must be understood, and the costs of the various aspects known. If there are regions or areas that already operate separate collections of food

waste, including through traditional methods for animal feed, then these can be built upon.

The environmental impacts of existing treatment and disposal techniques should be quantified and monetised.

An addition to the base case can be where regulations are changing and stricter environmental standards are being introduced at either regional or national level, which would impact the cost of the base case scenario in future.

3) Assess the national policy and regulatory framework

As outlined in Section 7.3 above, an understanding of the wider policy framework and how local waste management can be coordinated with this is essential for the effective implementation of any scheme.

The regulatory environment also needs to be evaluated and understood. There are significant health and safety, environmental, land management and water quality safeguards which need to be in place to operate AD plants, which will be governed by national legislation, or may need developing at a wider level.

4) Identify the required expertise, potential partners

Municipalities need to understand the skills and experience required to deliver changes to food waste management. These include policy development, project management, lifecycle carbon analysis, communications, public sector finance, project finance, contracting, procurement and tendering, logistics, planning, engineering, environmental management, and experience of AD operations.

⁴⁸ADBA (2017). *Practical Guide to AD* <http://adbioresources.org/library/purchase-the-practical-guide-to-ad/>

Some of these skills will not be available in the municipality from the start of the project. The municipality in this case then needs to build links with experts in other public sector institutions, intergovernmental organisations, academia and the private sector.

5) Develop food waste prevention strategies

Identify the food waste prevention strategies best suited for each of the food waste generator categories (e.g. household type x, y and z, and business type x, y and z). These may be one or a combination of activities - communication (e.g. leaflets, knocking on doors, stickers) and media activities (e.g. local newspaper announcements), engagement with non-profit organisations and trade associations, institutional initiatives, and reporting and regulatory initiatives. These have been discussed in Chapter 3.

6) Assess the feasibility and cost-benefit of different collection and treatment techniques

As outlined in previous chapters, separate collection of food waste for digestion offers a variety of benefits to jurisdictions. However, the cost of establishing separate collections and building new digestion plants are significant, and need to be compared not only against the base case scenario but also to the other options outlined in Chapter 4. The cost of separate food waste collections includes the household and business food waste containers, communication requirements, collection vehicles etc. (see Chapter 3).

Then the capital and ongoing operational cost of the AD plant needs to be accounted for (see Chapters 5 and 6 on AD and its products). This is often the most difficult and complex aspect of the process. For AD, the expected income stream depends on factors such as what the local demands are for energy – if there is a high demand for an output such as heat, or the local municipality is seeking to reduce air pollution through a move to biomethane vehicles, then the income the overall project can generate will be much higher, therefore reducing a cost to the waste management aspect of the project. Chapter 6 outlined all the potential uses for biogas, and the selection of what to use it for will have a significant impact on the overall project economics.

The use of digestate also needs to be considered at this stage. No assumptions can be made about the market for digestate without initial market testing. Income streams from digestate can be achieved with proper consideration, which will improve the overall economics of the project.

This feasibility stage is where an understanding of the national policy framework on waste, carbon and energy can also become extremely important – the project will be more viable if it can benefit from all the wider policies outlined in Section 7.3.

This is also where the assessment of the indirect costs of the current system is important – all of the carbon and health costs of the different options need to be calculated.

7) Set sufficient budget for communications and public relations

Communications play a very significant role in the success of a food waste collection and digestion project, especially when it comes to municipal projects. Communications include:

- Educating the public about climate change, energy security, food security, sanitation and sustainable industrialisation and why it is important;
- Raising awareness about how individual citizen's every day actions contribute towards these bigger targets;
- Making people and enterprises aware of their changed waste disposal responsibilities;
- Providing clear instructions on the separation of waste – what is considered food waste, what cannot be put into food waste recycling, whether liners for food waste caddies can be used or not, and what kind of liners can be used;
- Providing clear instructions on troubleshooting problems: how to prevent spread of rodents and disease, what to do if you get maggots, how to keep your bin clean etc.;
- Communication of collection schedules and any variations that may happen due to inclement weather or holidays; and
- Communication about where help can be sought in case of problems, such as phone numbers and email addresses.

It is therefore essential that sufficient budget is allocated to communications activities. Chapter 3 on food waste collections has examples of communication activities that have been most effective.

8) Propose an integrated waste management strategy

During this part of the process, an integrated waste management strategy that includes collection and treatment of food waste from municipal, commercial and industrial generators should be laid out. It will be integrated with all the other decisions on waste, consumption, resource efficiency and energy that the jurisdiction is

making. It considers not only food waste, but issues like the frequency of general waste collections, the collection of garden and other non-food organic wastes, dry recycling and the treatment facilities available. How can food waste collections be best integrated into this wider strategy? What other service changes are being made? Is existing land or infrastructure available to support food waste treatment – for example at sewage sludge treatment works or other existing digestion facilities?

The International Solid Waste Association's (ISWA) *Solid waste: Guidelines for Successful Planning* provides further details on this⁴⁹. Consultation with stakeholders is a key aspect of this.

9) Run a pilot programme, phasing-in changes

Before making significant investments, running a pilot programme for food waste collection and digestion can help in ironing out functional difficulties that may be faced during the actual project. Different processes and equipment for collection may be tested during the trial run with fewer inhabitants, enterprises or industries. Participation and contamination rates can be assessed.

Analysis of the feedstock can be used to specify requirements for the biogas plant. This allows the optimisation of feedstock mixing and biogas production when the construction of any digestion plants are specified, so that full scale investment can be made with higher confidence and fewer operational issues.

Further to this, a phased approach to any changes could be considered, meaning some areas could initially be covered by a scheme, with lessons learned then being taken to the next phase of investment. The first phase could include areas which are likely to have higher participation rates, with the more challenging areas being tackled later.

⁴⁹International Solid Waste Association (not dated) *Solid waste: Guidelines for successful planning* http://www.iswa.org/index.php?eID=tx_iswknowledgebase_download&documentUid=2512

10) Prepare financing and implementation model

As outlined in Section 7.2 above, and has been widely disseminated⁵⁰, financing improvements in waste management is one of the principle barriers to implementation, especially in developing countries. For business food waste, where private sector collection arrangements are likely to be the norm, the cost to the municipality is likely to be in the form of enforcement

of any regulations and in ensuring appropriate treatment capacity is planned effectively. For household food waste, where municipal authorities are more likely to have responsibility, 'The Global Waste Management Outlook' discusses the various options for financing of municipal waste collection and treatment capacity⁵¹. It describes the municipality as the "Client" in the following model, while the operator could be the private sector or the municipality itself:

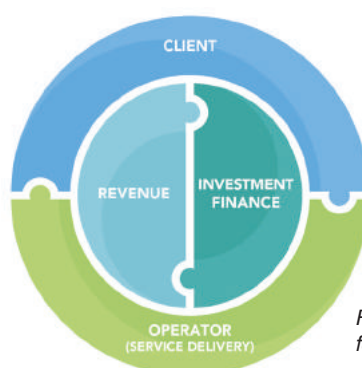


Figure 20: Financing Mechanisms for Waste Infrastructure

Local circumstances will dictate whether both the collection and treatment are operated by the municipality, or contracted out to the private sector: "There is no evidence to show that either private or public service provision or financing for MSWM is more frequent or is more efficient or beneficial than the other."⁵² In terms of food waste treatment through AD, there are many different models that a municipality can follow itself or through a tendering and contracting process. They need to cover the designing of the plant, its construction, its ownership and its transfer and could include:

- Build- Operate-Transfer
- Build-Own-Operate-Transfer
- Build-Own-Operate
- Build-Lease-Transfer
- Design-Build-Finance-Operate
- Design-Build-Operate-Transfer
- Design- Build-Transfer-Operate

What is unique about the construction of an AD plant is its integration into local markets. It needs to be integrated not only into the local waste collection system, but also into the local energy network (or developed to create a new network) and agricultural community. Where local energy, fertiliser, water and organic matter costs are high the project will be of far more value to the local market than where these costs are low, impacting on the cost effectiveness of the project.

⁵⁰UNEP ISWA (2015) Global Waste Management Outlook Waste http://web.unep.org/ietc/sites/unep.org.ietc/files/GWMO_flyer_0.pdf

⁵¹Ibid Sections 5.4. and 5.5

⁵²Ibid

THE MICROBIOLOGY OF DIGESTION AND ITS RELATION TO GAS OUTPUT IS A COMPLEX PROCESS AND MANY PROJECTS FAIL DUE TO A LACK OF UNDERSTANDING OF THE PROCESS

Whether contracting services or providing services in-house, the most important aspect of introducing new services is clarity regarding what is being proposed, set out in clear documentation, covering all details of the project.

11) Set high operational standards

Once food waste collections and digestion are operational, ongoing management is required. For collections it will be to ensure service level agreements are accorded to and participation rates are met.

If a municipality is to own and operate an AD plant then it needs experience of operations. The microbiology of digestion and its relation to gas output is a complex process and many projects fail due to a lack of understanding of the process. Experience is essential so will need to be bought in where not available. Where contracting the operation of the service or plant municipalities must ensure the operations have the equivalent experience and expertise. Literature and advice is available through a number of different means⁵³.

12) Monitor, evaluate and feedback improvements

Ongoing monitoring of the project needs to be undertaken to test its effectiveness against the initial goals.

This will include periodic feedback from the inhabitants of jurisdiction, businesses and industries on the performance of collection system to help in optimisation of the process and improve the experience of the participants.

It also includes aspects such as cost, participation rates, monitoring of contamination levels and other factors of importance to the digestion process.

If the policy is not meeting the original rationale then it should be amended or stopped.

These are the “Monitoring, Evaluation and Feedback” stages of the project⁵⁴:

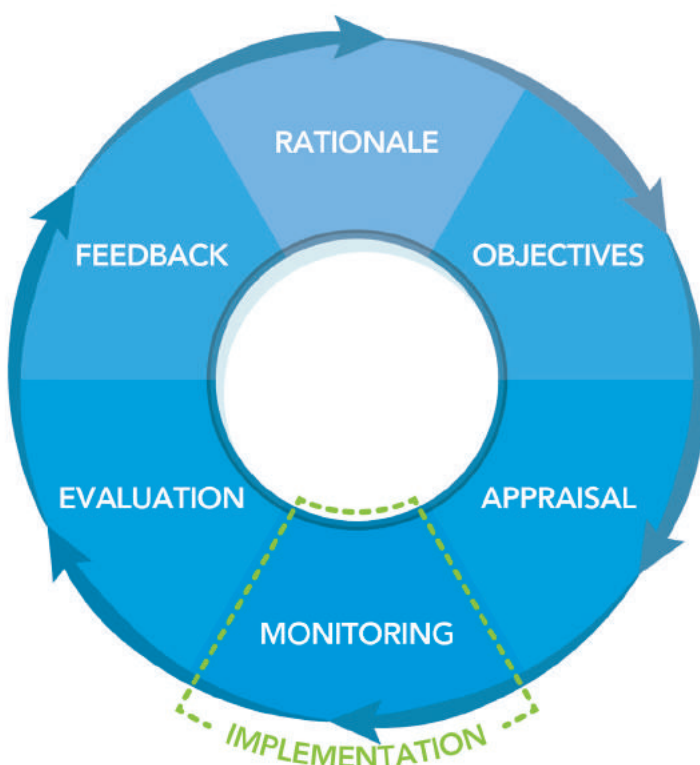


Figure 21: The cycle of monitoring, evaluation and feedback

⁵³See <http://task37.ieabioenergy.com/biogas-handbook.html> and <http://adbioresources.org/library/purchase-the-practical-guide-to-ad>

⁵⁴Institute for Government (2011) Policy making in the real world: evidence and analysis <https://www.instituteforgovernment.org.uk/sites/default/files/publications/Policy%20making%20in%20the%20real%20world.pdf>

AUTHORS



WORLD BIOGAS
ASSOCIATION

Dr Sarika Jain, David Newman:
World Biogas Association



FOOD, WATER AND
WASTE PROGRAMME

Ricardo Cepeda-Márquez, Kathrin Zeller:
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World Biogas Association

Sustainable Bankside, 105 Sumner Street, London SE1 9HZ

E: info@worldbiogasassociation.org

P: (+44) 020 3176 0503

www.worldbiogasassociation.org